THE UNIVERSITY OF CALGARY

GIS Analysis of Speed Related Traffic Collisions

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "GIS Analysis of Speed Related Traffic Collisions" submitted by Robert M. Arthur in partial fulfillment of the requirements for the degree of Master of Science.

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Abstract

This thesis begins with an exhaustive international literature review of police intervention strategies, behavioral studies and research into the phenomenon of speeding. It was discovered that there existed only a tenuous link between operating motor vehicles at excessive speed and the probability of accident occurrence. Given this dilemma, the thesis establishes statistically a better link between the two. Along with this, GIS was used to illustrate its utility as a research and data management tool in this area. After establishing intersections and interchanges as areas of high accident rates with greater levels of severity, maps and tables were developed within the GIS that show the relative amount of risk associated with each location. Behavioral and motivational models were then analyzed in an attempt to explain why this problem occurs and Risk Homeostasis Theory was presented as a possible explanation. As complex as this theory is, certain criticisms are developed, and out of them a more comprehensive explanation is presented.

Acknowledgments

There are so many that have aided me along this arduous journey that I am remiss to write this section least I miss someone out. It is impossible to include all that helped, but below is a partial list.

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In closing, I wish to state that any errors and omissions in this work are solely those of the author, the final decision always lay at my discretion.

Dedication

"The first power to come into being was Chaos."

Hesiod, The Theogony. (trans. R. M. Fraser)

I dedicate this work to my wife Linda, who aided me in forging this out of a chaotic mass of ideas. Her strength and love saw in me what I did not know was there. Her constant aid and encouragement propelled me through those inevitable hard times when one is ready to abandon hope. Being able to share the triumphs that I was fortunate enough to experience during this project increased my happiness tenfold. It is indeed my good fortune to have in my wife not just a lifelong companion, but my best friend. Without her, this never would have seen completion.

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1.0 INTRODUCTION

> *"To counteract irresponsibility and potential disorder, formal controls tend to be resorted to. Without rigid adherence to predictable routines a large compact society would scarcely be able to maintain itself. The clock and the traffic signal are symbolic of the basis of our social order in the urban world."*
>
> *Louis Wirth, Urbanism as a Way of Life*

Municipalities the world over have dedicated extensive resources to the development of roadways since the right to mobility is seen as fundamental to society and aids in the economic development of the city (Sabay & Taylor, 1979). Ever since Henry Ford revolutionized automobile production, automobile ownership has risen steadily. Thus the car has become entrenched in our culture to the point that many consider it a necessity. Many changes have been wrought on our city landscapes as a result; urban sprawl, air pollution, and the division of inner city neighborhoods to make way for access to the central business district are just a few. Of all the impacts caused by the automobile, none is more expensive or destructive than that which results from automobile accidents.

Traffic accidents range from minor inconveniences to debilitating tragedy. They are the leading cause of death amongst young people between the ages of 1 to 25 in most industrialized countries (Sabay & Taylor,1979; Rosman & Knuiman,1994). The cost to our health care system is in the millions of dollars a year and, in addition, there is the social cost of time lost at work and increased insurance premiums. Furthermore, the tragedy of serious injury or death exacts an emotional tribute from all involved, one that is impossible to measure strictly in monetary terms. For the purposes of assessment, KMPG Consultants recently tabled a discussion paper for the Alberta Government in which they stated that the total cost to society of a single fatality is 3.8 million dollars (KMPG Consultants, 1996).

The problem of traffic safety has been dealt with in many ways: safer cars with numerous protection devices, better roads, and the imposition of speed limits. It is to this latter approach that this research turns. The relationship between speeding and accident severity has been well documented and is explained by fundamental physics, but the relationship between accident occurrence or causation and speeding is tenuous (Connolly & Abers,1993; Hakkert, Yelinek & Efrat, 1990; Sabay & Taylor, 1979). This relationship becomes even more insubstantial within the urban environment as it has been mostly explored in regard to the highway system. The singular effort of municipal and provincial legislation to combat this problem through the imposition of speed limits coupled with the immense amount of effort by the police services to monitor and issue summonses for violation of these speed limits comes under question considering this slender connection. The resistance by the public to conform to speed limits seems to be a statement of disbelief by the average driver that they do in fact decrease risk.

It is the purpose of this research to explore this dilemma in greater detail. Several stages will be necessary:

1. Gather as much and varied information on accidents as related to speeding and perform a principal component analysis to search for variables that relate to speeding and occurrence of accidents.
2. Place all relevant data within a GIS system so that spatial analysis may be applied to the data and so that specific sites that are considered of high risk may be identified.
3. Statistically determine the probability of risk associated with speeding behavior.

4. Determine the relative risk at various locations within the City of Calgary.
5. Seek for behavioral models of explanation and interpret them within the framework of the previous research.
6. Attempt to determine if there are any greater, more global factors, such as prevailing moods in society that would assist in understanding the nature of this phenomenon.

It is believed that a better understanding of the spatial and temporal nature of the variables that link speeding to accident causation will allow for more efficient deployment of photo-radar units. The utilization of these automated policing units has come under criticism by the public as there appears to be a general feeling amongst the public that they are more of a revenue generating device than one that increases the public safety (Collins, 1994). If deployment can be supported through detailed research, the public perception of the usefulness of police services will increase which will lend more credence to intervention campaigns.

The impetus for conducting research into this particular problem came from a value-for-money audit (Western Management Consultants, 1991) that was prepared for the City of Calgary Police Services, Traffic Section. One conclusion was that the Police Services were in possession of large amounts of data that were not utilized to their full benefit. By analyzing this information, they claimed, it would be possible to increase efficiency and effectiveness of various intervention campaigns: radar, photo radar, check stops and the various selective traffic enforcement programs (STEP).

Upon approaching the Police Services, it was discovered that the information was stored electronically and comprised of information gathered from the Alberta Collision Report Form (Government of Alberta: 1991) (Figures 1 & 2). Provincial law requires the

Alberta Collision Report Form

LOCATION

1. ☐ In 2. ☐ Near	City, Town, Village, Hamlet of (Give National Park, Indian Reservation)	Occurrence Date	Occurrence Time (24 hour clock)
On	Primary/Secondary Hwy No OR Street/Avenue	Reported Date	Time Reported (24 hour clock)
At Intersection with	Primary/Secondary Hwy. No OR Street/Avenue	File Status ☐ 1 SUI ☐ 2 Concluded ☐ 3. Forward To	
If Not at Intersection	☐ metres ☐ km ☐ N ☐ S ☐ E ☐ W of Street, Highway, Town, etc.	Severity of Collision ☐ 1. Fatal ☐ 2. Injury ☐ 3. Property Damage	Diary Date
Special Reference	If location can be described more precisely, enter here — Special Facility / Road Alignment / Road Class / Collision Location	Total No. Veh. / Total No. Injured	Total No. Fatalities
		☐ Original Report ☐ Amended Report / Hit and Run ☐ 1. Yes ☐ 2. No	Scene Visited ☐ 1. Yes ☐ 2 No
Do Not Write in This Space		Special Studies ☐ 1. ☐ 2.	

Primary Event

01 STRUCT OBJECT — 02 OFF ROAD LEFT — 03 RIGHT ANGLE — 04 PASSING - LEFT TURN — 05 LEFT TURN - ACROSS PATH — 06 SIDESWIPE OPPOSITE DIRECTION — 07 OTHER/SPECIFY

08 REAR END — 09 OFF ROAD RIGHT — 10 HEAD ON — 11 PASSING - RIGHT TURN — 12 SIDESWIPE SAME DIRECTION — 13 BACKING

DRIVER/PEDESTRIAN (two columns, one per party)

☐ 1. Driver 2. Pedestrian 3. Motorcyclist 4. Bicyclist 5. Parked Veh. 6. Train 7. Animal 8. Other Veh. 9. Other Property

Surname — First Name — Initial

Address

Date of Birth — Sex — Home Phone — Work Phone

Operator's Licence Number — Prov./State — Valid Licence ☐ 1. Yes ☐ 2. No — Proper Class ☐ 1. Yes ☐ 2. No

VEHICLE

Year — Make — Model — Color

Licence Plate — Prov./State — VIN

Dangerous Goods — Class — PIN — Estimated $ Damage

OWNER

Company Name/Leased By

Surname — First Name — Initial

Address

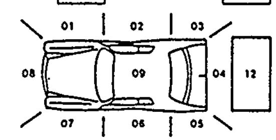
Home Phone — Work Phone

Insurance Co. and Agent

Policy Number — Expiry Date

Initial Point of Impact

Vehicle # ☐ Vehicle # ☐



10. Undercarriage 11. Rollover 12. Attachment 99. Unknown

INDEPENDENT WITNESSES

Surname — Name

Address

Address

Home Phone — Work Phone

Surname — Name

Address

Address

Home Phone — Work Phone

Additional Witnesses on File ☐ 1 Yes ☐ 2 No

ALL INVOLVED

Object #	Position	Safety	Injury	Age	Sex
#					
#					
#					
#					
#					
#					

Position in Vehicle
1. Driver 11. Bicyclist
2.-9. Passenger(s) 12. Pedestrian
10. Motorcyclist 98. Other 99. Unknown

3	6	9
2	5	8
1	4	7

Safety Equipment Used
1. Lap belt only
2. Lap/Shoulder belt assembly
3. Shoulder belt only (i.e. automatic belt)
4. Lap/Shoulder with Air bag
5. Airbag
6. Child safety/booster seat
7. Helmet
8. None
98. Other/Specify
99. Unknown

Injury Severity
1. None
2. Minor (treated but NOT admitted to hospital)
3. Major (admitted to hospital)
4. Fatal (death occurred within 30 days of collision) Include date and time of death

Surname	Name	Address
Surname	Name	Address
Surname	Name	Address
Surname	Name	Address
Surname	Name	Address
Surname	Name	Address
Surname	Name	Address

Investigator Reg. — Signature — Unit — Approved by Reg. — Signature — Date

MTS 284/R91

Figure 1.1 The Alberta Collision Report Form (Part 1)

Figure 1.2 The Alberta Collision Report Form (Part 2)

Alberta COLLISION REPORT FORM

Collision Case No.	Police Service	Police File No.
091807		

Diagram: Use Solid Direction Lines Before Impact and Broken Lines After — North

Description: Include: Direction of Travel, Travelling Lane, Vehicle Movement, Obstructions, Fixed Object, Traffic Signs.

Proposed Police Action

Contributing Road Condition (1 2)
- 01. No Unusual Condition
- 02. Under Const./Maint.
- 03. Hole/Ruts/Bumps
- 04. Slippery When Wet
- 05. Oily Pavement
- 06. Soft/Sharp Shoulder
- 98. Other/Specify
- 99. Unknown

Environmental Condition (Choose only one)
- 01. Clear
- 02. Raining
- 03. Hail/Sleet
- 04. Snow
- 05. Fog/Smog/Smoke/Dust
- 06. High Wind
- 98. Other/Specify
- 99. Unknown

Surface Condition (Choose only one)
- 01. Dry
- 02. Wet
- 03. Slush/Snow/Ice
- 04. Loose Surface Mat.
- 05. Muddy
- 98. Other/Specify
- 99. Unknown

Load Details (Choose one in A and one in B if applicable)
A (1 2)
- 01. Loaded
- 02. Unloaded
- 99. Unknown

B (1 2)
- 01. Load Not Spilled
- 02. Load Spilled
- 99. Unknown

Attachments (if applicable) (1 2)
- 01. Large Single Trailer
- 02. Large Double Trailer
- 03. Large Triple Trailer
- 04. Recreation Trailer
- 05. Small Utility Trailer
- 06. Farm Equipment
- 07. Towed Motor Vehicle
- 08. Oversize With Pilot
- 09. Oversize W/O Pilot
- 98. Other/Specify
- 99. Unknown

Trailer Type (If Attachments coded as 01, 02, 03)
- 01. Van/Box Body
- 02. Lowboy
- 03. Highboy
- 04. Tanker
- 05. Dump
- 06. Car Carrier
- 07. Livestock Carrier
- 08. Log Carrier
- 98. Other/Specify

Vehicle Condition/Contributing Factors
- 01. No Apparent Defect
- 02. Defective Brakes
- 03. Tires Failed
- 04. Improper Load/Shift
- 05. Lighting Defect
- 98. Other/Specify
- 99. Unknown

Unsafe Speed (1 2)
- 01. Yes
- 02. No
- 99. Unknown - N/A

Vehicle Appears Repairable (1 2)
- 01. Yes
- 02. No
- 99. Unknown - N/A

Light Conditions (Choose one in A and one in B)
A (1 2)
- 01. Daylight
- 02. Sunglare
- 03. Darkness
- 99. Unknown

B (1 2)
- 01. No Artificial Light
- 02. Artificial Light
- 99. Unknown

Traffic Control Device (1 2)
- 01. None Present
- 02. Traffic Signal/Lights
- 03. Stop Sign
- 04. Yield Sign
- 05. Merge Sign
- 06. Pedestrian Cross-Walk
- 07. School Bus
- 08. Lane Control Signal
- 09. RR Crossing
- 98.
- 99. Unknown

Traffic Control Condition (1 2) (if applicable)
- 01. Functioning
- 02. Not Functioning
- 03. Obscured
- 04. Missing
- 98.
- 99. Unknown

Pedestrian Action (1 2) (if applicable)
- 01. Crossing With ROW
- 02. Crossing Without ROW
- 03. Walking/Working On Roadway
- 04. Getting On/Off Vehicle
- 98.

Driver/Pedestrian Condition (1 2)
- 01. Apparently Normal
- 02. Had Been Drinking
- 03. Impaired By Alcohol
- 04. Impaired By Drugs
- 05. Fatigued/Asleep
- 06. Medical Defect
- 98.
- 99. Unknown

Object Identification (1 2)
- 01. Passenger Car
- 02. Pick-Up/Van <4500kg
- 03. Mini-Van/MPV
- 04. Truck >4500kg
- 05. Truck Tractor
- 06. Motorcycle/Scooter
- 07. Pedestrian
- 08. Bicycle
- 09. School Bus
- 10. Transit Bus
- 11. Intercity Bus
- 12. Other Bus
- 13. Fixed Object
- 14. Train
- 15. Animal
- 16. Motorhome
- 17. Construction Equipment
- 18. Emergency Vehicle
- 19. Farm Equipment
- 20. Off-Highway Vehicle
- 21. Motorized Snow Vehicle
- 22. Moped
- 98.
- 99. Unknown

Driver Action (1 2)
- 01. Driving Properly
- 02. Stop Sign Violation
- 03. Yield Sign Violation
- 04. Fail To Yield ROW Uncontrolled
- 05. Fail To Yield ROW Pedestrian
- 06. Followed Too Closely
- 07. Parked Vehicle
- 08. Backed Unsafely
- 09. Left Turn Across Path
- 10. Improper Lane Change
- 11. Disobey Traffic Signal
- 12. Ran Off Road
- 13. Improper Turn
- 14. Left of Centre
- 15. Improper Passing
- 98.
- 99. Unknown

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completion of this form for every accident in which $1,000.00 or more of damage has occurred. A wide range of information is collected on these forms including the location, whether speeding was a factor or not, environmental conditions and the severity of the accident which included property damage only (PDO), injury or fatality. The Traffic Section generously offered to make all 1993 and 1994 data available after 'sanitizing' the records. This process merely expunged all personal information such as the names and addresses of those involved in the collision.

It became readily apparent that the optimal way to process this data would be within a Geographic Information System (GIS). Not only would the relational database within the GIS be able to manage, manipulate and analyze the very large amounts of information but the spatial display and mapping tools of this software would be invaluable. Information pertaining to the road system (traffic flows, speed limits, divided or undivided status) could be incorporated and the address matching algorithms could prove to be all but indispensable in locating individual collisions. MapInfo was chosen as the GIS of choice as it can be used on the Windows operating system and because it allowed for the importing and exporting of data between a spreadsheet, Quattro-Pro (Weiskopf, 1993), and the Statistical Package for the Social Sciences (SPSS) (Norusis, 1993) making statistical analysis extremely efficient.

Following the quantitative analysis performed within the GIS the resulting information will be used to modify existing behavioral models in order to gain a greater understanding of why the phenomenon occurs. The Risk Homeostasis Model (Wilde, 1988) offers many insights and by incorporating this new information a strategic plan may be formulated to increase the efficacy of photo radar deployment.

Finally, a broader perspective will be employed as societal and philosophical issues will be discussed, again with an emphasis towards a deeper understanding. While many of these issues cannot be incorporated directly into policy, nevertheless, they can aid in fully comprehending the nature of the problem and can assist in longer term trend analysis and policy decision making. The complete and thorough understanding of the nature of this phenomenon will allow for greater sensitivity in management of traffic safety.

In the second chapter the pertinent literature is reviewed so as to set the background for this thesis. The third chapter will detail all the analytical, statistical and GIS work involved and present it in a logical order that results in uncovering the relationship between speeding behavior and collision occurrence and culminating in the identification, relative measurement and display of hazardous locations within the city. Chapter four will deal with the phenomena from the perspective of behavioral pschology and will concentrate on the Risk Homeostasis Model of Wilde (1988). In the fifth chapter the statistical analysis and the behavioral approach will be linked in order to adjust the model in keeping with the statistical findings. A short philosophical discussion will be included to illustrate a broader global and social perspective of the problem. Chapter six will summarize the thesis research findings.

2.0 BACKGROUND

"If one took all the cars in the world and lined them up end to end, some fool would still try to pass them."

(anonymous)

2.1 Introduction

The relationship between speed and traffic accidents can be split into two main areas of research. The first area, *severity*, relies on fundamental laws of physics and has been explored in detail. It relies on the premise that during a collision kinetic energy is released and transferred from one object to another. There are two basic, directly proportional relationships: the greater the mass of the moving object, the greater the energy, and the faster the speed, the greater the injury. The above underpins all research carried out that results in safer designs of automobiles and the creation of safety devices such as seat belts and airbags. The second area is that of speed being a contributive factor to the actual event we call a collision. This *causative* relationship has also been the subject of much research but has resulted in extensive controversy. In his study, What Causes Accidents - A Semantic Analysis, Haight (1980) states:

> *"In contrast, ... the term "cause" is a source of major confusion... we have abandoned the word cause and use the phrase "contributing factor"... to mean any feature of the system, the variation of the system, the variation of which will alter the risk of an accident."*

This thesis will follow Haight's convention and use the term contributing factor throughout.

Therefore, the present research will focus on the behavior known as 'speeding', defined as travelling faster than the posted speed limit, as a contributing factor to traffic collisions. Information will be gathered from the Alberta Collision Report Forms that are used by the City of Calgary Police Services whenever an accident occurs resulting in $1,000.00 worth of damage or greater. The multivariate techniques of principal components analysis and cluster analysis will be applied to this information as a data reduction technique.

2.2 Overview

Descriptive statistics are maintained throughout many countries that detail the tremendous cost to society brought about through the agency of traffic accidents. This information has led to a growing concern over this phenomenon resulting in research that attempts to understand the many contributing factors to collisions. Many researchers have concluded that the nature of this problem is extremely complex and difficult to understand. Not only is there a bewildering array of techniques, approaches, choice of variables, and conclusions, but the fact that little research has been conducted within the urban environment makes this a particularly difficult problem.

2.2.1 Social Cost of Traffic Collisions

The carnage on our streets has been with us now for many years. The tragic consequences of collisions have provided the impetus for research into this problem. It is probable that every Canadian has had his/her life touched by the grievous outcome of a traffic accident, either through personal injury, or the death of or injury to a loved one or close friend.

> *"In contrast with the risk to the individual, the occurrence of accident or injury presents a major problem to the community as a whole. In the whole world, it is now estimated that* 1/4 *million deaths and over* 10 *million injuries occur as a result of road accidents each year!"*
>
> (Sabay and Taylor, 1979)

The above quotation was written 17 years ago now which illustrates the persistence of this problem. The singular effect on our young people further adds to the poignancy of these events as can be seen in the following two quotations:

> *"However, with the general improvement in public health the significance of road accidents is manifest; they are now the main cause of death for young people between* 15 *and* 25 *years old."*
>
> (Sabay and Taylor, 1979)

> *"Road injury is recognized as a leading cause of premature adult mortality in motorized countries. In Western Australia, road crashes result in the loss of* 7500-*Life-Years between the ages of* 15 *and* 70 *each year. Road crashes are also the most common cause of death in those aged* 1 - 14 *years and the fifth leading cause of utilization of hospital inpatient services."*
>
> (Rosman and Knuiman, 1994)

The Alberta Traffic Collision Statistics for 1990 states that: "16 - 19 year olds were more likely to be involved in a casualty collision than any other age group." While there appear to be certain explanations for this age distribution, it is still impossible to ignore the impact to society when those with so much to offer are tragically affected so early in life. The same statistics indicate that 409 people were killed in the province of Alberta and 18,604 suffered injuries as a result of traffic collisions within the province during 1990.

While the above appears to be sufficient reason to commit resources to the study and alleviation of this problem, collisions have many other costs associated with them. Loss of time at work for all those that suffer severe injury, insurance costs resulting in higher premiums to all, litigious costs that tie up our courts and affect insurance and, increased cost to our health care system; all these may be added to the human suffering presented earlier to illustrate the dire need for intervention.

When speeding is introduced as a contributing factor other social costs may be introduced as well, such as increased fuel consumption and higher rates of pollution (Connolly and Abers, 1993).

2.2.2 The Relationship Between Speeding and Collision Occurrence

With the universal imposition of speed limits and the concerted effort by police departments the world over to enforce said limits, one could not be blamed for believing that operating a motor vehicle above the posted speed limit is a major, singular contributing factor to collision occurrence. The following quotations certainly support this perception:

> "*It is well documented that increased speed increases accident risk.*"
>
> (Østvik and Elvik, 1990)
>
> "*Increases in traffic speeds have been shown to give rise to increased accident occurrence.*"
>
> (OECD, 1981)
>
> "*Vehicle speed is an important factor in accident causation.*"
>
> (OECD, 1981)

The Alberta Traffic Collision Statistics report for 1990 also states that travelling at an unsafe speed is contributory to casualty collisions. Empirical evidence backs up these positive statements concerning accident causation and speeding behavior. The oil crises of the mid-seventies provided a watershed of information due to it causing a national reduction in interstate highway speed limits in the United States. Before and after studies have shown that the reduction in accidents was greater than the reduction in overall traffic, suggesting a positive relationship (Nilsson, 1981).

Further studies attempt to establish this linkage directly and develop models that predict the decrease in fatalities and injuries based on reduction in overall speeds traveled (Rooijers and De Bruin, 1990). Rothengatter (1990, p. 60) makes this sweeping statement in the same vein:

> "*Depending on situation, type of road, country and levels of police enforcement, between* 20 *and* 80% *of the drivers exceeded the indicated limits. It has been estimated that an estimated* 30 - 50% *reduction in traffic casualty accidents could be achieved if speed limits could be realistically enforced.*"

The final link in this chain appears to have been forged. Speeding causes accidents, increased enforcement reduces speeds, and reduction in speeds reduces collisions. Unfortunately the above argument is too simplistic and must be analyzed further.

2.2.3 Complexity

It must be remembered that the majority of studies on the relationship between speed and accident occurrence have been carried out in relation to the rural highway setting. The majority of fatal collisions occur on highways, 68% compared to 32% in the city.

However, this situation is reversed for injury accidents, 73% urban and 27% rural, and for collisions resulting in property damage only, 82% urban and 18% rural (Alberta Traffic and Collision Statistics: 1990). This concentration in the literature on rural highways makes it difficult to draw conclusions from the highway research and apply the results to the urban milieu.

> "*Traffic and accident patterns on urban roads are very different from those on the interurban network and therefore need a different approach. Some of the characteristics are: - a dense network of roads, including intersections and parking lots requiring a spatial approach; - areas of differing characteristics (Business district, shopping, residential, industrial, parks, and open spaces); - different types of accidents, pedestrian, intersection, etc.; - problems of congestion and peak hours; a lack of detailed information on traffic volumes.*"
>
> (Hakkert, Yelinek, and Efrat, 1991)

The above quotation illustrates the complexity of the issue that makes studying this phenomenon extremely difficult. In addition to the above complexity, the researcher is faced with the problem of not being able to control many of the relevant factors. Changes are occurring all the time that make comparison from one year to the next problematic. The change in car design is one such change that occurs continually. Automobiles are faster, handle better, are built stronger, lighter and safer than they were just a few years ago; also they incorporate many new safety devices. Laws are constantly changing. All models that wish to represent reality must somehow compensate for these ongoing variations that are beyond the control of the researcher. Perhaps Spicer (1973, p. 4) put it best when he stated "The effect of speed is again very complex and must be studied in relation to all other site factors."

The researcher must deal with the real world and is not allowed the luxury of laboratory conditions. Quite often proxy information must be used due to the difficulty in taking accurate measurements that are compounded by the congestion of urban traffic. These constraints result in a variety of techniques and methods being used in studies that can also make it difficult to compare results. While recognizing these complications in an introduction to the 1981 Proceedings of the International Symposium on the effects of Speed Limits on Traffic Accidents and Fuel Consumption, the OECD extols researchers stating: "Nevertheless, it is useful to extract as many conclusions as possible from the data collected" (p. iv).

Often these studies that focus on enforcement and whether intervention results in lower speeds and therefore fewer collisions, ignore the urban realm resulting in an overall lack of information.

> "*There is little information about enforcement in urban settings.*"
>
> (Connolly and Abers, 1993)

> "*The links between police enforcement, variations and accidents are not clearly understood. There is little quantitative evidence in the literature to relate specific types of enforcement to changes in the number of accidents and their severity.*"
>
> (Hakkert and Yelinek, 1991)

> "*Enforcement is naturally a major consideration in any attempt to control traffic speeds. Unfortunately, there is little evidence available about the effectiveness of police traffic law enforcement. The little research that has been undertaken has concentrated mainly on highway situations whilst the problem of enforcement in urban areas has been virtually ignored.*"
>
> (OECD, 1981)

It is not surprising to find a number of criticisms referring to work done in this area. A large degree of the criticism has to do with the descriptive nature of the studies that appear to be without any definite conclusions. (OECD, 1981). Data sets must be examined rigorously with an understanding of this complexity as well as the very randomness of the events. The data collected are often not gathered with the intent of being used for analysis. Police reports are designed for legal reasons and are not designed to facilitate quantitative analysis. They have a tendency of concentrating on information at or after the accident with little information regarding events and conditions preceding the collision (Treat, Jones and Joscelyn, 1980). Without due regard to these factors, it is easy to understand the following critique:

> *"A casual observer might be forgiven for believing that in no other field of applied scientific work are simple methodological rules ignored so widely as in road safety work. Hypotheses are rarely clearly stated, data limitations are ignored, and very many - and not just politicians or the publicists - commit the fallacy of 'post hoc, ergo propter hoc' ."*
>
> (Hearne, 1981)

2.3 Behavior

Previous studies of behavioral habits of drivers appear to focus on the influence of a small group of deviant vehicle operators, those who exceed the speed limit, and not on the other drivers. Some drivers ignore those passing them while others are influenced, imitators. We derive information from the behavior of others as well as using this information to assess ourselves relative to what others are doing (Zaidel, 1993). Zaidel (1993) goes on to stress the importance of this observation as follows:

> *"Of particular interest to traffic behavior is the finding that a minority opinion or position may have a disproportionately large impact when compared with the impact of the majority (Moscovich: 1985). This seems to give deviant, rather than common, behavior a larger weight in shaping collective behavior."*

The visibility of speeding behavior and its other attributes are characteristics that enhance diffusion; the benefits are clearly and easily understood as well as immediate, it is easy to speed and the influence can be quite high as many drivers do engage in speeding to some degree (Zaidel, 1993).

The above is directly related to what has been termed the 'normative factor'. This refers to how other drivers are acting, not to what drivers ought to do (Connolly and Abers, 1993). This holistic view of how drivers are influenced by, and influence others, has been termed the culture of driving by Zaidel (1993) or the contagion model by Connolly and Abers (1993). In the contagion model, three basic behavioral types are described; those that always speed, those that obey the posted speed limit, and those that speed only when a certain percentage of other drivers are engaged in speeding. What is important here is the variety in the reaction of those that respond to drivers around them. Do they begin speeding when only ten percent of the other drivers' speed or do they require a larger critical mass to encourage them to increase their speed. Connolly and Abers have created several hypothetical models based on varying percentages of offenders who influence the rest of the drivers as well as varying percentages of membership of the three constituent groups. It becomes apparent then that police intervention may only be required to alter the behavior of a small group of deviant drivers to effect a greater overall reduction in speed distribution. Unfortunately, it appears that deviant behavior spreads rapidly whereas intervention must be prolonged and concentrated to effect even a small change in overall behavior (Connolly and Abers, 1993).

Thus imitative behavior becomes an important concept in safety studies and must be understood thoroughly. There need be no coercion or communication between two actors for imitation to take place, it is merely necessary for one to be aware of the other's behavior. The speeder does not need to be aware of his/her influence and certainly does not need to have a desire to influence others. The imitator must be aware of the others' actions and must be susceptible to influence. This implies that she/he has the potential and ability to engage in the deviant behavior (Zaidel, 1993).

2.4 Intervention: Strategies and Successes

A variety of issues are at stake when one looks at the various intervention strategies. Obviously, the degree of success in reducing speeding behavior is paramount, but other concerns such as safety for the officers involved and time and economic costraints must be considered. The intensity of traffic has increased in our urban areas at a much faster pace than the police service itself, and to add further difficulties, other crimes have risen rapidly simultaneously placing further stress on overburdened police forces everywhere (Rothengatter, 1991).

2.4.1 Halo and Memory Effects

Studies of traffic behavior in the presence of stationary marked police vehicles engaged in radar monitoring have uncovered two phenomena, the halo and memory effects. The halo effect is spatial and describes the fact that upon noticing the police vehicle, vehicles slow down and continue travelling at this slower rate until well past the police car. The memory effect is temporal whereby the traffic will repeat this behavior of slowing down while travelling the same stretch of road for a period of time after the removal of the police car. Studies (Rothengatter, 1982) have measured both the time and distance involved in a highway setting:

> *"Stationary, visible police units have been found to affect the immediate behavior of drivers: both speeders and nonspeeders slow down in the vicinity of a police car. A 'halo effect' of enforcement is noticeble for about five kilometers and a memory effect lasts from 10 to 14 days."*

Doubts have been raised as to the efficacy of these effects within the urban environment (Nillson, 1981) and many would be skeptical about the five kilometer halo effect. Although personal observation leads me to believe that a halo effect of smaller dimensions would exist within a city, perhaps only as large as one-half to one kilometer. However, that this halo is purported to exist is important and will be utilized further in this work.

2.4.2 Automated Policing

There have been only a few studies so far on the effects of automated policing and the results would be too preliminary and tentative to be considered conclusive. The preliminary results are, however, favorable. Significant reductions in speeding have been obtained in Norway and chronicled over a two year study. Significant memory effects have been noticed as at one location the photo radar was only in operation for twelve hours a week and yet the reduction in speed remained stable. Even after the removal of the camera this lower speed remained in effect for up to two months (Ostvik and Elvik, 1991). The spatial halo effect was considerably smaller and could reflect the urban environment in which this study took place. Long term effects are yet to be studied and the above mentioned authors state their concern over public acceptance of such devices. They warn that this issue should be addressed at the outset so as to "direct the innovation of such systems in the right direction." A significant statement considering the argument of this thesis.

Knowing that photo radar is one of the more economical ways of improving and increasing enforcement it appears that its continued and even escalated use is the direction in which many police services are headed.

> *"Depending on situation, type of road, country and levels of police enforcement, between 20 and 80% of the drivers exceed the indicated limits. It has been estimated that an estimated 30 - 50% reduction in traffic casualty accidents could be achieved if speed limits could be realistically enforced."*
>
> (Rothengatter, 1991)

Mobility is a key advantage with photo radar as it may be deployed at particular sites that may be deemed hazardous. If a memory effect can be measured and documented, then once a photo radar has been situated at a particular location for a period of time, it may be removed for the duration of the memory effect and then brought back.

> *"When compliance level drops below a certain level (regardless of accidents), a 'booster shot' needs to be activated in the form of a dose of enforcement. With this approach, erosion of compliance after some time (as well as the diminishing impact of any safety measure) should not necessarily be taken as a failure. Rather, it indicates that many changes took place and a new or supplimentary action is called for."*
>
> (Rooijers and DeBruin, 1991)

2.5 Perception

When a driver engages in speeding behavior certain risks are incurred. An important element to understanding this behavior lies in determining what level of risk is perceived by the individual. Most studies express risk in aggregate terms as in total yearly fatalities or injuries yet fail to transcend the population of drivers to the individual driver (Sabay and Taylor, 1979). Alarming as the statistics are, what do they mean for the average driver? Conversely, Zaidel views this dilemma from the individual to the whole:

> *"However, driver behavior modelling lacks a connection between models of individual behavior and the (presumably) resultant population behavior as reflected in traffic characteristics, driver surveys, or driver records."*
>
> (Zaidel, 1993)

Sabay and Taylor (1979), in their study of 1977 accidents in Great Britain report that the risk of involvement in a traffic fatality is 1 in 2500 years, involvement in an accident resulting in injury 1 in 57 years and in an accident in which there are no injuries, 1 in 9 years. As they rightfully conclude, with such a low likelihood of risk it is no wonder that the public is not interested in measures to promote road safety. There are two different types of risk facing the motorist, risk of being involved in an accident and risk of apprehension for speeding.

2.5.1 Risk

Risk involved in travelling is not new to society. Mobility of all forms has been hazardous throughout the ages. Thus a certain element of risk has long been accepted, whether through robbery, loss of direction, being caught in extreme weather or being involved in accidents. This long history of danger has caused a certain acceptance of risk by society while travelling. As most have spent all their lives with automobiles as the primary source of mobility, acceptance of risk has become almost inbred and is only dimly perceived (Sabay and Taylor, 1979).

As the car is constantly being re-engineered with new safety devices and stronger construction, this results in a net perception of a drop in risk of injury should one become involved in a collision. On the other hand, cars are also designed to obtain higher speeds in general, accelerate quicker, brake faster and more effectively, and corner faster, thus resulting in an increasing overall improvement in handling ability. As Fuller (1991) argues:

> *"...they are all designed to ameliorate the consequences of unsafe driving behavior. As such, from a behavioral point of view, they may have the unintended and detrimental effect on the the motivation of safe behavior, the phenomenon known as risk compensation."*

Fuller also states how there appears to be little if any social control against unsafe driving behavior as even passengers are reluctant to speak out against their own drivers. He identifies two types of error: one being ignorance of the potential danger and the other being gambling with the probability that an accident might actually occur.

Sabay and Taylor (1979) argue for a better understanding of attitudes toward risk as the success of any countermeasure will be contingent on this knowledge. They feel that there is confusion in risk perception amongst the general population of drivers and that the results of safety measures are unpredictable as a result of this.

Risk of apprehension and punishment appears to be the strongest deterrent against unsafe driving habits (Sabay and Taylor, 1979). To be effective though, it must have the elements of deterrence theory, sureness, swiftness and severity (Epperlein: 1987; Abers: 1988; Fuller: 1990).

> "*Enforcement strategies are more effective the more they meet the criteria of classical learning theory concerning especially swiftness and probability of the feed-back.*"
>
> (Rumar, 1990)

2.5.2 Motivation

Thus there seems to be a lack of certainty between actions and consequences and therefore little to hinder the motorist from speeding behavior. Why engage in such behavior unless there is something to be gained? Two main motivational factors are present, the first being that speeding is pleasurable to many. People like to go fast and therefore it is rewarding. Also, speeding allows one to save time and the saving of time is an important value in society. To take this one step further, more time is saved the faster one goes. When aggregate behavior is observed, Fuller (1990) argues that society may be willing to accept a certain amount of cost, measured in accidents, in order to gain the additional time saved.

Fuller mentions three 'traps' that the motorist may become involved in:

1. The Consequences trap whereby the driver engages in unsafe behavior due to the rewards to be had: time saved, experience of thrill, and display of skill.
2. The Contingency trap where the driver is unaware of the risks taken due either to ignorance or being unable to recognize events preceding imminent danger.
3. The Conditioning trap where the driver has learned unsafe behavior due to the low risk of accident occurrence or due to becoming desensitized to hazardous events.

Østvik and Elvik (1990) point out that there is always some element of risk and probability of accident occurrence associated with any speed moreover total compliance to posted speed limits is virtually impossible so "Society, therefore has to decide on what level of mobility, enforcement and compliance it will have in relation to how many accidents society will accept."

2.5.3 Risk Homeostasis Theory

Wilde has developed a theory that he has called Risk Homeostasis Theory. He defines his theory as a number of hypotheses held together by a common thread. It is beyond the scope of this thesis to discuss this theory in its entirety, however, significant parts of this theory will be put to use as a means of operationalizing much of the quantitative analysis. The theory will also aid in explaining how intervention should affect the general population as well as providing a way to predict the outcome of various intervention strategies.

One of the more important points of this theory is that everyone has a particular level of risk which they accept when participating in the activity of driving a motor vehicle. They then adjust their actions in order to match the 'target level of risk'. Thus, if a car was made safer through improved handling characteristics the driver would traverse curves at a faster rate of speed in order to maintain the same target level of risk. This behavioral phenomenon is known as a compensatory feedback loop. Only by acting directly on the target level of risk, which lies outside the compensatory loop, will drivers respond by reducing their speed. It is this important part of the theory that will be used later in this work.

2.6 Summary

This chapter surveyed the literature covering areas such as the cost to society of collisions, the relationship between speeding behavior and collision occurrence as well as the complexity of this issue. Different points of view were presented concerning this topic. Police intervention strategies were also looked at. Behavioral studies were then reviewed that led into theories of perception, motivation and risk. Finally the Risk Homeostasis model was introduced as it will be utilized after chapter three where the analytical and statistical research will been explained.

3.0 QAUNTITATIVE ANALYSIS AND GIS

"Where there's law there's injustice."

Leo Tolstoy, War and Peace.

3.1 Introduction

The above quote underlies the need for rigorous measurement of traffic collisions, for without precise definition of the phenonomena it would be difficult to create effective management strategies. In this chapter, a series of strategies will be used in order to arrive at a greater understanding of the causal relationship between speeding and collision occurrence. Once arriving at the heart of the problem it is then possible to consider how the variables may be organized in such a fashion as to allow for a continuing management strategy.

This exploration will begin by using principal components analysis simply as a data reduction technique. This will present us with some components, or groupings of variables, that will provide choices as to what area would prove most fruitful for further study. Having chosen a component, it can be further explored by comparing locational factors. This will be accomplished within a geographic information system (GIS) which, among other things, has tremendous utility as a data acquisition and management tool. This preparatory research will then allow the formulation of a specific *a priori* hypothesis that will then be subjected to rigorous statistical analysis. The final step will be to reinject this information into the GIS and create snapshot images, providing locational, or geographic, as well as statistical views of the phenomena. A number of accepted engineering formulae will be utilized at this stage in order to create a model. This model which can be made dynamic by including numerous time frames, may be used by traffic analysts not only to analyze current trends but also to monitor the efficacy of specific intervention strategies.

3.2 Principal Components Analysis

As discussed earlier, the relationship between speeding behavior and traffic collisions is a complex one. The data set used here is large and the variables may be interrelated in an elaborate fashion. Compounding this problem is the fact that the researcher had to work with the available police collision reports, instead of being able to collect data that may better fit the methodology. It was simply too expensive to collect pertinent data that might have been better suited to an *a priori* hypothesis. This is a common problem for traffic safety studies. The tremendous volume of data necessary coupled with the seemingly random or stochastic nature of collision occurrence precludes any economically feasible data gathering technique. In the preliminary stages of investigation, the multivariate, data reduction technique of principal components analysis was found to be useful.

3.2.1 Study Area and Data

The study area is the City of Calgary, Alberta, Canada, a growing municipality located on the western edge of the Canadian prairies just east of the Rocky Mountains. It has a well designed road network that does not experience the major tie-ups, or grid lock, that plague many other large, modern cities. The generosity of the Calgary Police Service Traffic Division in supplying data and my familiarity with the city were the strongest determining factors in choosing this location. The City of Calgary covers 671.75 sq. km. (259.36 sq. miles) and supports a population of 738,184 (Clear-View Maps Ltd., 1995).

For GIS purposes, the computer program MapInfo (MapInfo Reference Manual, 1992) was chosen as was the MapInfo Streetfile of Calgary.

Most of the data utilized in this paper was graciously supplied by the City of Calgary Police Services, Traffic Sector. A selected group of variables was extracted from the files containing all information collected from the Alberta Collision Report forms. This selection included all those vehicular collisions, for which a form was completed, that occurred in the City of Calgary during the year 1993 (i.e., any collision resulting in an estimated $1,000.00 or more damage is required by law to be reported to the police). There was a total of 27,190 collisions of which 38 were fatalities and 2,148 were injuries. Two variables, road classification and posted speed limits, were obtained manually through the agency of comparing the collision location to an appropriate map containing the necessary information.

This material was entered into the Quattro-Pro (Wieskopf, 1993) spreadsheet program where it underwent a series of editing procedures so that it could be used for analysis. Once this was completed, two data sets were created. The first set contained all those accidents where the attending officer deemed at least one vehicle to be travelling at an unsafe speed regardless of whether this vehicle's operator was considered at fault or not. The second set is a subset of the first. Only those records in which road and weather conditions are favorable were selected. The rationale was to eliminate the subjectivity of the attending officer's judgement. Unsafe speed does not necessarily require the offender to be travelling faster than the posted speed limit, which is merely a limit if all road and environmental conditions are favorable. By ensuring that the road and environmental conditions were favorable, we eliminate the officer's decision as to what was a safe speed, and we can safely assume that all drivers represented by this second data set were in fact travelling faster than the posted speed limit. This reduced the data set to 1,181 cases in total, 7 of which were fatalities and 254 being injuries. For each collision 8 variables were recorded (table 3.1).

3.2.2 Background

When faced with a bewildering array of information without the benefit of a well-formulated hypothesis, the technique of principal components analysis can offer insights into the nature of the data. This is accomplished by the two main features of this procedure: (1) its data reduction capability, and (2) its ability to organize the data into components that often expose underlying structure within the data (Nie *et al.*, 1989; Tabachnik and Fidell, 1989). The data is reduced by grouping variables into components which summarize the patterns amongst the variables, and as the amount of significant components is less than the original complement of variables a parsimonious answer is presented (Tabachnik and Fidell, 1989). During the process of coming to an understanding of the individual components the researcher may discover new concepts and relationships within the dataset. Thus the exploratory, and hypothesis generating nature of this approach is revealed (Nie *et al*, 1989).

Principal components analysis and its companion, factor analysis, do have other statistical uses that include hypothesis testing, and when used as such they require rigid data screening. However, the exploratory approach is extremely robust with few constraints upon the data. Decisions regarding the number of components to be derived, the choice of extraction and rotation techniques and the theoretical and practical limitations are relaxed in exploratory applications of the technique so as to allow the researcher to be able to examine the data freely (Tabachnik and Fidell, 1989). More fundamental data screeening may also be relaxed proving this to be a most robust methodology:

Table #3.1 **Variables**

Category	Value	Value	Value	Value	Value	Value	Value
Severity of Collision	Fatality	Injury	Property Damage Only				
Object Type	Passenger Car	Pick Up/Van <4500 Kg	Mini Van/ MPV	Truck >4500 Kg	Truck Tractor	Motorcycle/ Scooter	Emergency Vehicle
Light Condition	Daylight	Sunglare	Darkness				
Traffic Control Device	No Traffic Control Device	Traffic/ Signal Lights	Stop Sign	Yield Sign	Merge Sign	Pedestrian Crossing	Railroad Crossing
Driver/ Pedestrian Condition	Apparently Normal	Had Been Drinking	Impaired by Alcohol	Impaired by Drugs	Fatigued/ Asleep		
Address Type	Intersection	Exact	Mid Block	Unclassified			
Road Classification	Residential	Collector	Major Street	Freeway			
Posted Speed Limit	30 Kph	50 Kph	60 Kph	70 Kph	80 Kph	100 Kph	

> *"As long as principal components analysis and factor analysis are used as convenient ways to summarize the relationships in a large set of observed variables, assumptions regarding the distributions of variables are not in force."*
>
> (Tabachnik and Fidell, 1989)

No previous assumptions regarding relationships in the data are required, so we allow the data to recombine into components freely in the hope that it may reveal previously hidden patterns of association amongst the variables. Each component is a linear combination of variables arranged in descending order of explanation. Therefore the first component is the 'best' combination of variables that explains the most variation in the data set. The second component is the linear combination that explains the most residual variance, or the remaining variance after the effects of the first component have been removed from the data set. The second component should be orthogonal to the first. This is possible when the variance it explains is not accounted for by the first component. This process of extracting components continues with one component being extracted for each variable (Nie *et al.*, 1989).

This last statement may sound confusing, if we extract as many components as there are variables then we have not reduced the data at all. What in fact occurs is a very rapid drop off in variance accounted for by each component, as measured by its eigenvalue. The researcher then must decide where to cut off the lesser valued components, retaining only the more significant ones.

3.2.3 Binary Data

While preparing the data for analysis it became apparent that attempting to place categories into components would prove useless for interpretation. For example, if there was a correlation between 'Speed Limit' (which would include all values in that category) and 'Severity' (which would include all values in that category) all we would be made aware of is that there is some form of association between these two categories. As there must be a speed limit and the accident must have occurred on a road, or at least have begun there, we are no wiser for our efforts. We cannot state what speed limit has an influence nor do we know whether the participants were injured, killed or not injured. It was decided to make each categorical value an individual variable and then it would be possible to compare particular units of data, such as a particular speed limit and injury only, directly to each other.

The first step in making this possible is to convert the data into a binary matrix. This was achieved by creating a column for each value and then transforming the information into 1s and 0s. A 1 would be interpreted as the presence of that variable while a 0 would indicate the absence of that variable. Some measure of association would be required between variables to be able to utilize this information in principal component or cluster analysis. The crosstabs procedure in SPSSX produces chi-square and Cramer's V statistics, the latter being a measure of strength of association between variables. Cramer's V has limitations since it ranges from 0 to +1 and thus it does not indicate the direction of the relationship and does not closely correspond to correlation statististics that are traditionally used in principal component and cluster analysis.

Tinkler (1971) has devised a coefficient of association (Ca) for binary data. It associates matched, or coincident, pairs and unmatched pairs and takes on the form:

$$\mathbf{Ca = 2\ (r/n - 1/2)\ or\ 2r/n\text{-}1} \tag{1}$$

where:

r = number of coincident pairs

n = total number of pairs

The range of values resulting from this equation is -1 to +1 with the negative values implying the inverse relationship. We now have a measurement similar to a correlation coefficient that when calculated between all pairs of variables may be assembled as an input matrix for principal components analysis. The difficulty of interpreting analysis derived directly from a binary matrix is avoided by using this measure of association (Tinkler 1971).

This coefficient is nevertheless based on binary data, and while having advantageous properties, must also be interpreted with its limitations in mind. Tinkler discusses both these features in the following statement:

> "*Multiplying the index by 100 gives the exact percentage amount of correspondence or lack of it above or below that expected under Ho and in this way Ca is more analogous to the square of the normal correlation coefficients which indicate the amount of covariance. A very crude estimate of a correlation coefficient is therefore obtained by taking the square root of Ca. This is not meant to imply such a procedure accurately estimates a correlation coefficient. Indeed, comparison of Ca and Spearman's rank correlation coefficient shows that the relationship is not good with Ca generally being of higher value than Spearman's coefficient and thus overestimating the rank relationships.*"
>
> (1971)

All coefficients being derived according to the above formula, the input matrix was constructed with ones placed in the diagonal as required for principal components analysis. It was during this process that a particular problem was revealed. Certain variables, once grouped under a categorical heading, being listed independently, began to match up against each other within the matrix. For example, in the row labelled with the value 'intersection' ,one could move across the matrix to the column entitled 'mid block'. This cell is problematic as it is impossible to be at both locations simultaneously, so the value of -1 was assigned to the cell, indicating a pure negative relationship. Having completed this correction, the input matrix was finalized and ready for use in principal component and cluster analysis.

3.2.4 Results

Several methods are available for determining how many components should be retained in the solution: eigenvalue size, percent of variance and scree plots are the most common tools for decision making. In the 'Initial Statistic' table, each component, or factor, is listed with its eigenvalue, percent of variance and cumulative percent of variance. As an eigenvalue of 1 theoretically means that the particular factor holds no more explanation of variance than a single variable, the decision to cut-off is traditionally above this point (Tabachnik and Fidell, 1989). This is also the default cut-off point used by the SPSSX program that was utilized for this research. Table 4.2 lists the information for all factors with eigenvalues above 1.

A general guideline is that the number of components with an eigenvalue larger than 1 should fall within the range determined by dividing the number of variables by three, for the upper limit, and five for the lower limit (Tabachnik and Fidell, 1989). The eight considered here fall within that range.

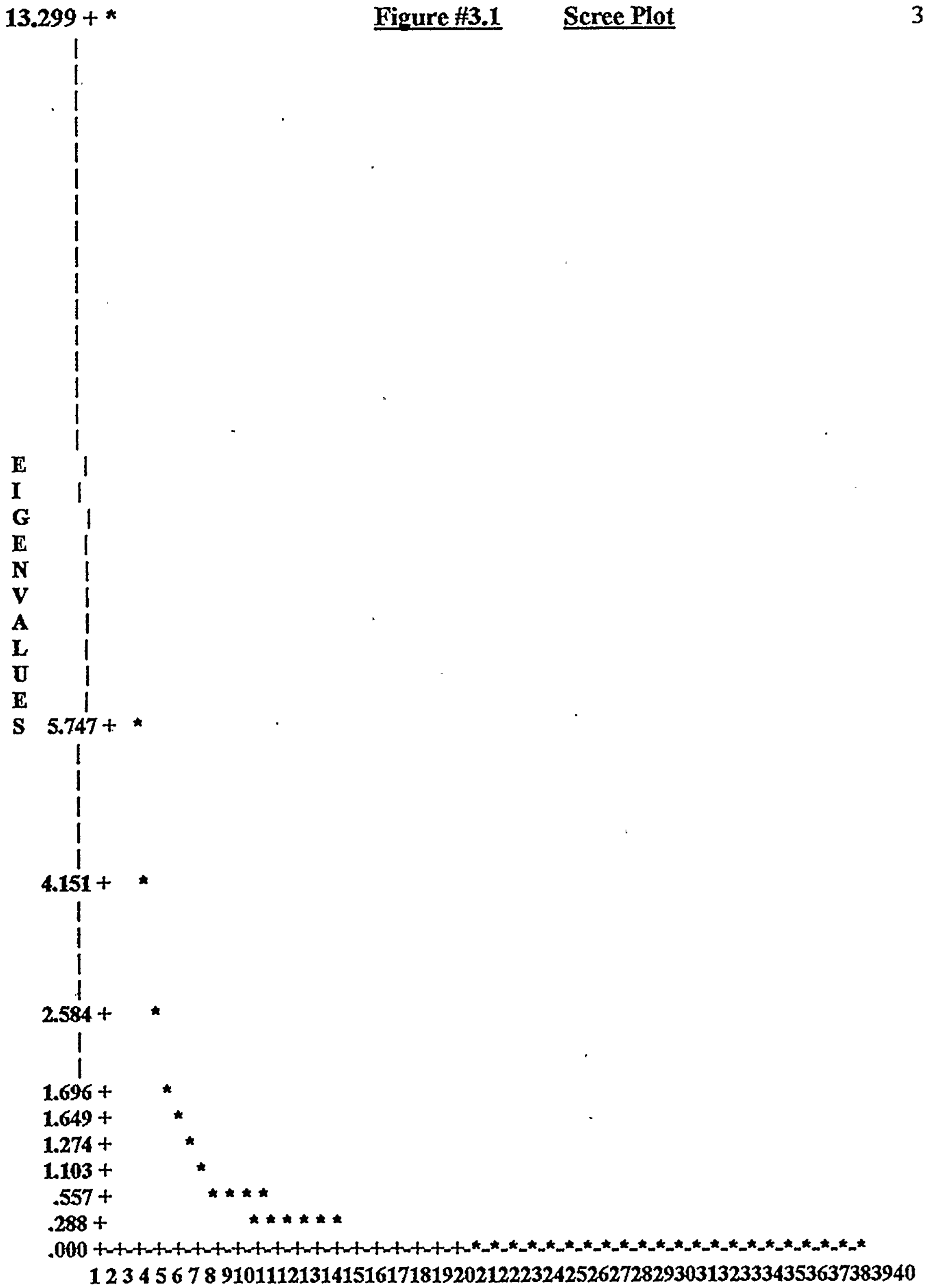
Table #3.2 **Initial Statistics**

FACTOR	EIGENVALUES	% OF VARIANCE	CUMULATIVE %
1	13.29931	33.2	33.2
2	5.74727	14.4	47.6
3	4.15070	10.4	58.0
4	2.58382	6.5	64.5
5	1.69585	4.2	68.7
6	1.64935	4.1	72.8
7	1.27386	3.2	76.0
8	1.10267	2.8	78.8

Another way of selecting factors involves plotting their eigenvalues in a 'scree plot'. The general convention is to draw a straight line diagonally through the first group of components and reject all the lower components that will deviate from this line. When this test is applied to the scree plot in the diagram on the following page, we find that only the first four components would be suitable for inclusion in the final solution (Tabachnik and Fidell, 1989).

Finally, the researcher must look for the aforementioned patterns within each component to decide the importance of each component and its utility for interpretation. This can be peformed by examining how the individual variables correlate to the components in the

Figure #3.1 **Scree Plot**



Source: Data source from City of Calgary Police Collision reports for 1993, plot created by SPSSX.

'loadings matrix'. Several characteristics aid in interpreting the variables and components: marker variables, complex variables, strength of association and number of variables within each component.

Marker variables are those that correlate highly to a single component. They assist in defining the nature of that component. Generally values higher than + or - 0.3 are accepted as adequate for loading correlations. Complex variables are the opposite of marker variables in that they correlate to more than one factor. They may cause further confusion in that they have a tendency to group together in factors that do not necessarily have anything to do with the underlying pattern in the data.

> "*Variables with similar complexity may correlate with each other <u>because of their complexity</u> and not because they relate to the same factor.*"
>
> (Tabachnik and Fidell, 1989. *emphasis in original*)

Components with only one or two variables are suspect and should be avoided. If it is believed that there is homogeneity within the data, lower scores may be accepted. Once variables are chosen for inclusion within a component the researcher attempts to name the component in such a way as to include the information of the variable within the component.

The following quotation from Tabachnik and Fidell (1989) explains the rule for selection of variables:

> *"As a rule of thumb, only variables with loadings of .30 and above are interpreted. The greater the loading, the more the variable is a pure measure of the factor. Comrey (1973) suggests that loadings in excess of .71 (50% overlapping variance) are considered excellent, .63 (40% overlapping variance) very good, .55 (30% overlapping variance) good, .45 (20% overlapping variance) fair, and .32 (10% overlapping variance) poor. Choice of the cutoff for size of loading to be interpreted is a matter of researcher preference."*

One last aid to interpretation is that of rotating the factor matrix. Several methods are available that fall into two broad categories. Orthogonal rotation attempts to alter the correlations to maximize the difference between components. Out of the several choices available, both orthogonal and non-orthogonal, the orthogonal Varimax procedure, was chosen. Rotation helps the researcher to interpret the loadings matrix by maximizing the higher variable correlations and minimizing the lower variable correlations. It peforms this without altering the original mathematical solution, although there is generally a slight reduction in the value of the first component. Oblique rotation allows for interrelationships to exist between the variables. It is often chosen if there is suspected homogeneity within the variables, but it does not always improve interpretability (Nie *et al.*, 1989; Tabachnik and Fidell, 1989).

The rotated Factor Matrix is presented in table 3.3 on page 38. The table is arranged for easy interpretation by the following conventions: the underlined correlation is the highest value for that variable, the variable name is underlined if it is considered to be a marker or it is italicized if it is considered a complex variable, underlined factor labels are those considered significant while those in italics will be removed from further analysis.

Factors 6, 7 and 8 have few variables and most of them are complex while Factor 5 captures eight variables, all of which are complex. Table 3.4 shows the remaining factors, or components, with their appropriate variables and the percent of variance explained. Each factor is named in such a manner as to shed light on its meaning.

3.2.5 Interpretation

The first component is labelled as 'Stimulus Overload' due to the presence of traffic control devices indicating intersections or interchanges. These locations will experience more maneuvers such as lane changes and merging as well as having a greater range in traffic speeds. This will be due to vehicles accelerating as they enter the traffic stream or decelerating as they leave it. This component will be explored further by re-examining some of the original data as it is the most important component, explaining over one third of the variance.

Factor two involves all vehicles other than passenger cars. Without further study it would be difficult to interpret this factor, although it may be the result of the low relative amount of these vehicles as compared to the passenger cars and yet they may be involved in a disproportionately high amount of accidents. It is advisable to remember that this data set represents accidents that involve speeding on good road conditions and therefore involves vehicles that are almost certainly exceeding the speed limit.

Factor three is easier to interpret and even though the 30 Kph speed limit is within this factor, it can be viewed as an anomaly. It represents a special case that is sparsely represented in the data set and stands for a special geographical location. Most of these areas involve school zones or playground zones. With most traffic slowing down, congestion can occur through compression and problems may result. The higher speed

Table #3.3 **Factor Matrix**

Variable	Factor 1	Factor 2	Factor 3	Factor 4	*Factor 5*	*Factor 6*	*Factor 7*	*Factor 8*
Fatality	.27343	.30988	.36271	.36830	.45044	.18851	.16501	.21335
Injury	.20890	.23820	.29211	.27326	.40818	.13264	.17451	.20718
P. Damage	-.35613	-.38018	-.40993	-.38390	-.43158	-.11961	-.12893	-.23372
Pass. Car	-.39618	.15535	-.43353	-.42162	-.47077	-.06888	-.12361	-.25255
Pick Up	-.05354	.86356	.01802	.01384	.03050	.07916	.08611	-.03042
Mini Van	.00318	.88408	.08410	.08755	.10648	.12608	.09271	.00444
Truck >	.04895	.76703	-.07595	.06175	.05673	-.22685	-.50329	.14238
Truck	.00681	.88540	.08880	.09132	.10995	.12328	.09752	.01000
Motorcycle	.00274	.88274	.08107	.08681	.10574	.14004	.08254	.00794
E. Vehicle	.00710	.88528	.08852	.09195	.11027	.12736	.09362	.01144
Daylight	-.21928	-.22517	-.17837	-.26135	-.20847	-.60066	.16079	-.07776
Sunglare	.30470	.34129	.39639	.38479	.46857	.11184	.16732	.23231
Darkness	.04200	.05600	.04841	.15345	.19831	.72098	-.05032	.04690
*No TCD**	.43930	-.34474	-.36383	-.28607	-.34948	.17441	-.20657	-.27539
Sig. Lights	.84169	-.09904	-.06261	-.08744	-.04038	.13508	.06096	.03260
Stop Sign	.89375	-.00294	.03365	.05627	.09409	.07418	-.00719	.03138
Yield Sign	.89903	.01639	.05494	.07633	.11727	.07360	.02176	.03418
Merge Sign	.89918	.02320	.05891	.08129	.11948	.09195	.02361	.03402
Ped. X'ing	.89912	.01570	.05394	.07714	.11642	.08117	.00488	.04109
Lane Device	.89922	.02179	.05872	.08222	.12116	.09220	.01635	.03719
RR X'ing	.86862	.06990	.05154	.05097	.04424	.19474	.18913	-.06240
Normal	-.23875	-.39077	-.24819	.29729	-.20548	-.65788	-.12399	-.03634
Been Drinking	-.01132	.02312	.18782	.80915	.12285	.11747	-.18770	.06515
Impaired Al.	.05955	.06537	.11825	.83722	.18625	.07905	.05503	.06828
Impaired Drug	.09287	.12479	.17841	.83030	.22473	.01340	.12322	.07978
Asleep	.04608	.19073	.17042	.77208	.11620	.15268	.37370	-.06370
Intersection	-.27065	-.42908	-.31557	-.36768	.02690	-.56106	-.12946	-.03564
Exact	.05748	.01651	.08261	.13568	.80208	.29009	-.16465	-.00726
Mid Block	.16451	.19096	.25129	.21967	.75087	.07422	.15908	.10960
Unclassified	.14685	.22508	.25562	.20785	.71022	.13361	.27192	.04025
Residential	.10779	.15839	.18772	.10419	.19618	-.02936	.65067	.39866
Collector	-.03685	-.08361	.00657	-.00632	.01186	-.02104	.01735	.86548
Major Street	.13183	.13428	.20168	.24007	.29593	.36470	.09760	.52984
Freeway	.19596	.19867	.26403	.27695	.35458	.29144	.11297	.50382
30 Kph	.01107	.12581	.83153	.17200	.08856	.21692	.17302	-.04475
50 Kph	-.20361	-.33919	.31932	-.23979	-.16381	.16427	-.72355	.05634
60 Kph	.01884	.03314	.84826	.08310	.10638	.04751	-.09925	.12105
70 Kph	.03208	.05938	.86449	.11188	.14057	.05587	-.01167	.03843
80 Kph	.03506	.04672	.85584	.10130	.14618	.06276	-.04699	.04982
100 Kph	.03189	.05364	.84521	.17973	.15268	.06767	.02265	.02824

(TCD stands for Traffic Control Device.)*

limits show that when one travels beyond this speed, the likelihood of collision increases indicating less room for error at higher speeds.

The last factor shows that if one is engaged in speeding while impaired, the risk of being involved in a collision has increased. This provides support for the campaign against driving while impaired and supports police efforts to reduce this behavior.

Table #3.4 Remaining Factors

Factor 1	Factor 2	Factor 3	Factor 4
33.2% variance	14.4% variance	10.4% variance	6.5% variance
Stimulus Overload	**Vehicle Other Than Passenger Car**	**High Posted Speed Limit**	**Driver Impaired**
No TCD	Pick Up/Van <4500Kg	30 Kph	Had Been Drinking
Traffic/Signal Lights	Mini Van/MPV	60 Kph	Impaired by Alcohol
Stop Sign	Truck >4500 Kg	70 Kph	Impaired by Drugs
Yield Sign	Truck Tractor	80 Kph	Fatigued/Asleep
Merge Sign	Motorcycle/Scooter	100 Kph	
Pedestrian X'ing	Emergency Vehicle		
Lane Control Device			
RR Crossing			

Four different areas for further study have been presented as a result of principal component analysis thus indicating the utility of this popular technique. It would be possible to perform this analysis over, using the first results as a guide for examining and removing variables that may make interpretation difficult. All complex variables should be reconsidered.

3.3 Cluster Analysis

Cluster analysis has been used as an aid in taxonomy (Davis, 1973). It also can be thought of as a data reduction tool although it is perhaps better thought of as a classification methodology. It too is useful for hypothesis generation and exploratory analysis. Cluster analysis creates homogeneous, distinct groups from the original data thus allowing the researcher to classify the information (Davis,1973). Just as in principal components analysis some subjective judgment is required of the analyst.

The particular method used in this analysis is that known as hierarchical clustering. This process looks for the two most similar observations and joins them together. A new observation is created from the joined pair and its measurement of similarity is reassessed. This pair now takes on the characteristics of a single observation and is then re-entered into the process which begins again. The operation is iterative, repeating until the last two pairs are joined. From this information a dendrogram is produced, as seen in Figure 2 on the following page (Davis, 1973).

The dendrogram is a graphic representation of how this technique combines the observations into larger and larger groups. The scale across the top represents the loss of information that is incurred as larger and larger groups are accepted into the solution. The skill in interpreting the dendrogram lies in being able to choose the largest groups while retaining the maximum amount of information. This can be accomplished by considering the members of the groups and then determining the appropriate level for the cutoff point. If principal components analysis is used in conjunction with cluster analysis, as was the case here, it may be wise to choose the same number of groups from the cluster analysis as there are relevant components from the principal components analysis and compare the results.

If four groups are chosen by using the principal components analysis as a guide, three clearly distinct groups form. The fourth and last group, located at the bottom of the dendrogram, tends to suffer from the condition known as chaining. Many of the variables in this bottom group (see table 3.5 for the list of variables) correspond to complex variables in the loadings matrix of the principal components analysis. They will thus require further analysis to determine whether or not they should be included or removed from the data set.

The first group appears to include what could be considered the variables that describe the typical collision, one that results in property damage only. It is suspected that the large amount of these collisions biases the sample, overwhelming all the other data. The second group corresponds to the first component and relates to 'stimulus overload'. The third group corresponds to the second component containing various vehicle types. The group of speed limits that comprise the third component gets put together with the complex variables.

Unfortunately, the chaining effect tends to degrade the solution. What is shown though, is the close correspondence between the groups derived in both processes, lending credence to the importance of these groups and directing the researcher to explore them further. Thus both techniques have reduced the complexity that was initially inherent in the data set. They do not suggest strength of relationship to any great degree, however. Certain variables may be checked for validity and other methods are suggested as a result of these analyses.

```
03 Feb 95   SPSS Release 4.0   Risc System 6K
09:25:40    University of Calgary  - ACS    Risc System 6000 Aix 3.1

* * * * * * * * * * * * * * * * * * H I E R A R C H I C A L   C L U S T E

 Dendrogram using Average Linkage (Between Groups)

                        Rescaled Distance Cluster Combine

  C A S E   0         5        10        15        20        25
 Label  Seq +---------+---------+---------+---------+---------+

           3  -+---+
           4  -+   +---+
          11  -+-+ |   |
          22  -+ +-+   +-+
          27  ---+     | +-------------------------------------+
          14  ---------+ |                                     |
          36  -----------+                                     |
          18  -----+-+                                         |
          20  -----+ |                                         |
          17  -----+-+                                         |
          19  -----+ +-----+                                   |
          16  -------+     +-----------------------+           |
          21  -------+     |                       |           |
          15  -------------+                       |           |
           8  -----+-+                             |           |
          10  -----+ +-+                           |           |
           6  -----+-+ +-------+                   +-----------+
           9  -----+   |       +-------------+     |
           5  ---------+       |             |     |
           7  -----------------+             |     |
          38  -------+                       |     |
          39  -------+                       +-----+
          37  -------+-+                     |
          40  -------+ +-------------+       |
          35  ---------+             |       |
          24  -------+-+             |       |
          25  -------+ +-+           +-------+
          26  ---------+ +-------+   |
          23  -----------+       |   |
           1  -+-----+           +---+
          12  -+     +---------+ |
          29  -------+         | |
          30  -------+         +-+
          13  -------+-----+   |
          32  -------+     |   |
          33  -------+-+   +---+
          34  -------+ |   |
           2  ---------+-+ |
          31  ---------+ +-+
          28  -----------+
```

Figure #3.2 Cluster Analysis Dendrogram

Table #3.5 Variable Key for Cluster Analysis

Number	Letter Code	Variable
1	A	Fatality
2	B	Injury
3	C	Property Damage
4	D	Passenger Car
5	E	Pick Up/Van <4500 Kg
6	F	Mini Van/MPV
7	G	Truck >4500Kg
8	H	Truck Tractor
9	I	Motorcycle/Scooter
10	J	Emergency Vehicle
11	K	Daylight
12	L	Sunglare
13	M	Darkness
14	N	No Traffic Control Device
15	O	Traffic/Signal Lights
16	P	Stop Sign
17	Q	Yield Sign
18	R	Merge Sign
19	S	Pedestrian Crossing
20	T	Lane Control Device
21	U	Railroad Crossing
22	V	Apparently Normal

23	W	Had Been Drinking
24	X	Impaired by Alcohol
25	Y	Impaired by Drugs
26	Z	Fatigued/Asleep
27	AA	Intersection
28	AB	Exact
29	AC	Mid Block
30	AD	Unclassified
31	AE	Residential
32	AF	Collector
33	AG	Major Street
34	AH	Freeway
35	AI	30 Kph
36	AJ	50 Kph
37	AK	60 Kph
38	AL	70 Kph
39	AM	80 Kph
40	AN	100 Kph

3.3.1 Discussion

As noted above, some variables do not associate as would be expected. The variable intersection, for example might be expected to correspond closely to the variables in component one as all traffic control devices would, by necessity, be located at intersections, except for the RR Crossing signs and Lane Control Devices. That this association did not occur was surprising and was deemed to merit closer inspection. The variable Passenger Cars was also interesting in that it was a complex variable and did not load specifically on any one component. Perhaps this is due to the great variety of accidents that these vehicles find themselves in.

To return to the issue of intersections and their apparent lack of association with variables that should be similar, research into the original data set helped clear up this problem. Simple comparisons of frequency counts between certain variables and the variable 'intersection' helped in understanding this phenomenon. Three graphs were prepared, the first two indicating the preponderance of collisions at these sites and the higher ratio of fatal and injury collisions occurring here. The first graph, figure 3.3, shows the amount and severity of collisions by address location in the data set used for this analysis, namely where speeding was a factor on good road conditions and with favorable weather conditions. Figure 3.4 compares all collisions in 1993 to the subset shown in figure 3.3. These two graphs have shown the need to address the problem of extremely high collision occurrence at these locations relative to other locations. The last graph, figure 3.5, details the lack of correlation between the variable 'intersection' and the variables relating to presence of traffic control devices. As can be deduced, approximately 50% of the intersections do not have any traffic control devices whatsoever. This appears to be a problem in the data set and may show a lack of consistency in completing the form by the reporting officer. Additional analysis may reveal a different solution to this problem though. As most fatalities occurred at these locations the original data was scanned for fatalities only. In the data set for unsafe speed regardless of road or weather conditions, eleven fatalities were found of which only one was not at an intersection, and yet this one had a signal light present! Three other signal lights were found, one with a 50 Kph speed limit and two with a 70 Kph speed limit. The other locations had the following distribution of speed limits; two 100 Kph, four 80 Kph, and one 60 Kph. The higher frequency of

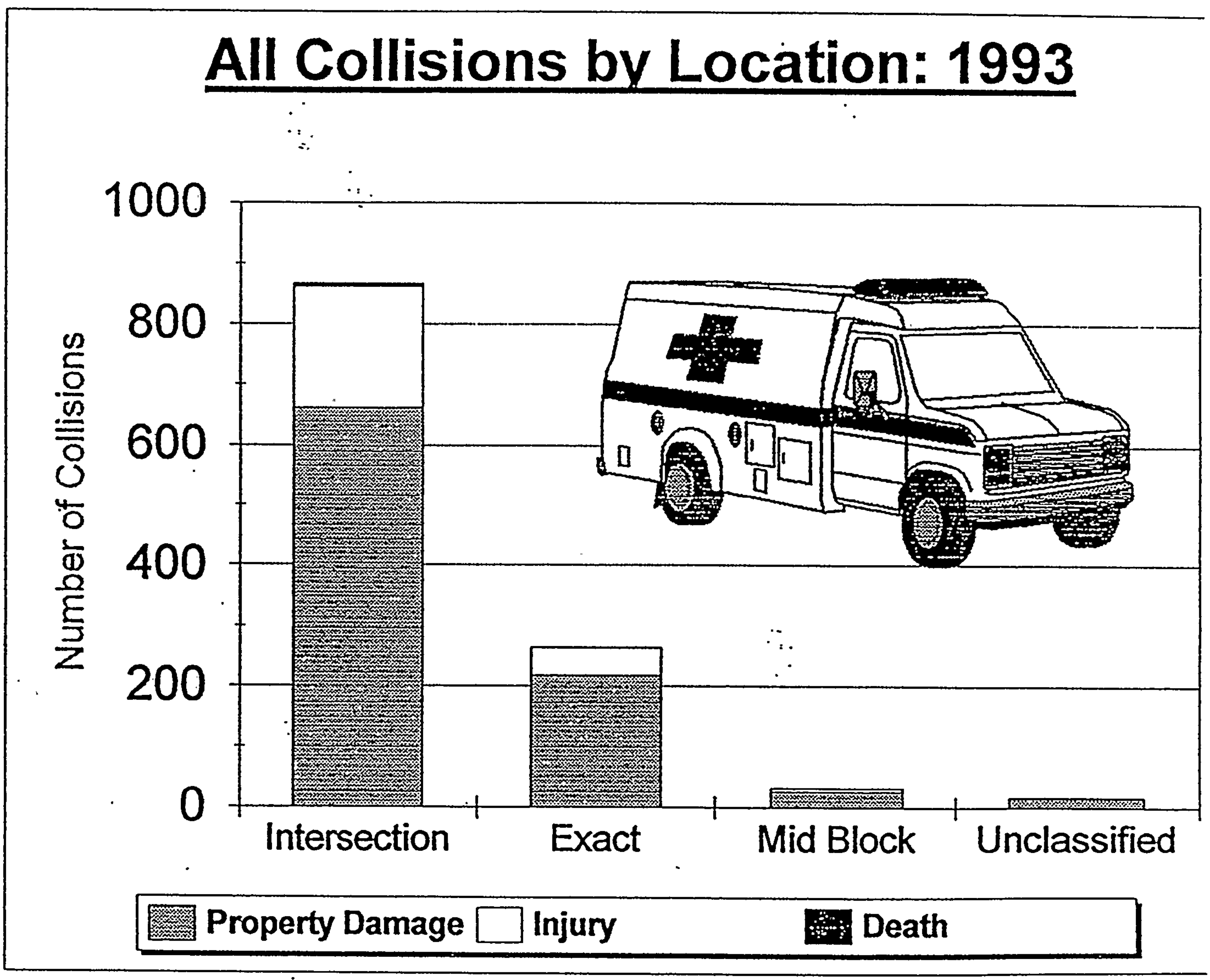


Figure #3.3 **Location of Collisions Where Speeding Was a Factor**

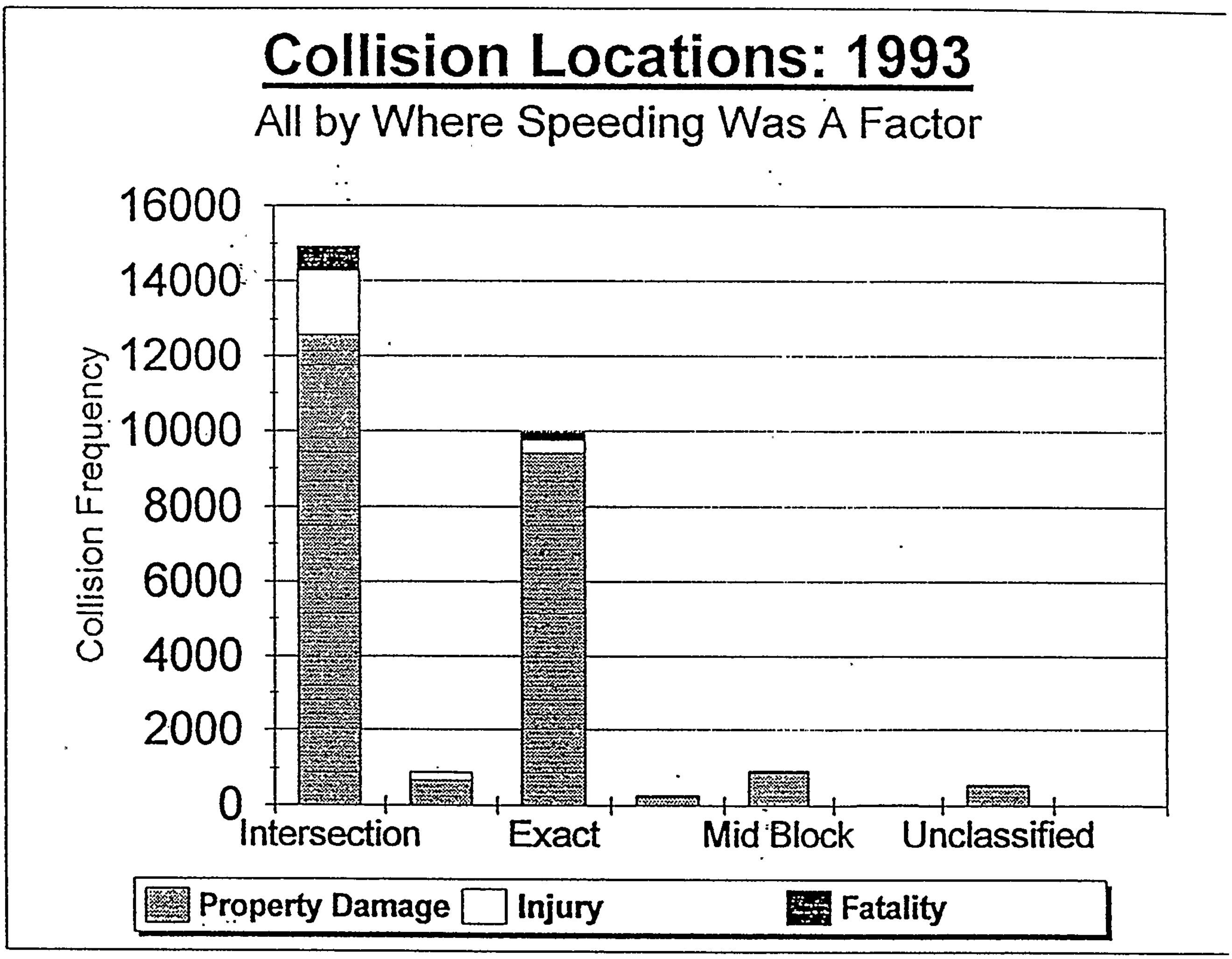


Figure #3.4:

Location of All Collisions Compared to Those Where Speeding Was A Factor

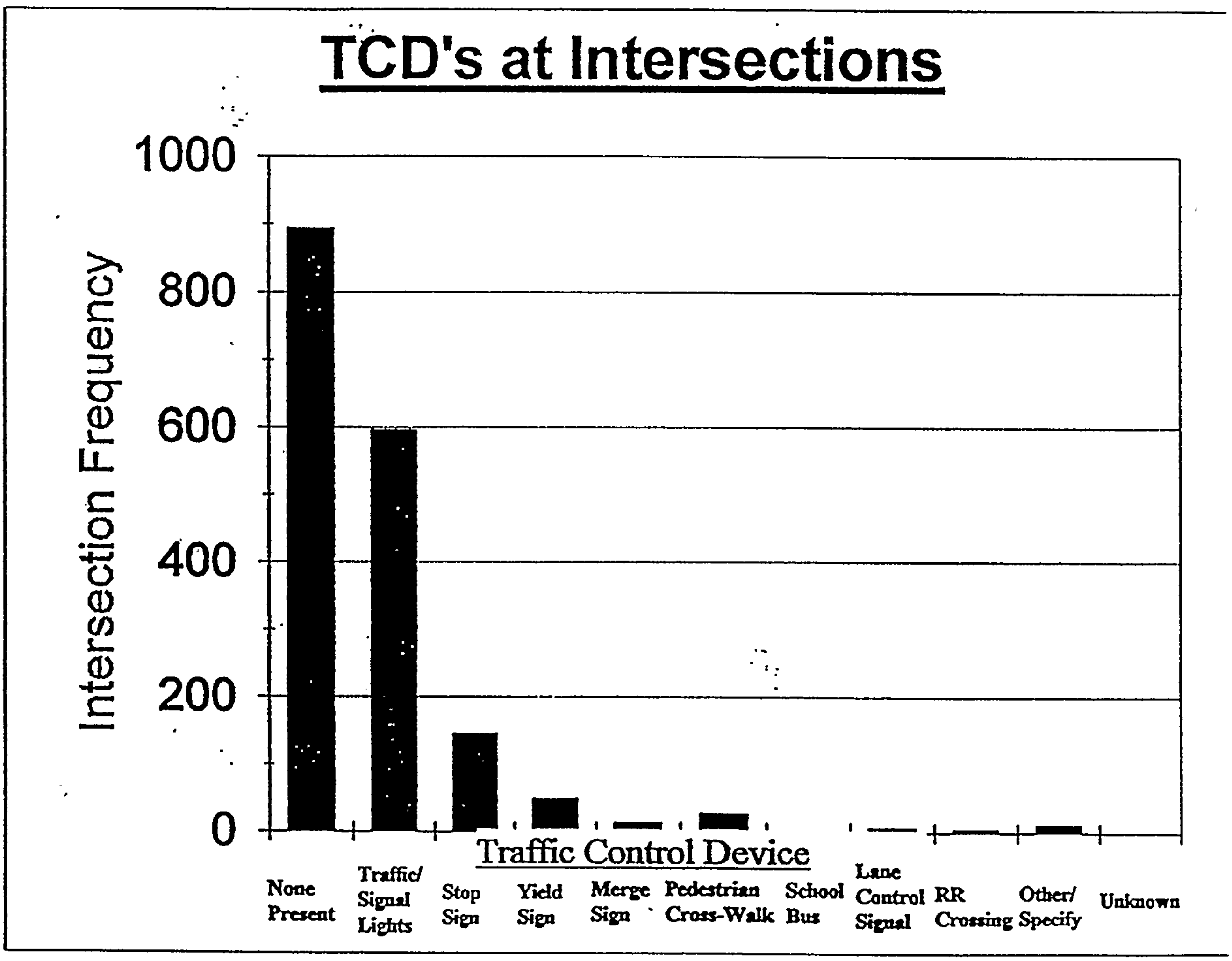


Figure #3.5 Traffic Control Devices at Intersections faster speed limits has made it possible to assume that perhaps these locations were at interchanges where the location of traffic signs is not so readily apparent as at intersections. The frequency of merge signs, for instance, is much lower than the frequency of interchange locations, such as those along Deerfoot Trail. Further analysis should unravel this problem and make clear just what this relationship is. Graphing a comparison of posted speed limits to traffic control devices would be beneficial as would extracting all cases that appear as "none present" in figure 3.5. The above is an example of what could be done with any variable, puzzling or not, but without the help of the principal components and cluster analysis, this task would be all the more difficult.

The utility of exploratory analysis has been exemplified by this work, while certain problems have been revealed this in no way denigrates the analysis. Instead it shows how this analysis assists the researcher in organizing and screening data for future research. The organizing power of these techniques has created several dimensions in the data, each one suitable for future exploration and analysis. Problems such as complex variables target specific areas for detailed analysis. Some of these problems are due to the nature of the original data set. As explained in the introduction, the Alberta Collision Report Form was not designed with this type of analysis in mind and the work here has shown the drawbacks in using this data. Some fields had to be ignored as either inappropriate, redundant or because they had internal inconsistencies which made certain fields suspect as to their validity. Other fields, such as the intersection variable, would reveal greater information after further investigation. In that way, more information might be teased out of the data than was originally thought.

The conclusion may be, in part, 'back to the drawing board', but one returns armed with a deeper understanding of underlying processes and able to formulate *a priori* hypotheses about certain relationships. What was a large bewildering array of complex data is now a smaller, organized array of data grouped into specific areas for future research. This research now explores the troublesome and specific location of intersections and interchanges, but other research directions have been identified for future research.

3.4 Creation and Utilization of GIS

The regulation of traffic laws, specifically those regarding speed limits through intervention has necessitated the allocation of large amounts of resources from local police services. Much of this is due in part to the widespread use and abuse of automotive transportation and, until recently, the difficulty police services had in monitoring our roadways. Deployment of radar units is often haphazard, relying on the knowledge that indivdual officers have of their area. There is sometimes a confusion over goals as the issuance of citations becomes confused with increasing public awareness and safety. If this trust becomes abused, as in the case of speed traps (speed traps being defined as stretches of road with arbitrarily low speeds for the apparent sole purpose of issuing speeding tickets and thus gathering revenue), then public outcry ensues (Drohan, 1995) and a loss of trust in the police services follows.

Recently in Canada, provincial governments have been debating over the merits of photo radar systems as a means for monitoring our roads. These devices have apparently fallen prey to their own efficiency and have been branded as 'cash cows'. The newly elected conservative government of Ontario has already dismantled the province's fledgling photo radar unit and debate is raging in British Columbia as opposition parties are attacking the present government's plans for instituting these devices (Yaffe, 1995). The party which proposed dismantle photo radar in B.C., the provincial Reform party, was subsequently soundly defeated in elections held in 1996. The province of Alberta has used photo radar for seven years, the longest of any province in Canada. Although there is public argument over the use of photo radar in Alberta, there is little political debate.

While it would be useless to deny the large amounts of revenue generated as the result of instituting photo radar (in Calgary approximately 66,000 citations issued at an average of $70.00 each, generating more than 4 million dollars in 1994) and while it must also be admitted that photo radar can be abused in the context of 'speed traps', their tremendous potential to increase public awareness and influence driving habits cannot be dismissed. Their efficiency and mobility may be put to good use if they are deployed based upon analysis of the tremendous amout of information concerning traffic accidents which is now available. An audit (Western Management Consultants) performed for the traffic Section in 1991 stated that it would be advisable to make better use of this large amount of information.

GIS would allow the Calgary Police Department to manage and display this information in such a manner that photo radar units may be located at or slightly in front of areas that continually exhibit high collision counts. When accident severity and speeding are factored in, then the locations most in need of intervention can be found and photo radar may be deployed to the greatest public good. It has already been discovered that these conditions are prevalent at intersections but this information was merely portrayed in tabular and graph form. Since it was difficult to determine the spatial distribution of this data GIS was decided upon as the tool for accomplishing this.

Knowing that a large amount of data would have to be geocoded or located on the map also influenced the decision to use a GIS. Approximately 20,000 collisions needed to be coded and without the use of GIS it would have been almost impossible to place these on a map within any degree of accuracy. As it was, many individual accidents had to be located manually within the GIS and this alone took hours of work to complete. However, once these addresses were geocoded into the GIS it was then possible to link them automatically to the accident attribute data in the relational database. Secondly, once built, the ease of working with the data both spatially and relationally made the GIS a perfect tool for managing the information required for this project. In addition, the ability to easily produce spatial displays during and after completion increased the utility of the GIS to an indispensable level. Criticism has been levelled in the form of 'why is this GIS' and I can only answer 'why not?' True, the argument can be made that this does not have to be performed with the use of GIS but if the system is the easiest and makes management of large quantities of data logical, fast and easy, then it would be difficult to dismiss the choice I made to avail myself of this software. Indeed no analysis really requires the use of computer software (it could all be done by hand) but this is simply not the most efficient and effective way to proceed.

Two types of data were used to construct the GIS which used the MapInfo system (MapInfo, 1992). These consisted of the information required to form the base map and a data set containing relevant information on each collision. The study area is the City of Calgary, Alberta, Canada, and the time frame for the collision statistics is the month of January, 1994. Later on in the thesis the information will span the year of 1994.

The street map of Calgary was constructed so that it would contain a variety of information concerning the road segments and was viewed as a framework for displaying the collision data. A Calgary street file also supplied by MapInfo (originating from Statistics Canada) was imported and then modified to suit these purposes. This file would serve as a background layer as well as a layer for georeferencing as it also contained street address information. A second layer was constructed in which most residential streets were deleted as not relevant to the study. Three categories of roads remained, as defined by the City of Calgary bylaws map: collectors, major streets and freeways. This was further refined by including divided or undivided status. Different line styles were used to symbolize this information with various colours indicating the posted speed limit and increasing line thicknesses denoting increasing traffic flow, of which there are seven categories. All was compiled in tabular form and this then formed the base map. Speed limits and traffic flows were collected from City of Calgary traffic engineering and planning maps while the divided or undivided status was gleaned from a privately published map.

The collision data was supplied by the City of Calgary Police Services Traffic Section and comprised information gathered from the Province of Alberta Collision Report Form. All files were "sanitized", having information containing individuals' names and addresses, among other things, removed. The sanitized files were editied and compiled with the aid of the Quattro Pro spreadsheet program and then exported to the GIS for georeferencing. Each month will be represented as a separate layer containing all the collision data which will be spatially displayed as individual red stars denoting the location of each accident. The total number of accidents in January of 1994 is approximately 2360. As can be seen, this will amount to an incredibly huge and unwieldy database once it spans the entire year, reinforcing the need for an information management system such as GIS. Figure 3.6 shows an area centered on downtown Calgary and extending for approximately three kilometers

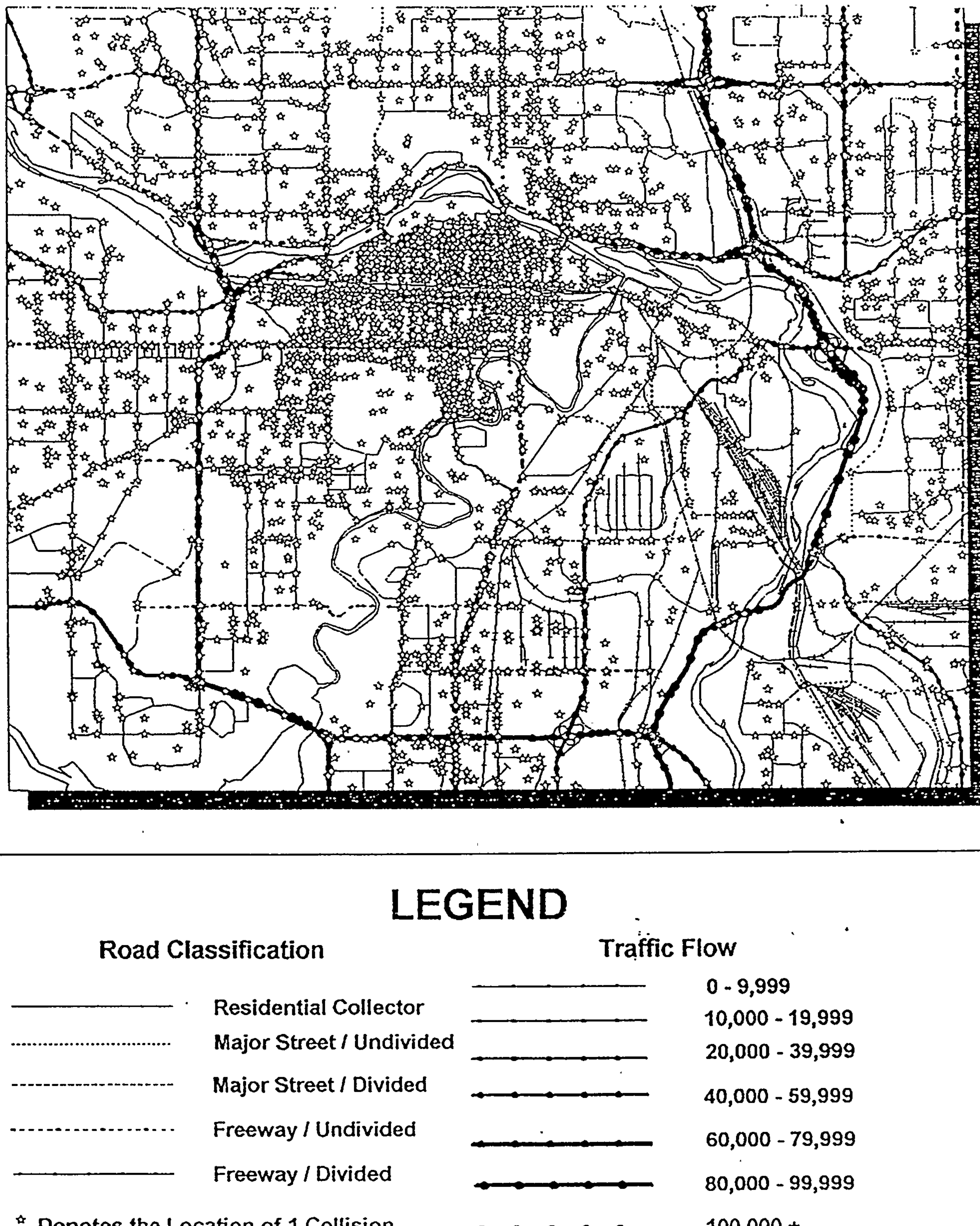
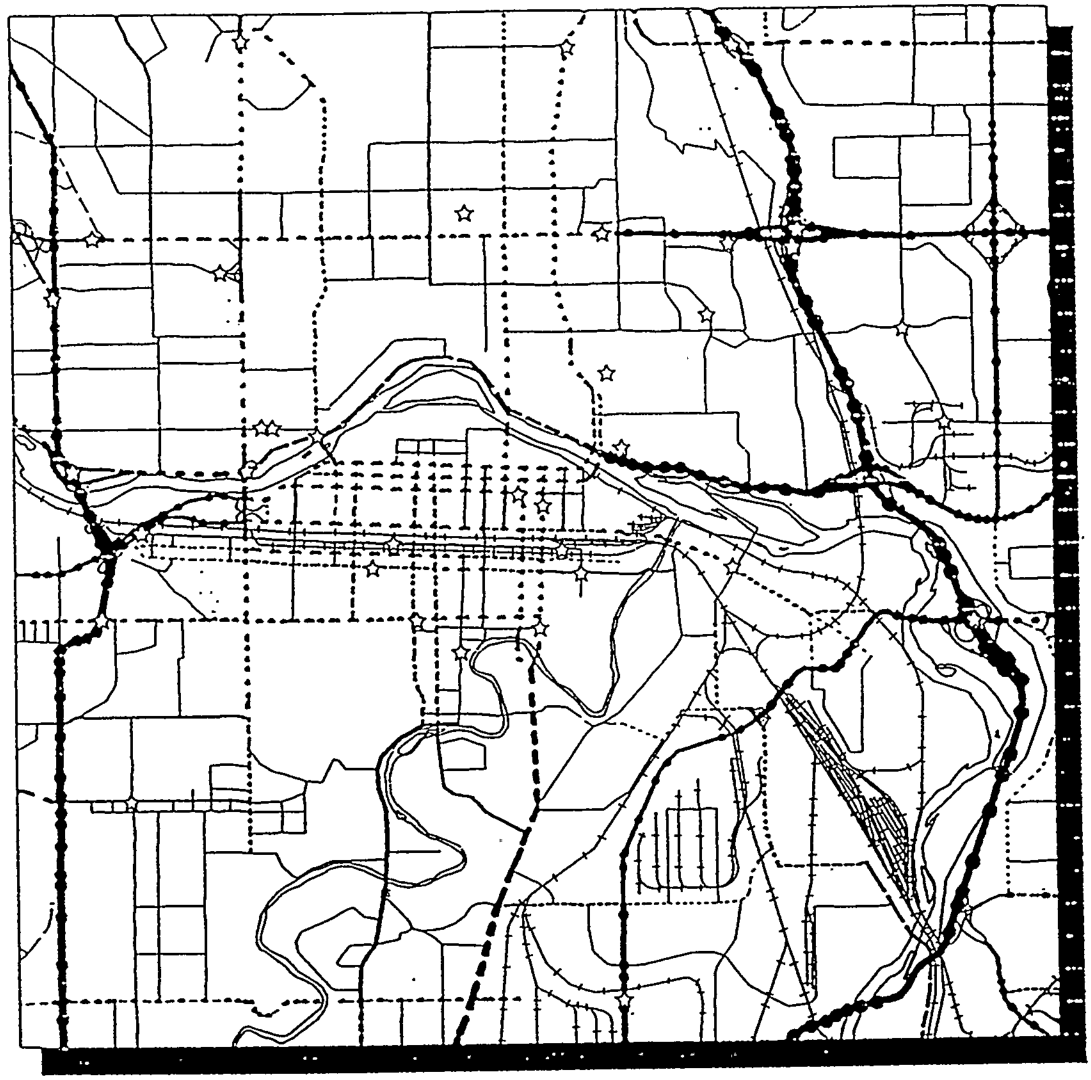


Figure 3.6

The City of Calgary - Downtown Area: Accident Locations Jan. 1, '94 to Jan. 15, '94 included in the database. These data are broken down into three categories: information regarding the circumstances of the collision, environmental information and some social data.

Table#3.6 Selected Collision Report Form Data

Collision Event Data	**Environmental Data**	**Social Data**
Date and Time of the Event	Surface Conditions	Age of Driver
Severity	Environmental Conditions	Gender of Driver
No. of Vehicles Involved	Road Class	Make of Vehicle
No. of Fatalities or Injured	Light Conditions	Model of Vehicle
Damage> $1000 (Yes/No)	Traffic Control Device	Year of Vehicle
Road Alignment	Contributing Road Condition	
Collision Location	Address	
Directon of Travel	Address Type (Intersection/Mid Block)	
Driver Action		
Unsafe Speed (Yes/No)		
Type of Vehicle		



LEGEND

Road Classification	Traffic Flow*
Residential Collector	0 - 9,999
Major Street / Undivided	10,000 - 19,999
Major Street / Divided	20,000 - 39,999
Freeway / Undivided	40,000 - 59,999
Freeway / Divided	60,000 - 79,999
	80,000 - 99,000
	100,000 +

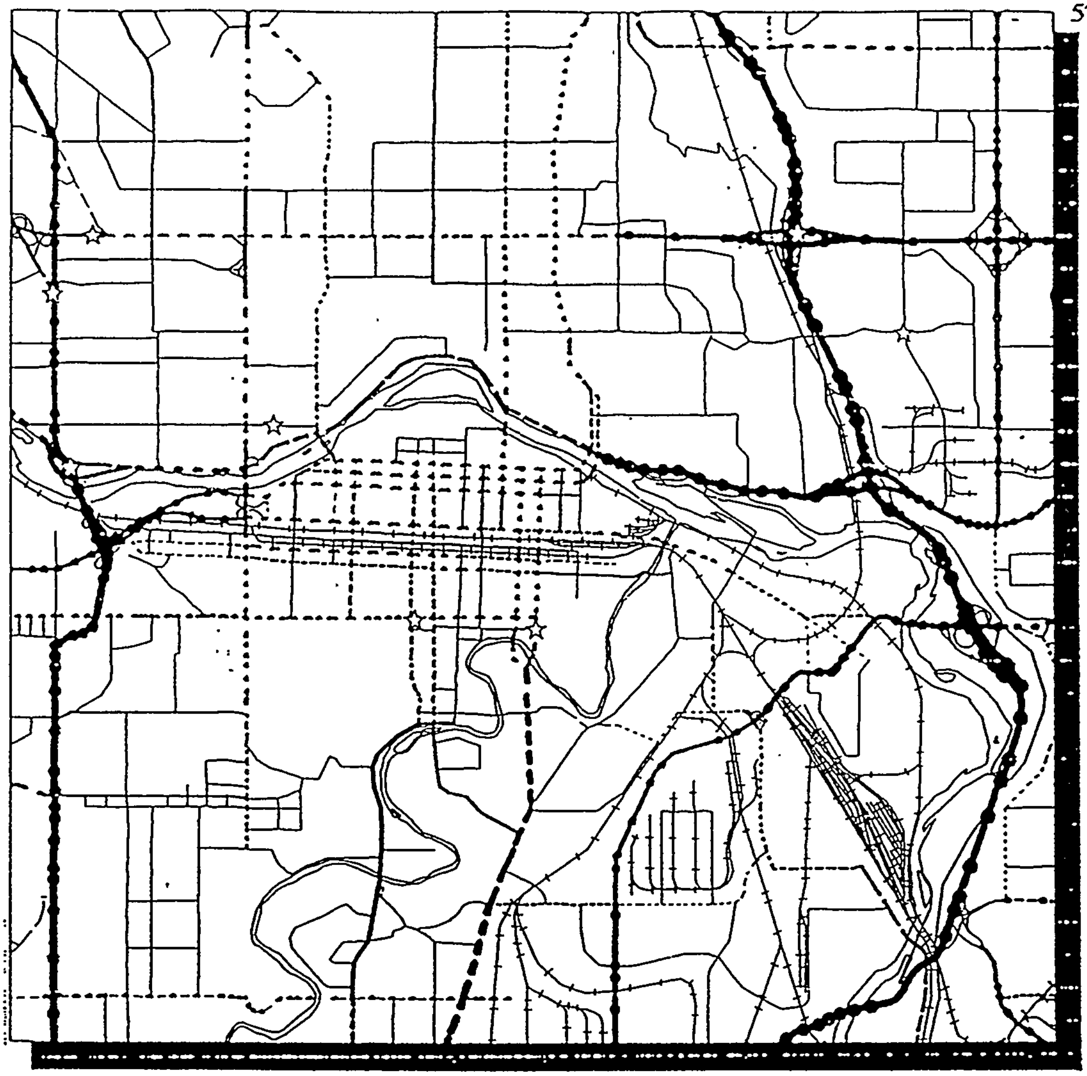
☆ Denotes the Location of 1 Collision

* *Average Weekday Traffic Volume*

Figure #3.7

The City of Calgary - Downtown Area:

Accident Locations Where Speeding Was A Factor Jan. 1, '94 to Jan. 15, '94.



LEGEND

Road Classification	Traffic Flow *
Residential Collector	0 - 9,999
Major Street / Undivided	10,000 - 19,999
Major Street / Divided	20,000 - 39,999
Freeway / Undivided	40,000 - 59,999
Freeway / Divided	60,000 - 79,999
	80,000 - 99,000
	100,000 +

☆ Denotes the Location of 1 Collision

* *Average Weekday Traffic Volume*

Figure #3.8

The City of Calgary - Downtown Area:

Injury Accident Locations Where Speeding Was A Factor Jan. 1, '94 to Jan. 15, '94

It is obvious that by combining the data concerning the collisions for an entire year with the information contained within the street map that many relationships may be explored. Spatial display of this tremendous quantity of data adds another dimension, increasing our ability to assimilate, visualize, understand and utilize this information. Two additional maps have been developed based on the original area of downtown Calgary, the first showing where unsafe speed was a factor, the second showing where unsafe speed was a factor *and* injuries occurred (figures 3.7 and 3.8). It should be remembered that the accidents displayed in all three of these maps represent only half of the January 1994 data. These maps were easily produced by selecting the required information using structured query language (SQL) commands. The same process allowed for aggregation of data in order to perform some statistical analysis. As only one month of data was available then, it was decided to aggregate the data and perform chi-square tests in order to determine which relationships were statistically significant (Siegel and Castellan, 1988).

3.4.1 Chi-Square Test

The relationships between accident location (intersection or interchange and mid block), accident severity and unsafe speed were explored with the help of structured query language (SQL) selections. The data was first divided into two locational categories, intersection/interchange and mid block. These two populations were then compared as to whether there was a significant difference between accidents occurring as the result of speeding or not. The GIS allowed for selection of this information by way of SQL selection and the totals were entered into a table. The chi-square statistic derived, 0.12 ($d.f. = 1$), showed no significant difference between the two groups at the 95% confidence level. This is interpreted as illustrating the ubiquitous influence of speeding.

Next, the nature of the severity of collisions by location was explored using the same statistical method. As each location was now in its own relational table it was a simple matter of searching for each of the four categories of accident severity, shown in table 3.7, recording its total and then removing it from the search table. The data was removed in a heirarchical fashion to prevent duplication in the resulting table. Otherwise an accident involving a fatality most likely also incurred a property damage of greater than \$1000.00 to the vehicles involved and would be entered twice, once as a fatality and once as property damage greater than \$1000.00. To avoid this potential duplication it would be recorded as a fatality and then removed from the search table. The order by which the data was removed follows the order in which it appears in the cross tabulation table shown below.

With a chi-square value of 16.53 (*d.f.* = 3), this proved to be significantly greater than the critical value of 7.81 with $\alpha = 0.05$. This means that there is a difference between the severity of a collision at these two locations with the higher severity occurring at the intersection/interchange location. This result can be attributed to the angle at which vehicles impact at these locations as well as the fact that they would tend to be travelling at least at the speed limit for vehicles passing straight through whereas those turning in most cases would tend to be travelling slower due to having to navigate the turn at a safer velocity.

The next tests compared the severity of collisions by speeding or not speeding at the two different locations. While the chi-square was relatively high at the intersection/interchange location, 4.20, it did not surpass the critical value of 7.81 for *d.f.* = 3 and $\alpha = 0.05$. Thus there was no statistically significant difference in accident severity between collisions occurring as the result of speeding or not speeding at these locations. This is indicative of the severe nature of accidents in general at these locations and should not diminish the concern over speed related accidents. The same analysis performed for the mid block collision data however showed a significant difference between accident severity and speeding or not speeding with a chi-square statistic = 17.53 (*d.f.* = 3). This is a great deal higher than the critical value of 7.81. Therefore any accident that occurs at a midblock location will have a much greater tendency to be in a high severity category if speeding were a factor.

Table #3.7 Crosstabulation of Collision Location by Collision Severity

Collision Severity	**Intersection/Interchange**		**Mid Block**		**Totals**
	(Totals	**Percentage)**	**(Totals**	**Percentage)**	
Fatality	1	0.1%	0	0.0%	1
Injury	113	11.4%	25	7.4%	138
Property Damage > $1000	521	52.6%	152	44.7%	673
Property Damage < $1000	356	35.9%	163	47.9%	519
Totals	991		340		1331

Cramer's V was calculated for these two datasets that proved statistically significant in order to obtain a measure of the degree of association for these relationships. This value is similar to r^2 in linear regression analysis (Norusis, 1993). For the test on intersection/interchange and midblock accident severity, Cramer's V was 0.45 and for the test on speeding/not speeding vs. accident severity at midblock locations the Cramer's V was 0.96.

3.4.2 Photo Radar Deployment and Other Applications

The above demonstration of data visualization and statistical testing displays the versatility and utility of GIS in aiding the understanding of large and complex data sets. By continually updating the information, accident location trends can be pinpointed and analyzed. The ability to analyze these collisions by location, road class, severity, speed limit and whether or not speeding was a factor can greatly aid in deploying photo radar. As a result of principal components analysis it was discovered that fully one third of all speed related accidents occur at locations where traffic control devices are present (signal lights, merge, yield or stop signs) indicating that these are intersecton/interchange locations. This, coupled with the increased severity of accidents at these locations, indicates that these areas are certainly excellent locations for greater scrutiny followed by intervention.

Statistical analysis can refine these target areas so that the most hazardous locations are pinpointed and displayed within the GIS and photo radar units may be deployed to greater effectiveness. Research has indicated that a halo effect occurs around the location of a radar patrol unit (Armour, 1984, see also discussion in chapter 2, above). This phenomena can be described as vehicles slowing as they become aware of the radar unit upon approaching it. They continue to drive at a reduced speed until a certain distance past the radar unit at which they then increase their rate of speed. This halo effect distance can be upwards of five kilometers on the highway but no doubt would be adjusted down within the urban environment. This phenomenon could be modelled within the GIS using a simple buffering (Berry, 1995) operation to predict the effectiveness of intervention at specific locations. Buffering may also be used to gather all collisions that occur at interchanges. Many of these cover at least an area of one kilometer in diameter and may be underrepresented in the collision statistics.

Many other forms of analysis may be performed with this information, all of which will tend to increase the safety of traffic operations within the city. Locations of accidents where the driver was determined to be impaired may be displayed and compared to existing check-stop locations so as to assess their efficiency. These locations may then be compared to the locations of known drinking establishments to search for other relationships. Environmental conditions may be analyzed for recurring collisions due to icing and this information passed on to City road crews. Locations of collisions due to wet roads or foggy conditions could be determined and warning signs appropriately placed as they already are on the Deerfoot Trail's Calf Robe Bridge.

With the continual addition of information to this database it would be possible to track these various forms of intervention and safety measures over time to see how effective they actually were as well as allowing the researcher to determine the duration of this effectiveness.

3.4.3 Conclusions

Support for police intervention is illustrated by the following quote from a conference studying enforcement strategies and effects:

> "*As the relationship between speed and accident rate seems to be strong and positive (OECD: 1982), a decrement of excessive high speeds leads to fewer and less severe accidents. As Salusjarvi (1982) has pointed out, even a small reduction of the mean driving speed can have a considerable positive effect on traffic safety.*"
>
> (Rooijers and DeBruin, 1991)

Police have many tools at their disposal for dealing with this problem, photo radar being one of the most recent and most capable of these tools. While relatively new and therefore not subject to a great deal of study, preliminary research has indicated that photo radar is an effective device for enforcing compliance amongst drivers (Ostvik and Rune, 1991; Ministry of Transportation Ontario, 1995).

The utility of photo radar may be augmented by making use of existing databases for identifying hazardous locations and increasing our understanding of collisions through statistical analyses. That GIS is the most significant way to manage, analyze and display this data has been illustrated. Perhaps with enhanced placement of photo radar as a result of research and increased evidential support for photo radar through statistical analysis some of the public debate will be quelled. After all, it is with the purpose of reducing accidents, especially those resulting in fatality and injury, that photo radar is being deployed and we should never lose sight of this, even when our vision may be obscured by dollar signs.

3.5 Formal Scientific Analysis of Traffic Collision Data

3.5.1 Introduction

Researchers utilizing (GIS) have been criticized for not adequately taking advantage of formal scientific methodology, tending to prefer the 'shot gun' approach:

> "*... there is a paucity of reported research that employs GIS concepts and capabilities to frame, test, assess, or depict hypotheses.*"
>
> (Wellar and Wilson,1993)

Being capable of handling large, seemingly unrelated information, GIS is able to search for, find and display relationships of these data sets in a meaningful way. Often though, the discovery of these relationships relies as much on serendipity as any *a priori* research agenda. The earlier work in this paper allows for the creation of a formal hypothesis.

In the city of Calgary, Alberta, Canada, the police service has engaged in the use of photo radar as a technique to reduce speeding behavior. Due to its success in generating revenue, photo radar has been subject to increasing public and political debate as to whether it is solely a revenue generator (the so called "cash cow") or an effective device for reducing speeding behavior, and therefore reducing collisions (Yaffe, 1995; Duncan, 1995; Collins, 1994). At the outset of this study, it was decided that a GIS would represent the best approach for analyzing and modelling traffic collision information. Upon completion of the analysis the data will be displayed in a meaningful fashion so that effective deployment of photo radar devices would ensue. The placement of photo radar at identified, dangerous locations would help to ensure the populace that photo radar was in effect there for the public safety and not just located where the most citations could be issued. A dynamic GIS model could then be built that would be continually updated with new information and the entire road network could be monitored. This would allow for current and effective deployment strategies with the added benefit of being able to retroactively study the changes resulting from various intervention strategies.

One major issue became apparent at the outset of this study, namely what is the relationship between speeding and accidents? The literature provides examples of two relationships: one being the relationship between accident severity and the speed at which the vehicles where traveling at impact (Arthur and Waters, 1995a), and the other being the relationship between accident occurrence, or probability, and speeding. The first relationship relies upon physical laws concerning the transference of energy and is well established: the faster the vehicle is traveling the greater the damage. This has been studied in clinical experimental conditions as vehicles are intentionally crashed while being monitored with a wide range of devices, including crash test dummies that simulate human involvement. The latter relationship has been only weakly established using proxy information. The reduction of highway speed limits in the United States resulting from the oil embargo in the mid seventies provided an opportunity to examine the change in accident statistics as a result of lower speed limits. In general, the results where favorable showing a decrease in the accident rate (Johnson, Klein, Levy and Maxwell, 1981). However, the trend over the past few decades has been for a reduction in collisions anyway and it has not been established if this particular reduction is statistically different from the prevailing trend. Accident severity is also declining, resulting from the technical and structural improvements in automobile manufacture. Also, these studies were conducted by U.S. federal agencies utilizing highway information only, whereas our interest is in the urban milieu, a totally different driving environment. Another conclusion, again drawn from highway studies, shows that the greater the difference in speed a vehicle is traveling from the average, whether higher or lower, the greater the probability of collision. In other words, the higher the standard deviation the higher the risk of collision occurrence (Treat, Jones & Joscelyn: 1980). Upon examination this proves logical as it implies that the greater the interaction (i.e., the more vehicles are passing each other) the greater the risk of error and therefore collision.

Since an extensive literature search showed that this relationship between the probability of occurrence and speeding behavior was tenuous, it was decided to explore this topic further. After all, if speeding does not result in greater risk, it becomes difficult to support intervention strategies of any kind, including the use of photo radar.

3.5.2 Background

Previous research shows a focus on intersections (including interchanges) as areas of high collision occurrence. Using a set of data from one year, 1994, and using only collisions where speed was considered a factor, a principal components analysis (PCA) was performed. PCA is often used as a data reduction technique and as a way for searching the data for relationships that are not readily apparent due to the size and complexity of the database. It is extremely useful at this stage when no formal hypothesis has been formulated. The conclusions from this analysis showed that the first component explained one third of the variance within that data set as discussed earlier in this chapter. The variables grouped together in this component all related to intersections or interchanges, most of them involving the presence of traffic control devices. This provided a statistical basis for concentrating on intersections and interchanges as areas of high risk. Given a locational reference for this research an attempt was made to understand the nature of collisions at these areas.

To perform this locational analysis, a GIS model was built and the collisions geo-referenced. Using a smaller data set of collisions, covering the first half of January 1994, the data was extracted based upon whether the collision occurred at an intersection or at a mid-block location. They were then compared to see if any differences existed in the different populations. Several conclusions were drawn from this work:

- There was no relative difference between the two locations as to the total amount of accidents resulting from speeding. This illustrates the ubiquitous nature of speeding.
- There was a statistically significant difference in the severity of collisions between locations, with the more severe collisions occurring at the intersections/interchanges.

- Most collisions occurring at intersections/interchanges were severe, regardless of whether speeding was a factor or not.
- At mid-block locations, accidents were more severe if speeding was a factor, than if it was not.

It has therefore now been determined that not only do more accidents occur at intersections but they are also of a higher severity resulting in greater risk of injury or fatality. This reinforced the assumption that intersections and interchanges are areas of higher incidence, but it is still ncessary to determine the influence speeding had as a causative factor. Therefore the following hypothesis was developed:

The accident rate for any given location would be greater for the population of vehicles exceeding the speed limit than for those that travel within the posted guidelines.

In the ensuing test of this hypothesis several conditions are imposed:

1. The accident rate is defined as accidents per million vehicles entering an intersection/interchange (Hummer, 1994);
2. The location is defined as within one hundred feet of an intersection (Hummer, 1994) and encompassing an entire interchange, including off-ramps;
3. The population of vehicles exceeding the speed limit were determined to be 15% of the traffic flow and non-speeders, 85% of the traffic flow (Mitchell and Parker, 1992).

Each of these conditions will be dealt with at greater length under the heading of methodology.

3.5.3 Proxy Data

Researchers in the field of traffic safety studies are rarely able to observe the occurrence of a collision under clinical conditions. Only by chance could such an observation occur, and seldom is an individual prepared to make accurate observations at such a time. Therefore, information must be gleaned from secondary sources. Fortunately, many countries require by law that accident report forms be completed for any collision which exceeds a set dollar value (Arthur and Waters, 1995a). This presents the researcher with a tremendous volume of data but unfortunately this data was gathered for purposes other than research and analysis. These report forms are mainly used for settling insurance claims and as evidence should charges be laid against any of the participants in the collision. Much of this data is of a lower order, nominal or ranked, and proves difficult to use in statistical analysis. The task then is to sift carefully through the data and rearrange it so that it might be utilized in a meaningful fashion. This reorganization and management of information is the first major task for which a GIS is well suited.

3.5.4 Methodology

Once the original set of data was prepared in the spreadsheet, it was exported to the GIS and the process of geocoding began. Some loss of data occurred at this stage for the following reasons:

1. Some addresses were not in the original street file;
2. Not being able to find these automatically it was possible to determine some addresses using street numbers but this became increasingly difficult in the newer residential areas where all streets bore names instead of numbers, thus making locational referencing at times impossible;

3. The street file used was older than the collision data set, so some newer areas could not be used;
4. Duplicate intersections caused where roads looped around and intersected another road twice, similar to a 'U' with a line running through the top. In the case when the reference was "at the intersection of *x* and *y*," it was impossible to know which of the two intersections the report was specifying;
5. Some locations simply did not exist, were out of the city limits or were logically inconsistent: i.e., at the intersection of two parallel roads.

Approximately 10% of the original data were lost as a result of the above conditions but fortunately most of the loss occurred mid-block (i.e., not within the final study area) rather than at intersections or interchanges. Only the fourth factor affected intersections, but it generally involved collector roads of which there were few in the final analysis.

Next, the data was reduced due to the presence of many collisions occurring at, or in, parking lots, usually at one of the larger shopping malls. These records were purged from the file using a simple structured query language (SQL) database command. The size of the final data file is approximately 19,500 collisions (see figure 3.9 for a partial display). At this point the file of traffic collision data was ready for use. It was then necessary to select accidents from within interchanges or intersections, so a new layer had to be created from the original street file. Intersections and interchanges were dealt with separately due to the geographic complexity and variety of interchanges. 'T'-intersections were separated out from four-way intersections in order to create a total of three classes of reasonably homogeneous intersections. All intersections used in the study where indicated with a symbol on a new layer and that symbol was buffered to catch all collisions within a one hundred a fifty foot radius of the centre of the intersection as outlined in Hummer (1993).

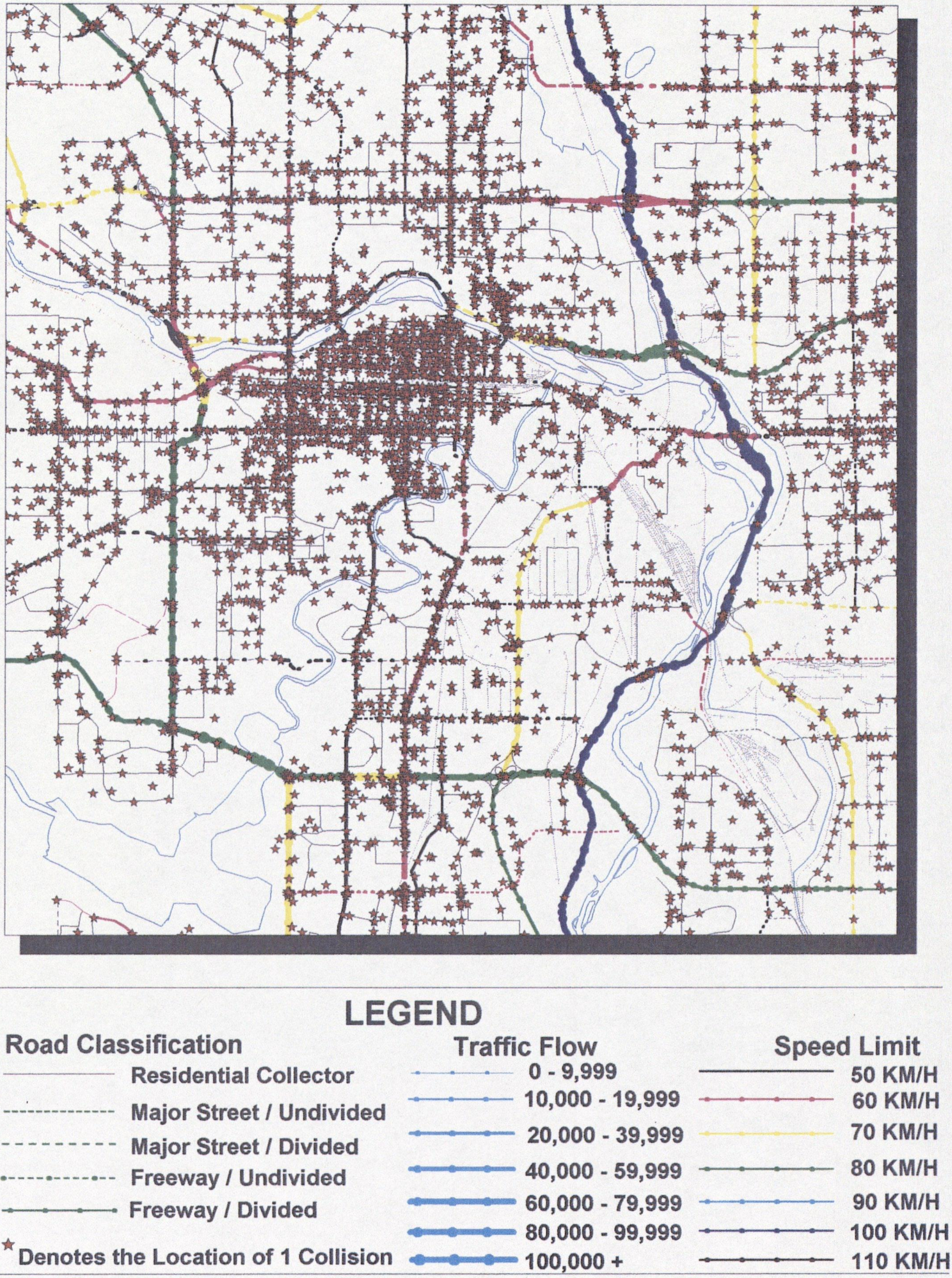


Figure #3.9 **All Collisions Within Central Calgary - 1994**

A polygon was drawn around those interchanges, while avoiding the inclusion of other streets, to encompass the entire interchange including exit and entry ramps. This then became a layer for use within the GIS. To determine the number of accidents occuring at such an interchange involved overlaying the collision layer with the buffer layers and then requesting all collisions that exist *within* the buffer.

The resulting information was added to data collected from the original buffer maps and the subsequent data file was exported to a spreadsheet for further refinement. The output file contained information regarding traffic flow for the intersection/interchange, the number of accidents where speeding was considered a factor, the number of accidents where speed was not considered a factor and a locational reference number.

Accidents where speeding was or was not a factor are indicated on the Alberta collision form and are thus easy to determine. The population of speeding vehicles was more difficult to ascertain and was deduced using the following argument. Traffic engineering studies indicate that 85% of the drivers will operate their vehicles at a speed that is considered safe given the particular environmental and design conditions, this is known as the 85th percentile rule. This means that 15% of the total population of vehicles travelling along any section of road is doing so at a fast and unsafe speed. Above the 85th percentile is the area at which traffic speeds express high dispersion, indicating high rates of interaction (Mitchell and Parker, 1992). The posted speed limit is often set at approximately 10% less than the speed at which the 85th percentile travels. Traffic citations for speeding are not usually issued below the 85th percentile and often not until the rate of speed is well into the 90th percentile (Nelson, 1996).

It was decided to use 15% of the traffic flow for any location to represent the population of vehicles entering an intersection at a high rate of speed and the remaining 85% for everyone else. Using the equation in Hummer's article as follows:

$$\mathbf{RSP = 1{,}000{,}000\ A\ /\ 365\ T * V} \qquad \textbf{(2)}$$

where:

RSP = the accident rate for the spot

A = number of reported accidents

T = time frame of the analysis, years

V = AADT (average annual daily traffic)

(Hummer, 1994)

According to Hummer, "Accident rates account for exposure, which is the chance that an accident will happen to a particular driver, vehicle, or highway segment." Therefore two separate rates were determined for each location, one for the speeding population and one for non-speeding drivers, and these four rates were exported to a statistical software package for final examination.

The distributions of the two samples were examined for normality and it was decided to transform the data by the $\log_{10}$ which brought the data within acceptable parameters. We now had the necessary elements with which to test the stated hypothesis for two separate but related populations. The mean of the speeding rates should exceed the mean of the non-speeding rates for all three classes of intersections if our hypothesis is correct. Since both sample populations being compared are subsets of the total amount of vehicles entering an intersection it was decided that a paired *t*-test would be most appropriate (McClave and Dietrich II, 1992).

3.5.5 Results

Each class of intersection was entered individually to remove any complexity or spurious results that might occur as a result of the wide range of design considerations. The null hypothesis is that there would not be a difference between the sample means if the two population rates were drawn from similar populations, or, to put it another way, the risk at a particular type of intersection is no greater for those speeding than for those not speeding. Conversely, if the working or research hypothesis proved to be true, a difference would exist. Each class is examined individually.

3.5.5.1 'T' Intersections

The *t*-test was originally run at a 95 % confidence level producing the results found in table 3.8 below.

The following results can be interpreted by stating that if these were statistically similar populations, the probability of a *t*-value being as large as 17.21 is less than .0005 (due to rounding) and is thus statistically significant at our chosen 95% confidence level.

A positive correlation coefficient (Corr) between the means of the two samples indicates that by pairing the samples, we have effectively reduced the variability between the mean differences, and it follows that the higher this value, the greater the benefit realized (Norusis, 1993).

Table #3.8 **t-tests for Paired Samples 'T'-Intersections**

Variable	Number of pairs	Corr*	2-tail Sig	Mean	SD	SE of Mean
Speeding Rate				.5068	.331	.041
	64	.134	.292			
Non-Speeding Rate				-.5021	.379	.047

*Corr is the correlation coefficient

Paired Differences Mean	SD	SE of Mean	t-value	df	2-tail Sig
1.0090	.469	.059	17.21	63	.000

95% CI (.892, 1.126, upper and lower limits)

3.5.5.2 Interchanges

Interchanges have fewer individual locations but each location contained many collisions, thus increasing the size of the overall data set. Output for a 95% confidence level is supplied in table 3.9.

Table #3.9 **t-tests for Paired Samples Interchanges**

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
Speeding Rate				.6164	.340	.061
	31	.361	.046			
Non-Speeding Rate				-.6285	.334	.060

Paired Differences

Mean	SD	SE of Mean	t-value	df	2-tail Sig
1.2449	.381	.068	18.19	30	.000

95% CI (1.105, 1.385, upper and lower limits)

3.5.5.3 Four-Way Intersections

This being the largest data set, containg 184 individual locations and 3,885 collisions, we felt that it would present the most significant resuts. Table 3.10 contains the output for this data, again at the 95% significance level.

Table #3.10 t-tests for Paired Samples Four-Way Intersections

Variable	Number of pairs	Corr	2-tail Sig	Mean	SD	SE of Mean
Speeding Rate				.6904	.292	.021
	187	.215	.003			
Non-Speeding Rate				-.5158	.338	.025

Paired Differences

Mean	SD	SE of Mean	t-value	df	2-tail Sig
1.2062	.396	.029	41.62	186	.000

95% CI (1.149, 1.263, upper and lower limits)

It was possible to again reject the null hypothesis. A discussion of these results continues below.

3.5.6 Interpretation

It appears that regardless of intersection type the results remained strongly significant, indicating that speeding behavior and its attendant risk is ubiquitous throughout the city. As the accident rate is a measure of exposure to risk it becomes clear that speeders are constantly being exposed to greater levels of danger. Due to the tremendous complexity of the phenomena, it is impossible at this time to predict accurately when or where an accident might occur, but these results firmly support the use of photo radar or other intervention strategies to reduce overall speeds at specific locations. As these strategies do not affect those traveling at speeds within the 85th percentile, since they are not being targeted at them, it is possible to suggest that the standard deviation of the entire traffic flow should shrink, thus decreasing interaction and increasing safety. No study in the safety literature has been found which directly relates speed to accident risk in such a fashion in an urban setting and thus it is argued here that the importance of such a discovery cannot be downplayed. Further research should explore the temporal aspect of this problem, the effect of various weather conditions and most importantly of all, further analysis of accident severity.

3.5.7 Within Groups Comparison

It is possible to compare the accident rates for each location with all others within its group in order to assess their relative standing. They could be ranked as a quick and simple procedure, or for greater scientific accuracy, the Rate Quality Control Method (Hummer, 1994) can be employed. The rate quality control method indicates if a location is hazardous if the following inequality is satisfied:

$$\mathbf{OBR}_i > \mathbf{XS} + \mathbf{K}\,(\mathbf{XS}/\mathbf{V}_i)^{0.5} + \mathbf{1/2V}_i \qquad (3)$$

where:

OBR_i = accident rate observed at location i

XS = mean accident rate for locations with characteristics similar to those of location i

V_i = volume of traffic at location i, in the same units in which the accident rates are given

K = constant corresponding to a level of confidence in the finding

(Hummer, 1994)

Hummer describes problems in determining XS as follows:

> "*The question of which locations are similar enough to include in the comparison of XS is difficult. Generally, agencies have used relatively broad definitions of similarity to compute XS.*"

Three important parameters apply to the rate quality control method:

1. It applies only to accident rates, not frequencies.
2. It assumes that the number of accidents at a set of locations follows a Poisson distribution.
3. It compares the rate of a particular location to the mean rate at similar locations rather than at all locations (Hummer, 1994).

To satisfy the second parameter, a Kolmogorov-Smirnov test was applied to the data to test for goodness-of-fit to a Poisson distribution (Davis, 1973). The distribution of speed related accidents for all three locational types fit well within this constraint. Again, as this research concerns intervention strategies such as photo radar only speed related collisions have been selected. Table 3.11 on the following page shows the outcome of this comparison for all the speed related collisions at interchanges.

The two rows that are highlighted in bold type are where the rates exceed the values determined in equation (2). The severity ratio is a value created for this research and simply involves dividing the accident rate by the value it is compared to in the column entitled 'Dangerous if Greater Than'. This result is then multiplied by ten in order to

Table #3.11:

Rate Quality Control Table for Speed Related Collisions at Interchanges

Location	Traffic Flow	Total Number of accidents	Accident Rate	Dangerous if Greater Than	Severity Ratio
=======	============	===========	=======	===========	=======
197	**12075**	**30**	**6.8068**	**5.3154**	**12.8058**
362	11925	4	0.9190	5.3156	1.7288
364	6150	4	1.7819	5.3292	3.3437
365	**13350**	**27**	**5.5410**	**5.3137**	**10.4278**
366	13125	17	3.5486	5.3140	6.6778
367	**21750**	**70**	**8.8175**	**5.3066**	**16.6161**
368	**16875**	**37**	**6.0071**	**5.3101**	**11.3126**
369	12600	6	1.3046	5.3147	2.4548
370	**17850**	**119**	**18.2648**	**5.3093**	**34.4018**
371	**18675**	**46**	**6.7485**	**5.3086**	**12.7122**
372	**18225**	**62**	**9.3203**	**5.3090**	**17.5558**
373	14325	24	4.5901	5.3126	8.6401
374	13200	4	0.8302	5.3139	1.5624
375	15450	12	2.1279	5.3114	4.0064
376	**20250**	**50**	**6.7648**	**5.3075**	**12.7456**
377	**24225**	**58**	**6.5595**	**5.3053**	**12.3642**
378	**28575**	**113**	**10.8343**	**5.3033**	**20.4292**
379	9300	2	0.5892	5.3202	1.1075
380	17925	27	4.1268	5.3092	7.7729
381	7875	11	3.8269	5.3236	7.1886

382	12300	22	4.9003	5.3151	9.2197
383	10800	10	2.5368	5.3174	4.7707
384	**10650**	**29**	**7.4603**	**5.3176**	**14.0294**
385	**26025**	**69**	**7.2638**	**5.3044**	**13.6940**
386	14550	27	5.0840	5.3123	9.5703
387	**13500**	**38**	**7.7118**	**5.3135**	**14.5136**
388	17250	18	2.8588	5.3098	5.3841
389	7650	13	4.6557	5.3242	8.7444
390	19575	37	5.1785	5.3080	9.7561
391	18150	19	2.8680	5.3090	5.4022
392	12000	17	3.8813	5.3155	7.3018

increase the absolute value of the results. This value will be returned to the GIS software and be used to determine a graduated symbol size on the map for display purposes. Therefore, the larger the size the greater the relative risk at that location. All values above the 'Dangerous if Greater Than' value will be marked by a symbol (a flag, see figure 3.10). The dynamic model is now complete and can be set into operation. Data could be entered into the model and subsequent intervals and changes duly noted. This strategy could also be applied to specific campaigns to produce before, during and after 'snapshots' of the results.

LEGEND

Road Classification	Traffic Flow	Speed Limit
Residential Collector	0 - 9,999	50 KM/H
Major Street / Undivided	10,000 - 19,999	60 KM/H
Major Street / Divided	20,000 - 39,999	70 KM/H
Freeway / Undivided	40,000 - 59,999	80 KM/H
Freeway / Divided	60,000 - 79,999	90 KM/H
Interchange	80,000 - 99,999	100 KM/H
Indicates High Risk Interchange	100,000 +	110 KM/H

Figure #3.10 **Relative Risk at Selected Interchanges**

3.5.8 Discussion

This chapter has dealt with a number of issues, not the least of which has been to illustrate the advantages of GIS in this area of research and in the aid of those charged with public safety; *i.e.*, the police service.

> *"If there is anything professionals do agree on, it is that traffic safety is, in an expression attributed to B.J. Campbell, 'not to be solved, but to be managed.' This difference of emphasis carries with it important consequences in specific plans for action."*
>
> (Haight, 1980)

The utility of GIS for management has also been illustrated in this chapter and, as municipalities continue increasing their store of data within GIS this task will be reduced in complexity. An audit prepared for the City of Calgary Police Services, Traffic Division, discusses how the Service might better avail itself of the tremendous amount of data which it now collects and possesses (Western Management Consultants, 1991). By creating a GIS in which to store and manipulate this data, the Service would realize this potential. Earlier in this chapter, the ease by which data might be selected to represent certain criteria such as fatalities or injuries only, and then be displayed visually was discussed. The relational databases within GIS and their use of SQL reduces this task to a series of simple steps that allows users access to a tremendous range of data. Thus data mining, or searching for relationships within the database, as discussed by Berry, becomes a fruitful experience (1995).

Beyond this it has been shown that GIS may be used for formal scientific research. An *a priori* hypothesis can be formulated followed by gathering data from within the GIS, and then by the testing of hypotheses and the spatial display of the findings. With the explosion of software packages for the desktop GIS market and the rapid strides made in increasing the processing power and storage capabilities of these computers we anticipate great strides to be made in the management and research of traffic safety issues.

3.5.9 Conclusion

Primarily, this chapter has supplied a sound and logical argument in support of photo radar and other traffic management intervention strategies. It creates a foundation underlying the need for intervention since it shows that in certain locations, that speed does in fact increase exposure to risk of collision. When coupled with the numerous papers that relate the success of various intervention strategies (Ostvik and Elvik, 1991; Zaidel, Hotcherman and Shalom, 1993), the research reported here should allow those agencies that utilize these methods to express their utility to the public and increase support for these approaches. Support from the general populace is extremely important to the success of a long range campaign. This point has been illustrated by the success of the Drunk Driving programs in existence throughout the modernized world. Organizations such as MADD (Mothers Against Drunk Drivers) and TADD (Teenagers Against Drunk Drivers) are excellent examples of how the public can aid the police in these campaigns. Informing the public via the media has proved extremely effective, expecially when held in conjunction with a specific campaign (Rooijers and DeBruin, 1991).

Furthermore, this chapter has shown how GIS allows for the successful management and monitoring of this urban malaise. If societal costs of collisions can be reduced, this indeed becomes an economically sound practice. In a recent discussion paper prepared for the government of Alberta by KMPG Consultants (1995), they estimate these costs to be as follows:

$3,800,000 per Fatal

100,000 per Injury

12,000 per Property Damage Only

These figures are meant to reflect the costs of pain and suffering as well as direct costs. It is impossible, however to account in any way for the loss of a loved one as the paper states:

> *"Placing a dollar value on human life is difficult and to some morally offensive. Yet in order to evaluate which type of safety program is most effective in protecting the public, an acceptable societal cost needs to be determined."*

Considering that the City of Calgary experienced fifty fatalities on its streets in 1995, a higher than average amount in recent years, the need for successful strategies aimed at reducing the population of those traveling at rates above the 85th percentile becomes self apparent.

3.6 Summary

This chapter is purely analytical and deals initially with problems in the database. This ranges from the inappropriateness of some of the information and its inconsistencies to its complexity. Then the data is reduced to components using the statistical technique of principal components analysis. This is where the location of intersections and interchanges first becomes apparent as a trouble spot. The data is then geocoded into a GIS and explored initially with a chi-square test which indicates that intersections and interchanges experience more severe accidents. Finally, a hypothesis is formulated and tested whereby a statistical link is forged between speeding and accident probability. The utility of the GIS is further explored by creating a map that indicates hazardous intersections, relative to other intersections, and their relative potential for danger. The next chapter will explore behavioral models explaining why this problem exists.

4.0 DRIVING BEHAVIOR

"Facts are simple and facts are straight
Facts are lazy and facts are late
Facts all come with a point of view
Facts don't do what I want them to
Facts just twist the truth around
Facts are living turned inside out
Facts are getting the best of them
Facts are nothing on the face of things
Facts don't stain the furniture
Facts go out and slam the door
Facts are written all over your face
Facts continue to change their shape."

David Byrne, Crosseyed and Painless

4.1 Introduction

The previous analytical work of chapter 3 presented us with many quantitative facts: they defined the phenomena, located it in space, gave us a means of measurement and a methodology for study and comparison, but they still do not explain *why* or *how* these phenomena occur in the first place. Without some attempt to come to grips with the human element, the reasoning and frailties of the operator behind the wheel, no enforcement strategy will be successful. This chapter will outline some of the behavioral studies and will culminate in a discussion of Risk Homeostasis Theory, which appears to offer a plausible working model. The previous work can then be incorporated into this model making it operational. Then recommendations may be derived as to a police intervention strategy. This will be accomplished in the following chapter.

The majority of this work has been conducted by behavioral psychologists who attempt to explain the mental interaction between the driver, the road environment and the vehicle. Such work must also include the information processing ability of the driver as well as the driver's penchant for selecting and prioritizing information and tasks. Driver motivation must also be considered. It is easily recognized that the individual has a range of emotional and mental states that may come in to play at any one time. Even physical abilities fluctuate over the course of the day as energy levels increase and decrease let alone factoring in the added effect of the possible ingestion of drugs, prescription or otherwise, and or alcohol. This is all greatly complicated by the large number of individuals using the system at any one time.

4.2 Background

There are two main areas of study when examining the individual driver: (1) perceptual and motor capabilities and, (2) cognitive and motivational aspects. The first area generally results in ergonomic research that focuses first on the physical capacity of the driver and second on aiding the operator in the gathering of information. Such research includes: the improved road design, better and more coherent signage, improved vehicle handling and improvements in the instrumentation so as to present important information to the driver more quickly and with a minimum of effort and confusion. The latter aspect is considered more important as it takes into account the decision making process and cognitive filtering. If one considers the first aspect (perceptive) as our capability and the latter (cognitive and motivatioal) as our behavior, the importance of this distinction is made clear in the following:

> *"Driving performance is probably more indicative of the limits of our capabilities while driving, while driving behavior determines actual behavior somewhere below these limits."*
>
> (Shinar, 1978)

Another way of illustrating the above point would be by examining various studies of drivers' ability to recognize and remember various road signs. Under laboratory conditions, subjects generally rate highly in recognizing and remembering the messages presented on signs. This represents our capabilities. When research is performed in the field, vehicles are flagged down and the driver is requested to state what the last road sign was a different pattern emerges. Performance is lower and it is selective. Driver's make decisions as to what to pay attention to, and they therefore dismiss certain signs while paying attention to others, regardless of whether they have the capability to read and understand the sign (Shinar, 1978).

4.2.1 Driver Capability

While the large volume of work concerning driver capability has improved the safety of our roadways over the years, it is not necessary to include much of it here as speeding behavior is mainly that of choice, the driver makes a decision as to what speed to travel. The improved performance, handling and safety characteristics of vehicles facilitates this decision, but while many of these improvements have sprung from ergonomic research, the actual decision to speed is one of motivational and cognitive reasoning. The relevant information from this area pertains to studies of the driver as an information processor (Shinar, 1978).

The individual processes information continually during the task of driving. There is a constant monitoring of environmental, physical and mental variables that work within a closed feedback loop that results in either minor adjustments to driving, or in the case of unexpected events, major compensatory actions. Depending upon the individuals' state of alertness, emotional level (i.e., stressed, angry, relaxed etc.) the driver can process information at a particular rate. Quite often this processing is routinely performed as when traveling along straight stretches of limited access roads. In these situations the majority of traffic is moving together, hence low vehicular interaction, low signage and few or no pedestrians and commercial signs. This can change quickly though as the person approaches an interchange where vehicle speeds vary due to cars entering and exiting the traffic stream and changing lanes or merging to do so. Road signs increase so as to inform the public of what roads they are approaching. There are also additional safety signs such as merge and yield signs. Thus a greater amount of information must be processed and the driver may select only certain information and ignore other. The only other way to compensate for this added presentation of information is to adjust the rate at which this information is received, which entails adjusting the vehicle speed. Thus the slower the velocity of the vehicle, the slower the rate at which the information is received and the driver may be able to pay greater attention and process more information, instead of having selectively to ignore some information. We all can remember the anxiety of driving in an unfamiliar city for the first time and approaching interchanges where we attempt to read all the signs and watch the traffic simultaneously.

This point of adjusting speed is important in that if the individual is already traveling at a high rate of speed, the ability to process information is greatly reduced. This can be further exacerbated when we examine individuals who have a tendency to increase their rate of speed so as to run a yellow light at an intersection. While it is true that there may be certain individuals who possess remarkably rapid information processing capabilities there maybe so many drivers on our roads that we can safely generalize that this activity will generally impair information processing. Furthermore, the speeding of one driver with high information processing ability may still cause a collision due to his or her interaction with another individual with lower capabilities who is also entering the intersection. Most collisions, especially those resulting in higher severity, involve two or more vehicles.

Reaction time, or the time lag between the perception of a hazard and when avoidance maneuvering is initiated, is also affected due to this information processing capability. Not only can reaction time be reduced by other stimuli thus delaying the initial perception of the hazard, but as the difficulty of the decision increases, so does the lag time. It is proposed here that with increased speed (and therefore an increase in the stress of processing information at a more rapid pace) the difficulty is also increased for decision making regardless of the hazard. The circumstances of the hazard will be in addition to the already stressful condition under which the driver has placed his or herself. As a final factor, uncertainty plays an important role in determining the length of this lag time.

> *"In discussing reaction times we noted that we need more time to respond to an unexpected event than an expected one - but we made no attempt to clarify expectancy. If we measure expectancy as the probability of any event, then we can note that the greater the number of possible events that could occur the lower our expectancy concerning the actual occurrence of any one particular event. ....It turns out that there is a direct relationship between reaction time and the quantifiable measures of uncertainty: reaction time increases as uncertainty (or number of potential outcomes) increases.*
>
> (Shinar, 1978)

The emphasis on intersections and interchanges found in the previous chapter reflects this greater number of potential outcomes. Intersections and interchanges thus represent areas of greater uncertainty.

4.2.2 Motivational and Cognitive Aspects

In keeping with the above discussion as to expected and unexpected events, Wilde (1976) outlines the social interaction between two drivers and the ability of one driver to predict the behavior of another driver. He posits that drivers operate under either formal or informal systems, acting either in compliance or deviating from these norms. This can be illustrated in a table, as below:

Figure 4.1 Patterns of Conformality and Deviance With Respect to Formal and Informal Rules of Behavior.

		Formal: Compliance	Formal: Deviance
Informal	Compliance	a	b
	Deviance	c	d

Source: Wilde, G. 'Social Interaction Patterns in Driver Behavior: An Introductory Review' Human Factors. 1976, 18(5), 480.

> *"Thus, four types of behavior may be distinguished [see figure 4.1]: (a) maneuvers that are in conformity with the legal norms and also with the informal norms, (b) maneuvers that deviate from legal rule systems but conform to the informal norms, (c) maneuvers that conform to the legal norm but deviate from the informal rules, and finally (d) maneuvers that deviate from both norm systems.*
>
> (Wilde, 1976)

Except for behavior categorized under cell 'a', decisional uncertainty arises and social disorganization results in each of the other three instances. A contemporary example would again be the driver running a yellow light, deviance from formal norms, colliding with a vehicle making a legal turn in order to clear the intersection. Many people can recall the indecision as to whether we should complete a left turn or wait to see if oncoming traffic will actually stop, thus obeying the formal rules.

As the driver is an individual with his or her own personality traits, these could be considered part of the complex of variables that are attributed to motivation. Furthermore, day to day changes in attitude can add to the emotional make-up of the driver. Studies have indicated that those under stress, such as those in the midst of a divorce for example, tend to have more accidents than those who are not under stress. Being preoccupied with worldly worries can inhibit one's ability to concentrate on the task of driving and impair the rate at which information is processed. Some research has looked into the aggregate of overall personality profiles and attempted to correlate them with general driving habits. Shinar (1978) quotes a study by Tillman and Hobbs (1949):

> *"It would appear that the driving hazards and the high accident record are simply one manifestation of a method of living that has been demonstrated in their personal lives. Truly it may be said that a man drives as he lives. If his personal life is marked by caution, tolerance, foresight, and consideration for others, then he would drive in the same manner. If his personal life is devoid of these desirable characteristics then his driving will be characterized by aggressiveness, and, and over a long period of time he will have a much higher accident rate than his stable companion."*

This particular point can be aggregated to the social level and will be discussed later under the concept of global, overarching social philosophy.

Other studies have focused on either improving the skills of the individual operator or conversely, making the overall driving task easier by improvements in the design of the road. As skill level increases, via training, the operator is involved in a proportionally greater amount of accidents. This is attributed to a rise in confidence by the driver resulting in riskier driving habits. A study between professional competition drivers and a comparison group showed that the professional drivers not only were involved in more accidents per driver but also received more speeding, moving and non-moving violations. This led to the conclusion that:

> *"Caution is indeed needed regarding the assumption that advanced driver education in crash-avoidance and related techniques can be translated into reduced crash experience."*
>
> (Summala, 1985)

Realizing these limitations, work then focused on making the driving task easier for the vehicle operator by improvements in engineering and design of the road environment. Unfortunately, the results were ambiguous at best, having a decrease in fatalities per unit distance driven, but there was a steady increase in the total loss due to road traffic. The conclusion here being that "*technical improvements as such were not necessarily safety-promoting.*" (Summala, 1985).

This seemingly paradoxical situation is explained as a regressive tendency whereby as the driving task is made easier, or the driver increases her/his skill level, they compensate by driving faster. However, Summala (1985) quotes Smeed (1949) as saying:

> *"..., but I see no reason why this regressive tendency should always result in exactly the same number of accidents as would have occurred in the absence of active measures for accident reduction."*

Thus the regressive tendency becomes more of a dampening effect that would require greater in-depth analysis to quantify its reduction in the rate of improvement. The regression tendency can be defined as a feedback or compensatory loop and research then began to focus on how to break this loop (Summala, 1985). Research shifted to the driver as explained below:

> *"It was only in the 1960's and 1970's that the view of driving as a self-paced task in which the driver himself is able to adjust the difficulty of his task started to gain popularity. Emphasis was more and more given on "what the driver actually does in any given traffic situation rather than on his driving skills and/or the traffic conditions as such" (Naatanen and Summala, 1974)."*
>
> (Summala, 1985)

A definite lack of understanding, or perception, of the effects of speed is one general factor inhibiting the efficacy of safety measures. The impact of a 50 km/h collision is comparable to that resulting from falling out of a three story window. Most people are inhibited from leaning too far out of said window due to a healthy respect for heights which appears to be ingrained. However, many do not wear seatbelts when traveling at the rate of 50 km/h because they feel that they can protect themselves by bracing with their arms, also they mistakenly believe that the stopping distance at that speed is close to zero.

> *"It is therefore not surprising that speed is one of the variables that correlates best with accidents. High speed is the second most frequent human error found in accident in-depth analysis."*
>
> (Rumar, 1985)

Another perceptual problem is the public belief that the probability of being involved in a collision is very low, thus the public tends to ignore many safety campaigns. If the emphasis is switched to the lifetime probability of collision involvement and loss, then the individuals' perception is greatly increased (Kunreuther, 1985).

As the driver gains in experience, skill level increases. This is mainly due to a change in the cognitive processes to a 'pre-attentive' level which reduces the requirement for information processing as they do not occur at a high level of consciousness (Wilde, 1988). The best way to understand how this is brought about is to recall the way in which an individual learns to drive and internalizes many of the tasks involved.

When an individual first learns how to drive he/she is faced with what appears to be an overwhelming variety of tasks that need to be performed simultaneously. Not only does the novice driver have to coordinate the physical actions of both hands and both feet into control of the vehicle but the novice must also learn to pay attention to the external environment in front of, behind and to both sides of the car. The task seems to take more information processing ability than the new driver is able to bring to bear which is why they drive slowly and often learn on side roads where the ambient traffic is slight. Fortunately the driver soon learns to automate many tasks, such as vehicle tracking, and thus to internalize them. This removes the task from conscious thought, freeing the mind up to concentrate on other things.

> *"Vehicle handling can hence be conceived as a series of predetermined motor patterns which are slightly corrected during their actual execution (Kelly, 1968; Adams, 1971; Johannsen and Ruse, 1979)."*
>
> (Summala, 1985)

In addition to internalizing driving tasks, the driver, through experience, begins to be able to predict the activity of the traffic around him. Cars continue in certain ways, pedestrians cross the road at a set pace, etc.

> *"Just as he has learned to predict ballistic trajectories he learns to predict the behavior of other road users (and of the behavior of his own vehicle, of course); with experience he acquires internal models and expectancies which, as pointed out by Naatanen and Summala (1976) are* ***perception-like, deterministic*** *in nature.*
>
> *Unfortunately, the traffic system is not as deterministic as the driver's internal representation of it. This is the very critical point when road safety is considered. When the drivers behave according to their deterministic expectancies they do not reserve sufficient safety margins for exceptional situations."*
>
> (Summala, 1985. emphasis in original)

The driver soon becomes lulled into a feeling of complete control over the car and gains confidence in not only being able to predict the movement of vehicles around him or her, but also acquires a false sense of being able to avoid a collision should one arise. Experience reinforces this perception every time that the driver successfully completes a journey without incident. So seldom does a driver ever find him or herself in a hazardous situation that they never learn the required quick reflexes in order to avoid such dangerous events. Worse still, experience teaches the driver that such skills are not required.

> *"The very problem in road safety is indeed that such severe conflicts and, accordingly, accidents are so infrequent that drivers are not able to take them into account and, what is more, it would not even be rational."*
>
> (Summala, 1985)

The following two quotations suggest a direction for future research:

> *"The object of attack should not be the material causes of accidents but the balance between the motivating and inhibitory forces of positive and negative motivating events."*
>
> (Summala, 1985)

> *"In other words, most researchers of traffic-related behavior (including this author) do not give enough attention to the fact that functional relationships between drivers and driving environments are intertwined within a complex ecobehavioral system of other relationships between social, physical, and environmental variables."*
>
> (Geller, 1985)

It is the contention of the present research that the Risk Homeostasis Model presented by Wilde can indeed aid in bringing all these variables together. The following sections include a discussion and explanation of the model which will then, in the next chapter, have the previous analytical work injected into it so as to integrate and operationalize the two lines of research. From this not only will it be possible to formulate strategies and tactics for police intervention, but it should also be possible to use the model as a means to understand what type of impact the intervention will have. This will offer us some predictive ability.

4.3 Risk Homeostasis Theory

Wilde describes this theory as a group of hypotheses that are interrelated and gathered together under the one overarching theory. It is beyond the scope of this thesis to delve into all aspects of this theory so the reader is directed to the numerous articles published concerning this theory (Wilde, 1976, 1982a, 1985, 1988). However, it is useful to quote from the following general discussion by Wilde that offers an overall description of the salient points of his theory:

> *"What the theory of Risk Homeostasis posits concerning traffic accidents may be roughly outlined as follows. At any moment of time, road users monitor the level of accident risk to which they feel exposed and compare this level with the degree of danger they are willing to accept. This preferred or target level of risk depends on their perception of advantages and disadvantages accruing from their amount and manner of mobility. The actions taken to keep 'experienced' risk in balance with 'preferred' risk carry an objective-likelihood of accident. The actual accident loss incurred by a jurisdiction is the consequence of these actions. This loss, in conjunction with everyday experiences of risk, influences the perceived level of risk among road users who have had no fatal accident. Thus, accident loss and the degree of caution displayed in road-user behavior are related to one another in a compensatory process, and only those accident countermeasures that are effective in decreasing the preferred level of risk can reduce the accident loss per capita."*
>
> (Wilde, 1988)

Thus in order to break the regressive compensatory loop, according to Wilde, one must operate outside the loop and increase the individual's target level of risk. Figure 4.2 on the following page shows that efforts must be made in a motivational fashion at box 1, which is outside the loop.

The above is contained in Proposition 9 of the theory which is as follows:

> *"Any intentional or fortuitous change in conditions that is effective in altering the individual's target level of traffic-accident risk, modifies that individual's actual traffic-accident risk in the same direction."*
>
> (Wilde, 1988)

Figure #4.2

Homeostatic Model Relating Accident Driver Rate to Driver and Vice Versa

(Source: Wilde, 1982a)

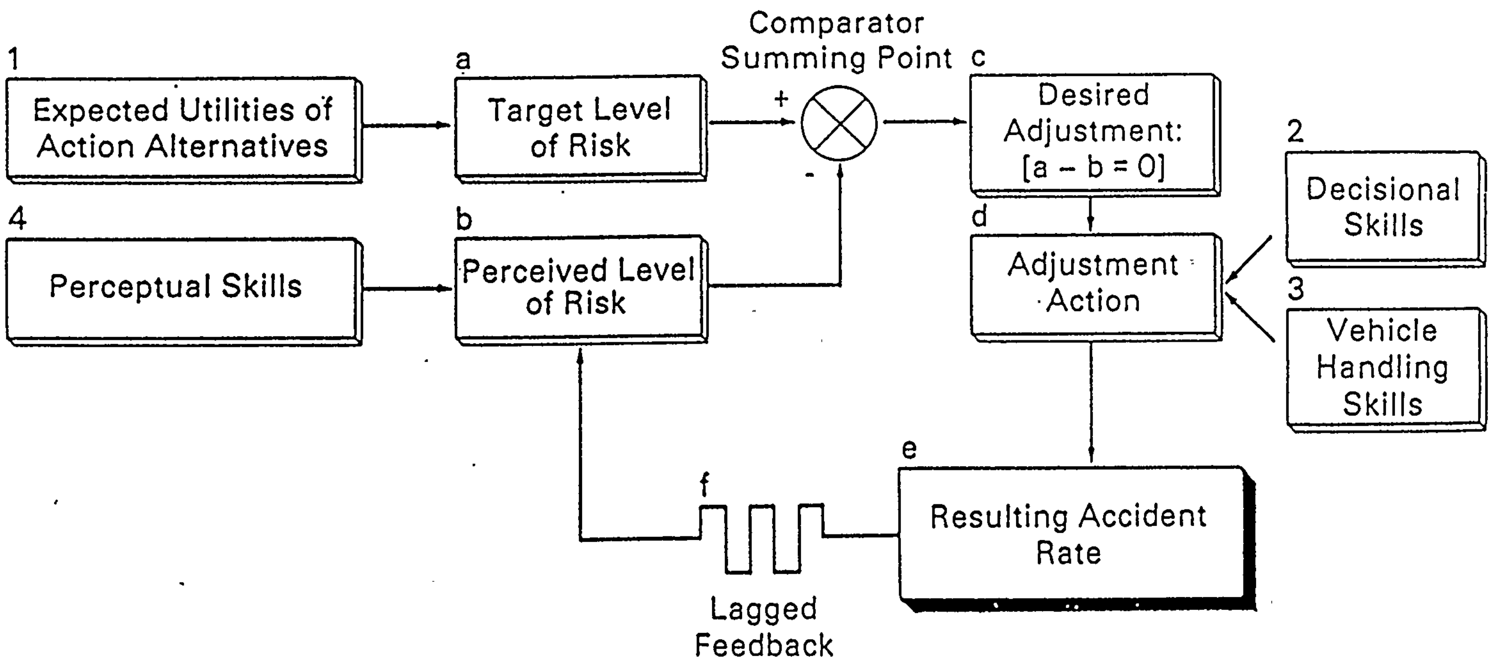


Figure 1. Homeostatic model relating accident rate to driver behavior and vice versa (from Wilde, 1982a)

The target level of risk is a balance struck by the individual between the perceived gains to be had by driving faster (these can range from the saving of time to the hedonistic pleasure derived from the thrill of driving fast) and the perceived loss to be incurred. We have already seen that the perception of accident occurrence may be lower than it actually is which indicates one area where education may be helpful. Risk may also be viewed, as far as speeding behavior is concerned, as the risk of apprehension and subsequent fine. This point will be discussed further in the next chapter. The target level of risk is an individual choice and will therefore vary for all drivers. It appears that young drivers and generally male drivers derive greater benefit from driving faster so they will have a higher target level of risk (Wilde, 1988).

This might explain then why different strategies aimed at increasing safety have not resulted in the overall expected drop in accident rates. Safer, better handling cars reduce target risk levels inducing the drivers to compensate by driving faster and the same can be said for improved road conditions and training programs that increase the drivers skill. Figure 4.3 illustrates how all the various factors influencing the individual driver operate within the compensatory feedback loop that results in the regressive tendency discussed earlier.

Figure #4.3 Cognitive and Motivational Model of Driver Behavior

(Source: Wilde, 1976)

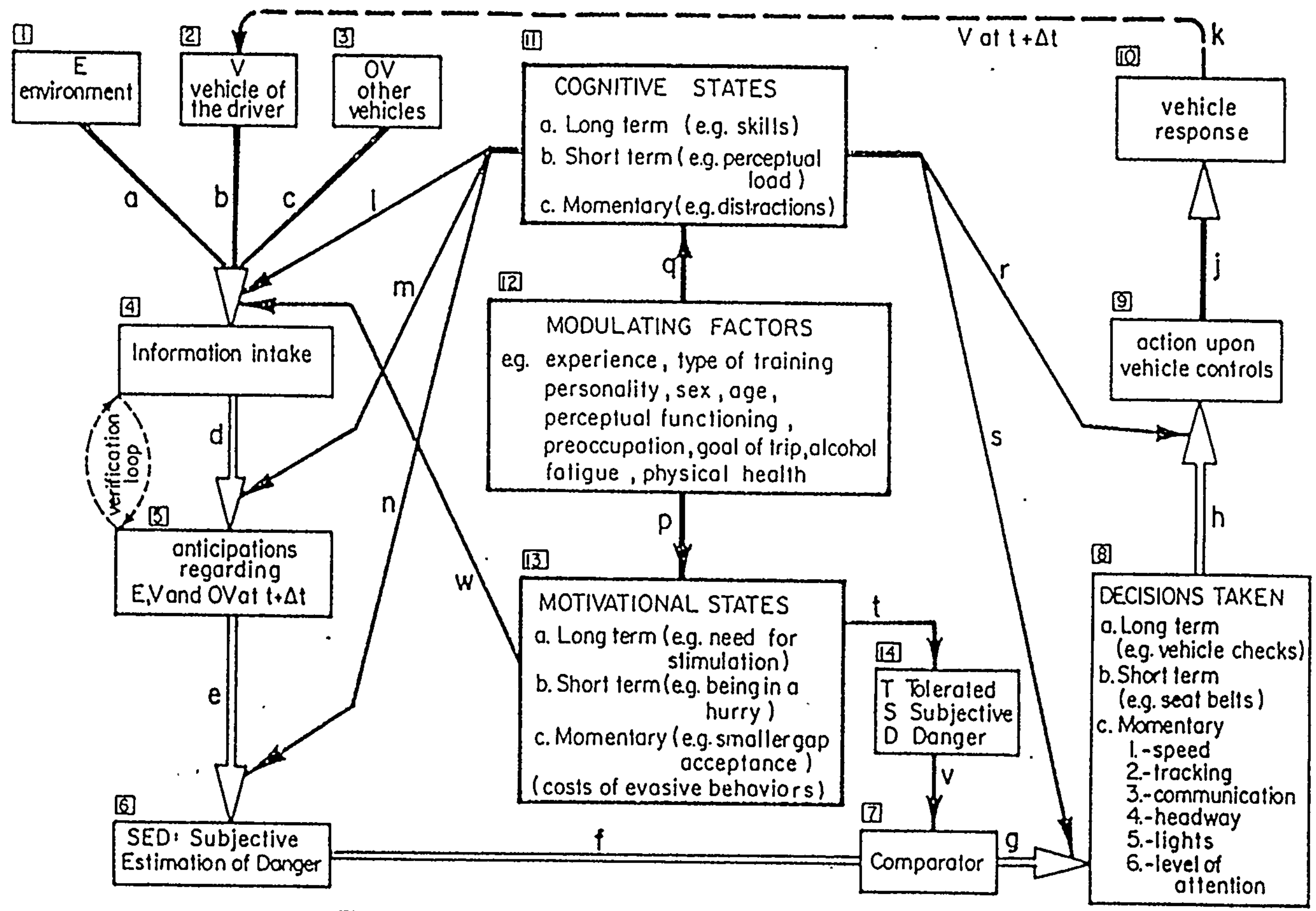


Figure 1. *Cognitive and motivational model of driver behavior.*

The theory can be translated from the individual, disaggregate level, to the social, aggregate, level. Wilde (1976), explains this quite well in the following:

> *"... the author has argued that a reduction in risk tolerance may be the only factor in Figure 4.2 which is capable of bringing about a long-term reduction in the frequency and severity of accidents, while changes in the other factors (perceptual, decisional, and control skills) can only have a temporary influence on accident rates. This is the consequence of the assumption that an actual reduction in accidents will, after some time lapse, lead to a reduction in the general level of perceived collision risk in the population of road users.*
> *If anywhere in the causation of road accidents, it is here that a social mechanism par excellence is encountered. It may be paraphrased simply as follows: if any driver A is aware that many accidents happen to others, his need to be cautious will be stimulated and his tendency to engage in precautionary behavior will be reduced if few people are killed or seriously injured. As the degree of caution determines the accident likelihood of any driver A and therefore the total accident toll, accident tolls and caution relate to one another in a compensatory function. This results in only temporal fluctuations of accident frequency, provided that the level of risk tolerance remains invariant."*

Summala (1985) discusses an interesting case study of the Nordic countries and their change in speed limits in the early seventies resulting from the OPEC oil embargo. In Finland, where there were no speed limits on highways, the president issued a declaration on New Year's Day 1973 that the accident toll was intolerable and speed limits would be immediately imposed. This resulted in a continued reduction in fatalities not only on the highways but also in the urban areas where speed limits had already been in effect. It is the contention of the present research that the publicity around such a dramatic change mandated from the highest political figure in the country resulted in an increase in overall target levels of risk. This appears to be confirmed by Summala (1985) himself in the following:

> *"Besides their 'immediate' safety-promoting effects on the speed level, the scatter of speeds, and the resulting reduction in passings,* ***the speed limits, apparently, broke the compensatory loop."***

Risk homeostasis theory does however have its criticisms (Graham, 1982; McKenna, 1982; Slovic and Fischoff, 1982; Evans, 1985). Wilde has been criticized for selected empirical studies that support his hypotheses while either ignoring, or not adequately dealing with those studies that appear to contradict his findings (Graham, 1982). Wilde admits that it is problematic and no doubt ethically impossible to test his theory on human subjects in situations that replicate his results. He did, however, attempt to test his theory in laboratory conditions where he created a video game with monetary rewards, in the hope of gaining insight (Wilde, Claxton-Oldfield, Platenius, 1985). The results where not statistically significant and in addition to that, it is my contention that they do not adequately represent the cost-benefit analysis necessary for deciding the target level of risk. One would be willing to accept almost any level of risk when the stakes are as low as they were in the experimental game and the range of risk levels accepted might vary greatly, whereas, in a real life situation where your life might be at risk, such as in a traffic collision, not only would the target level of risk change but the variation in that level would be lower as most people would desire very little room for error.

Along this line of reasoning, it appears that the explanation behind the decision making process that arrives at a target level of risk is not adequate. A simple cost-benefit analysis does not fully explain this phenomenon. If we look at box 1 of figure #4.2. We see that the actual setting of the target level of risk is not explained. Is it a minimum or maximum level, or somewhere in between? If we are maximizing our benefits as opposed to our risks, then we would choose to select the highest comfortable level of risk, but might not one wish to maximize safety where one would accept a minimum level of risk, or, perhaps accept a level in between? Moreover, given a range of alternatives, can the level of setting fluctuate over time? This then would change the concept of homeostasis fundamentally. If we use Wilde's analogy of a thermostat, we have to accept that once a temperature setting is decided upon, it remains static. However, many influences may act upon the driver during his trip and he or she may alter this setting at will. The contagion theory mentioned earlier is one such example. Suppose the operator is driving relatively fast, at the 85th percentile for the sake of argument, and turns onto a road were the other drivers are all driving at or below the speed limit. Our driver may take this information as a clue to slow down, regardless of the risk level, merely because he or she does not want to stand out in the crowd, as it were. Also in figure 4.2, there is a lack of internal feedback directed at the target level of risk. Perhaps the driver has experienced something, such as being cut off, and decides to reassess his or her level of risk accordingly.

Lastly, I wish to address the dynamic nature of this setting of risk levels in that it must be pointed out that time is equated also with distance. While the driver is assessing the conditions around the vehicle, the vehicle is moving and therefore, the conditions are also in a state of in flux. A decision based on a couple of seconds ago as to this setting of speed, may need to be altered due to the change in conditions resulting from progressing forward. This point will be developed further in the next chapter as I believe it adds information to the argument of intersections as dangerous locations.

4.4 Summary

This chapter discussed the important issues of why people behave the way they do when driving. Perceptual abilities were introduced and followed by an explanation of how drivers use the information presented to them and how they select information. This falls under the area of cognitive and motivational factors. Finally, the Risk Homeostasis Model was introduced in an attempt to integrate many of these factors into a comprehensive theory. The next chapter will bring together the pervious analytical research of this work and the Risk Homeostasis Model in order to explain more fully the phenomenon.

5.0 DISCUSSION

"Power seemed to have outgrown its servitude and to have asserted its freedom. The cylinder had exploded, and thrown great masses of steam against the sky. The city had the air and movement of hysteria, and the citizens were crying, in every accent of anger and alarm, that the new forces must at any cost be brought under control."

Henry Adams, The Education of Henry Adams.

5.1 Introduction

The two previous chapters have provided us with enough information to proceed with a sound and logical strategy for the effective deployment of photo radar. Knowing, from earlier work, that speeding increases the probability of collisions, and that this probability is highest at intersections and interchanges it can then be inferred that any intervention strategy should emphasize these locations. The problem is further exacerbated when it is realized that severity is also highest at these locations. It is here then that action must be taken to change driving habits so that safer attitudes are adopted. Also, it is at these locations where intervention efforts would realize the greatest rewards. Furthermore, these locations can be narrowed down to the intersections or interchanges that have the highest probabilities of collision occurrence, relative to other intersections or interchanges within the city. It is also known that the only way to effect a lasting change is to intercede outside the compensatory loop by affecting the target level of risk. The present research argues that this can be accomplished on two fronts: the disaggregate level through intervention via photo radar units and other speed measuring devices and the aggregate level through education.

5.2 Photo Radar Intervention

Since photo radar units are mobile, the motorist is never really sure where he or she might be detected by photo radar and receive a fine if traveling too fast. This insecurity increases the target level of risk (risk being that of receiving a fine), operates outside the compensatory feedback loop and causes drivers to be more cautious. This effect will be ubiquitous to those drivers who feel their target level rise. If the contagion theory holds true, then this effect will cause other drivers to slow down, reducing overall traffic speeds. It is at the specific site, where the visible photo radar vehicle is located that the greatest benefits will be found though.

It is already known through numerous studies that a halo effect occurs around a marked police vehicle wherein motorists slow down. If the photo radar unit were to be deployed in such a fashion that it would be upstream from a targeted intersection, but close enough so that the halo covers the intersection, then the majority of the traffic stream passing the photo radar vehicle would slow down and remain traveling at a slower rate of speed until it was through the intersection. This would prove to be the most effective way of reducing collisions at the noted high risk intersections and interchanges.

A secondary, beneficial effect would arise from such a strategy in that the driver response to an emergency situation would be enhanced for two reasons. The first being the increased ability to process information as the rate of flow of information slows down with the determined speed allowing the driver to perceive more data. Second, the lag time, or time between seeing a situation and responding to it, would decrease as has been proven in studies that show that the driver's attention is accentuated by witnessing the police vehicle. As illustrated in the previous chapter, many processes involved in driving are internalized and operate at the subconscious level. The presence of the police vehicle brings to the fore the need to concentrate on the task of driving, thus making some subconscious processes conscious again. Lag time, which is also known as latency, is discused by Summala (1985) as follows:

> *"The latency decreased, however, when there was a special warning flasher at the pedestrian crossing or a patrol car parked at some distance before the measurement point. General alertness hence decreased response latencies to an unexpected situation and in special situations alerted drivers are capable of even much quicker responses."*

Therefore, the driver is traveling slower, hence decreasing the force of impact. The driver is able to process more information and is also in a heightened, relatively speaking, state of awareness that results in quicker responses.

The physical forces at play here should not be overlooked as the reduction in speed brings about a tremendous economy of safety. The severity of an impact, or increase in energy, rises fourfold as speed doubles. The combined stopping distance, defined as the perception and reaction distance plus the braking distance to bring the vehicle to a halt, also decreases greatly with slower speeds. Assuming test conditions of straight, dry, level roads and the vehicle's brakes being in good condition stopping distances increase as speed increases.

> *"This means that a reduction in speed of the vehicle from 150 km/h to 100km/h reduces the stopping distance by 132 metres or over 27 car lengths. A decrease from 150 km/h to 120 km/h improves the stopping distance by 84 metres or over 17 car lengths."*
>
> (Safety Research Office, 1995)

The effectiveness of photo radar has been documented in the various locations where it has been in effect. A study undertaken in 1978 on the German Autobahn where a 100 km/h speed limit had been recently imposed showed a drop from 300 collisions, 80 injuries and 7 fatalities to 9 collisions, 7 injuries and 0 fatalities. A 1993 study in Melbourne, Australia, found a reduction of 20% in the amount of casualty collisions on a 60 Km/h road. A three month study in Arlington, Texas showed that photo radar was effective in reducing the proportion of vehicles traveling above the posted speed limit on densely traveled urban roadways. During the four months that photo radar was operating in the Province of Ontario, a test was conducted that compared a site with photo radar to a comparable site without photo radar. The test site showed a remarkable reduction in the percentage of vehicles traveling in the highest speed "bins". The reductions were between 70 and 80% (Safety Research Office, 1995). The control sites also showed modest reductions in overall speed, no doubt illustrating the overall awareness of Ontario drivers to photo radar and their consequent increase in perceived level of apprehension which can be translated to increased target level of risk as explained by Risk Homeostasis Theory. Another test from Norway is discussed below:

> *"An ongoing study of automatic speed enforcement in Norway has found that the average speed on a 80km/h road was up to 100 km/h. Such effects have been found two years after the introduction of the counter measure even if the cameras were active for only about 12 hours a week. The percentage of offences were reduced from 43% to 14% at one point, from 35% to 7% at another point, which is calculated to a relative reduction of up to 69% when taking into account the speed on the control road. On a 50 km/h road with much local traffic the reduction of speed only seems to be found at the camera with only a small halo effect. Our study seems to indicate that the change of speed choice persists even with inactive periods by the camera of up to two months."*
>
> (Ostvik and Rune,1991)

Another study from the state of Virginia focused on the ORBIS system that utilizes induction loops buried in the pavement and stanchions with cameras in them mounted on either side of the road. Before installation, vehicles traveling the speed limit by 10 or more miles an hour exceeded 800 per day. This number was halved a week after the system was installed but before ORBIS was activated. After activation the amount of speeding vehicles declined steadily until they reached a relatively stable rate of 15 to 25 offenders a day (Shinar, McKnight and James, 1985).

By adopting this particular strategy then, we allow many various forces to interact and increase the safety of the location in question. At this disaggregate level, the risk of apprehension, or receipt of a fine is an important factor.

One factor, related to lag time, has not been discussed and is, in my opinion, one of importance in these locations. In figure #4.2 there is a lag time between the assessment of all factors and the perceived level of risk. As mentioned earlier, this lag time also equates to distance travelled. If we assume that the driver in question is traveling along a link, or stretch of road between intersections, the speed at which the driver is willing to travel may be slightly higher as these stretchers of road have less signage, less interaction (other vehicles are not entering or leaving the traffic stream) and most other vehicles are traveling at a relatively similar speed. Then, the driver enters an intersection or interchange and the environment is radically altered. Information flow increases, as there is more of it, and vehicle interaction increases. The driver is also traveling at a specific rate of speed that may carry the vehicle through the intersection before the driver has had enough time to assess the new conditions and alter the vehicle's speed accordingly. Therefore, a short time period may exist where the driver is actually accepting a higher level of risk than that with which he or she may be comfortable. Combine this with the previously discussed effect of having a greater variety of outcomes and the attendant lag in decision making ability associated with that and the danger increases dramatically. It is the contention of this thesis that the above explains why intersections and interchanges are associated with greater amounts of collisions and why they therefore should receive special attention by the police services.

5.2.1 Risk of Apprehension

In order to influence drivers and increase the level of compliance to the speed limits it is necessary to ensure that there is a sufficient level of *perceived risk of apprehension.* The greater the individual driver's perception, the greater the compliance level amongst the populace. This, again supports the use of photo radar due to its unique ability to be mobile and because of the public's perception that it is an extremely effective device. Its effectiveness is due to the automated aspect of the device so that it constantly monitors the traffic stream. This has a tremendous advantage over the traditional patrolman operating a radar gun, as the radar equipment is effectively not utilized during the time it takes an officer to issue a ticket, usually about twenty minutes. Therefore, even though a stretch of road is monitored by a patrol car, if it was apprehending motorists one after another, it would still only be capable of ticketing three offenders an hour when operating at peak capacity. This has been improved with the addition of a second vehicle, where the second officer is charged with writing up the ticket and the first car's officer can continue to operate the radar gun. Studies have shown that this configuration is more effective, using halo and memory effects as an indicator (Shinar, McKnight and James, 1985).

Certain conditions are considered necessary in order to increase the perceived risk of apprehension:

> *"To have an effect upon a driver's behavior, an individual enforcement unit must be seen as a threat. For an enforcement unit to appear threatening, it must have the following characteristics:*
>
> - ***It must be visible** - Approaching motorists must see the unit if they are to perceive a risk of apprehension. While hidden units may increase the objective risk of apprehension, they don't affect the perception of it.*
> - ***It must be identifiable** - To influence the risk of apprehension, it must be seen as an enforcement unit. It cannot be mistaken for a disabled vehicle or simply someone parked by the roadside.*
> - ***It must be prepared** - The enforcement unit must look like it is prepared to enforce the law. A driver will not perceive the risk of apprehension if the vehicle is positioned where it cannot give chase or if the officer seems oblivious to passing vehicles.*
>
> (Shinar, McKnight and Jones, 1985)

While the last point mentioned above refers to traditional methods and not photo radar, it is argued here that photo radar has an extremely high perception of preparedness amongst motorists due to its mechanical and automated nature.

An important point mentioned by Shinar *et al. (1985)* compares the difference between the risk of apprehension and the severity of punishment. They state that there is extensive research that supports the effectiveness of risk of apprehension as a deterrence over severity of punishment. This research also shows that an increase in severity of punishment does not change behavior to as great a degree as increasing the risk of apprehension. This would support the acquisition of more photo radar units over an increase in fines. Shinar *et al. (1985)* discuss what the goal of such enforcement should be:

> *"However, the goal of enforcement, insofar as compliance strategies are concerned, is not to apprehend and fine but rather to use the threat of such to lead to compliance with the law. The benefits of increased compliance should be realized in a reduction of death, injury, and property damage resulting from accidents."*
>
> (Shinar, McKnight and Jones, 1985)

If the public were made aware of such goals through media campaigns, were educated to comprehend properly the risk that is associated with speeding and finally made aware of the increased risk of apprehension, then this information would work to increase the target level of risk as stated in Risk Homeostasis Theory.

5.3 Public Information

Many safety initiatives have been made public with exceptional results. Two such programs that illustrate the strength of grass roots support are the seatbelt programs and those that attempt to eliminate driving while impaired. As for the latter, groups spring up such as Mothers Against Drunk Drivers, or MADD, to lend community support to such initiatives. This form of support aids in promoting the safety initiative as one that protects the members of the community and lends a humanitarian image to the police force as they respond to the needs of the community.

Numerous studies have also indicated that advertising intervention campaigns raise public awareness of such issues and, if nothing else, increase their risk of apprehension (Summala, 1985). Calgary Police Services periodically make use of Selective Traffic Enforcement Programs, or STEP programs which entail intensive media saturation at the onset of the campaign. The media campaign is usually carried out in newspapers, radio and during television newscasts over a week before the program is put into effect. The coverage continues during the campaign and is usually concluded with some sort of summary as to the effectiveness of the campaign including how many citations were issued. Studies have stated that this type of enforcement, selective and in concert with high profile publicity, is the most effective in reducing speed (Rooijers and DeBruin, 1991):

> *"In the first place, it is always the combination of selective enforcement of speeding behavior and publicity that leads to the largest speed reduction,"*

In order to enhance further the effectiveness of photo radar, the Calgary Police Services post a daily bulletin in each of the two papers alerting motorists of some locations where photo radar will be in operation that day. This information is also disseminated through the various radio stations. Hopefully, the alerted motorist will adjust the speed to be in compliance with the posted limit during the journey instead of just when within visual proximity of the photo radar unit. This advertising also aids in increasing the general population's risk of apprehension.

5.4 Global and Societal Issues

The majority of the issues dealt with so far in this research are at the micro level but there are other approaches that may inform the topic. Drivers do not exist within a vacuum and are affected by prevailing social pressures and attitudes. Alternative philosophies within social geography seek to explain and understand how these issues impact the individual and how the individual manifests his or her internalization of these issues in their daily lives. Two such approaches will be considered here. These two schools of thought, structuration and postmodernism, are of very different backgrounds but each may contribute to the study of the phenomenon of why people speed. Both theories are based on different philosophical approaches, structuraction is bases on ontological ideas while post-modernism is developed on epistemological grounds. Neither philosophy will be dealt with in full as they are both complex and would require at least a chapter of their own. The purpose here is to illustrate that these macro level, alternative approaches allow us to approach the issue from a different point of view that may be equally valid and as important as what has already been presented.

5.4.1 Structuration

Structuration theory has developed from many years of work by Anthony Giddens, Professor of Sociology at Cambridge. It recognizes the economic dependence of Marxist doctrine and tries to ameliorate it by introducing humanist concepts of agency. Furthermore, other theorists working in this area, such as Allan Pred, have incorporated concepts of time geography. These three ideas can be brought together to present the following argument that aids in explaining stresses that might be brought to bear on the individual (Marxist concepts) and how the individual will attempt to cope with these pressures (agency and time geography) (Cloke, Philo and Sadler, 1991).

It is of common knowledge that workers are expected to work longer hours and have been given greater workloads. In conversations with managers from IBM, it was brought out that the average employee is expected to work 50 to 60 hours a week. How then might an individual attempt to cope with this additional pressure? Structuration allows the individual to be an agent that may respond in a variety of ways. One such way might be to change his or her attitude to the way in which the time spent traveling to and from work might be used. With the advent of inexpensive cellular phones, many are resorting to conducting business calls from their car, thus making use of time otherwise lost to productivity, but adding to the stress level of the driver and forcing the individual to process even more information. Concepts gleaned from time geography inform us that perhaps the individual may respond by attempting to adjust this time by driving faster, running yellow lights and other strategies to shorten the trip. This obviously leads to greater stress and increases the potential for collision occurrence.

Time geography combines the spatial patterns of an individual's daily actions as constrained by time. This imparts a three-dimensional aspect to studying the movements and daily routines of people. It would be a fruitful area of research to select random individuals and then track their movements over time, constructing long and short range time diagrams. Then the participants could be surveyed as to how they view the various patterns in their routine, soliciting such information as their perceptions of time involved in their trip-to-work for example and how they might adjust the time used. Other factors arise, such as the decision as to where to purchase homes in relation to other places in the city that are frequently visisted; schools, work, shops, etc. Cloke, Philo and Sadler explain the utility of such research in the following (1991):

> *"... but the chief importance of these diagrams and their associated vocabulary lies in their depiction of regularities in how individuals* ***repeatedly*** *draw upon - and in how different individuals* ***simltaneously*** *draw upon -* ***the resources of time and space."***

Giddens also points out how there is an interaction between rules and resources and how the everyday actions of social practices can impact and cause a reformulation of the rules. While this particular theory tends to be more global and overarching in concept, this historical perspective does have ties to that of the post-modernistic perspective.

5.4.2 Postmodernism

The approach of postmodernism includes a criticism of scientific method and a distrust of many of the principals that came out of the Enlightenment period. It speaks more of a fractured society in which global, universal concepts lose their meaning. Local, historical effects are more relevant, and this approach looks more at the individual's viewpoint rather than some form of agglomerated view. Postmodernism has been described as both *object* and *attitude* (Philo, Cloke and Sadler, 1991).

If the philosophy expressed here is a correct interpretation of current societal viewpoints then it may be argued that many drivers are losing their respect for overarching laws such as speed limits. There may be a breakdown in accepting such formal controls as traffic signals at intersections. If this is true, then we would see increasing amounts of violations both of speed infractions and drivers running yellow and red lights. As people begin to reinterpret such laws from their own perspective and background and incorporating an increasing skepticism as put forward in postmodernistic tenets, refuse to accept the authority of such controls.

The post-modernistic perspective draws upon the resources of local histories as a method of informing a topic. A fruitful area of research would be to chronicle the change of laws regarding moving violations and compare the accident statistics accordingly. The statistics would represent the societal responce to the change in formal controls. Conversely, the violations might be assessed as a precursor to the change in laws, as the laws would be viewed as a result of changing social interactions as expressed by driving habits. A comparison between cities along these lines would also be advantageous so that local conditions might be compared. These types of studies would expose any contagion effects as discussed earlier.

A survey or questionnaire can be used to ascertain the public's view towards overall risk involved in the task of driving. With the assistance of the police services records, responses could be compared against driving records in an attempt to correalate responses to actual driving habits.

This discussion illustrates the holistic nature of the problem researched here and how, if all areas are not explored fully, measures such as photo radar will ultimately face resistance and difficulty in achieving the success that might otherwise be experienced. Knowledge of societal concerns will be most effective when informing educational programs and their delivery. It will be necessary to monitor constantly societal and global concerns as they never remain static and policy must remain abreast of these issues. This will allow for greater acceptance by all drivers thus increasing the efficacy of intervention strategies.

5.5 Summary

By bringing together all the elements of quantitative and behavioral research an effective strategy has been designed for use by any municipal police force that will result in a decrease in traffic collisions. The more serious the collision, such as those resulting in injury or fatality, the greater the reduction in relative numbers. Most importantly, the GIS model described in this research will aid in tracking success and failure in order to design ever more effective intervention campaigns. With greater research and quantification of traffic flows and patterns the model could be used predictively. For example, if a new residential subdivision was to be planned, numbers derived from engineering origin and destination studies would allow the predicted traffic flow to be added to the existing data to indicate where stresses might occur in the road system. This could obviously be replicated in the case of planning a shopping mall or industrial area.

As automated systems are relatively new, there is a need for more research as outlined by Ostvik and Rune (1991):

> *"There is little knowledge about the effects of automatic devices in speed enforcement. Some ongoing studies do, however, address this problem. There is as far as these authors know no information on what strategies should be used when performing automatic surveillance. Research must also be conducted to find other areas of using automatic policing systems. The social acceptance of the use of such systems should be addressed in order to direct the innovation of such systems in the right direction. Long term effects of automated enforcement is not yet studied. It is a clear possibility that drivers will take the same calculated risk of being apprehended as we know from manual enforcement if automatic systems are only operated from time to time."*

Finally, macro level or global societal concerns were looked at in such a way as to illustrate how changing attitudes in society and changing societal pressures might affect the motivational concerns of the individual driver.

6.0 CONCLUSION

"What a piece of work is a man! How noble in reason!
how infinite in faculties! in form, and moving, how
express and admirable! in action, how like an angel!
in apprehension, how like a god! the beauty of the world!
the paragon of animals!"

Shakespeare, Hamlet

As Shakespeare so aptly illustrates in his own inimitable way, there is much to be optimistic about as the human being is indeed a remarkable creation. In traffic safety, it is ultimately the driver who makes the decisions that will result in a collision, either through error induced through the physical environment such as ice, or cognitive error as in the driver believing that the vehicle can be operated at a high rate of speed safely. Engineers can and do minimize the physical difficulties and they also, with the aid of ergonomics and psychologists, may also modify the environment to make information processing easier and more intuitive. However, try as we may, if the driver wishes to be selective in what information to process or the driver incorrectly perceives this information, we are faced with a thorny problem.

We are fortunate that many dedicated people have studied these issues to great depth and have already brought to light a wide variety of problem solving techniques along with extensive insight into the nature of the way in which the driver operates. It is the bringing together of many of the results from these studies that has allowed this paper to finish on an optimistic note. As Sir Isaac Newton once stated, "I have seen far because I have stood on the shoulders of giants." This thesis, by utilizing prior research, has also stood on the shoulders of many and their work lends credence and substance to the present study.

The quantitative research that began this study allowed the construction of a dynamic model that can monitor our roadways and indicate where problem areas exist. The dynamic nature of this model lends itself to revisiting specific areas in order to measure the effect of intervention and the success of such strategies. Once built, the model becomes much easier to maintain and the more years of statistics that are entered, the more accurate the model becomes. The GIS model also presents us with graduated circles indicating the relative probability of collision occurrence at each intersection and the accompanying table may be queried to determine actual values. This information would be important for prioritization of intervention strategies.

Finally, the quantitative work has enabled the present research to establish a link between speeding and the probability of collision and add the significance of rigorous statistical testing to lend credence to the findings. This point is extremely important as previous studies did not establish this link strongly and it is the underpinning idea behind intervention of any kind, whether photo radar or more conventional methods. It also allows the claim to be made that these strategies will not only be effective at reducing speeds but that this will reduce collisions and by extension, injuries and fatalities.

As this research progresses, we are drawn into the world of ergonomics and how to improve environmental conditions in order to make the driving task easier. While these aid the driver in information processing, other models suggest that in time these improvements do not aid in decreasing the accident rate. Even engineering designs that improve the safety of the automobile do not reduce overall collision rates, although it is argued here that they would decrease the fatality rate and lower the amount of serious injuries. Accident statistics are difficult to interpret, especially those involving injury, as over time the population has become more litigious and soft tissue injuries have increased in their diagnoses. This has resulted in an increase of injuries more than the increase attributable to actual increase in serious collisions.

Logically, this research progresses to behavioral research that mainly has been the province of psychologists. This work proves to be the most fruitful as it drives to the heart of the problem, the cognitive and perceptual skills of the motorist. By exploring this topic we enter into the area that represents the *why* of the problem. What motivates the drivers to do what they do. After all, if speeding leads to collision, injury or death, what more motivation should someone need? However, this is not the public's perception and other motivating factors tend to override these concerns. Culminating in the Risk Homeostasis Theory, the present research has provided meaningful insight. Risk Homeostasis Theory encompasses many of the above concerns and packages them into a model that might be used in a predictive fashion.

Bringing all this work together, as was done in chapter 5, shows how we can assist the police services by giving them methods of improving their intervention strategies and by making better use of existing data sources. The data has been scrutinized and errors and problem areas identified which will make continued use of these methods easier. Practical solutions have been derived and can now be put into operation.

That this research is finished at the same time that political debate is rising over the use of photo radar is fortuitous. We can only hope that the government will use wisdom and will not simply be guided by the popularity concerns when making a decision whether to continue with the use of photo radar. It would be a sad day for all if that were the case. The need for future research is clear, and if nothing else, this paper is a testament as to how much still requires to be done. More detailed studies similar to that done by the Ontario government should be performed to lend credence to the present research. These studies should proceed over a larger time span, perhaps five years are needed for the study of fatalities and injuries. This would allow for the inclusion of enough information to give increased statistical significance to the numbers.

Temporal aspects should also be considered. The traffic flows in this study are aggregated to a high degree. These flows should be broken out to account for seasonal fluctuations and they should also be broken out in order to understand diurnal patterns in greater detail. It is considered that the accident rate during the two rush hours is actually low due to traffic densities acting as a self limiting or dampening factor. If this is true, then other time frames could be extremely hazardous. Combining this knowledge with the locational information presented in this report would further increase the efficacy of photo radar intervention. By placing all this information within a GIS a deployment schedule might be determined for photo radar resources. Number of units and time frames to be used can be included in the model and a location allocation model of sorts would prepare a deployment schedule for the police services that would utilize resources where and when they can be most effective in reducing collisions.

The two years spent immersed in researching this thesis has led to one factor presenting itself over and over. It is a factor that we must never lose sight of, that of human suffering and death. We can never fully eradicate this horror, but even if one life is saved, or fewer injuries occur it is a work well done. At a more mundane level, it is appropriate to quote from the province of Ontario's report:

> *"In Ontario, 228,834 motor vehicle collisions occurred in 1993. There were 1,135 people killed and 91,174 people injured. It is estimated that the total societal cost of collisions is approximately 9 billion dollars annually for property damage, emergency services, health care and lost wages, and the human consequences of crashes."*
>
> (Safety Research Office 1995)

When we also see that this toll is exacted on the youngest and hence most productive or most potentially productive portion of our population then we must agree that the cost of traveling at a faster rate is one that is much too high. This thesis has shown how we can all work together to bring this cost down.

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