

**AN EVALUATION OF CRASH RISK AMONG OLDER
DRIVERS WITH RESTRICTED LICENSES IN BRITISH
COLUMBIA**

by

Glenyth Nasvadi

B.Sc. (Honours), York University, 1977

THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARTS

In the Department of Gerontology

©Glenyth Nasvadi, 2007

SIMON FRASER UNIVERSITY

Fall, 2007

All rights reserved. This work may not be reproduced
in whole or in part, by photocopy or other means, with
out permission of the author.

APPROVAL

Name: Glenyth Nasvadi
Degree: Master of Arts (Gerontology)
Title of Thesis: An Evaluation of Crash Risk Among Older Drivers with Restricted Licenses in BC

Examining Committee:

Chair: Charmaine Spencer
Adjunct Professor, Gerontology, SFU

Andrew V. Wister
Senior Supervisor
Professor and Chair, Gerontology, SFU

Dr. Habib Chaudhury
Supervisor
Assistant Professor, Gerontology, SFU

Dr. Barbara Mitchell
Supervisor
Associate Professor, Gerontology, SFU

Dr. Anthony Perl
External Examiner
Professor, Urban Studies and Political Science, SFU

Date Defended: Dec 19, 2007



SIMON FRASER UNIVERSITY
LIBRARY

Declaration of Partial Copyright Licence

The author, whose copyright is declared on the title page of this work, has granted to Simon Fraser University the right to lend this thesis, project or extended essay to users of the Simon Fraser University Library, and to make partial or single copies only for such users or in response to a request from the library of any other university, or other educational institution, on its own behalf or for one of its users.

The author has further granted permission to Simon Fraser University to keep or make a digital copy for use in its circulating collection (currently available to the public at the "Institutional Repository" link of the SFU Library website <www.lib.sfu.ca> at: <<http://ir.lib.sfu.ca/handle/1892/112>>) and, without changing the content, to translate the thesis/project or extended essays, if technically possible, to any medium or format for the purpose of preservation of the digital work.

The author has further agreed that permission for multiple copying of this work for scholarly purposes may be granted by either the author or the Dean of Graduate Studies.

It is understood that copying or publication of this work for financial gain shall not be allowed without the author's written permission.

Permission for public performance, or limited permission for private scholarly use, of any multimedia materials forming part of this work, may have been granted by the author. This information may be found on the separately catalogued multimedia material and in the signed Partial Copyright Licence.

While licensing SFU to permit the above uses, the author retains copyright in the thesis, project or extended essays, including the right to change the work for subsequent purposes, including editing and publishing the work in whole or in part, and licensing other parties, as the author may desire.

The original Partial Copyright Licence attesting to these terms, and signed by this author, may be found in the original bound copy of this work, retained in the Simon Fraser University Archive.

Simon Fraser University Library
Burnaby, BC, Canada

ABSTRACT

Aging is associated with declines that affect driving ability, but loss of a driver's license has negative impacts on the well-being of older adults. In keeping with Person-Environment Fit Models, restricted licenses are sometimes used to allow continued driving under conditions that do not exceed abilities. This cohort study of older drivers used provincial insurance claims data to compare crashes caused by drivers with restricted versus unrestricted licenses. Restricted drivers were more likely to be male, older, and involved in prior at-fault crashes. Results demonstrated that restricted drivers caused more crashes before restrictions than after the restrictions were applied. Cox survival analysis also revealed that restricted drivers continued to drive crash-free for longer compared to unrestricted drivers, and their risk of causing a crash was 87% that of the unrestricted drivers. These findings have important implications for driver licensing policies, and for the health and well-being of an aging population.

Keywords: restricted license; older driver crashes; de-licensing; driving cessation

Subject Terms: driving; aging drivers; driver licensing

DEDICATION

For Alyssa and Blair, my source of inspiration to always do my best. And in memory of my father Nicholas Caragata, who was deeply attached to his car as his source of pride, enjoyment, friendship, and comfort, especially in his final years.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to my Senior Supervisor, Dr. Andrew Wister, for his patience, support, and guidance with this thesis, and to my Thesis Committee Supervisors, Dr. Habib Chaudhry and Dr. Barbara Mitchell, for their very valuable suggestions for improving the study and this manuscript.

Special thanks to my dearest friends Bruce and Debra, who continue to believe in me even more than I believe in myself, and who encouraged me through this entire process.

Thanks also to the Insurance Corporation of British Columbia, and especially to Peter Cooper, John Vavrik, and Linda Andersen for their support in conducting this research.

TABLE OF CONTENTS

Approval	ii
Abstract	iii
Dedication	iv
Acknowledgements	v
Table of Contents	vi
List of Figures	viii
List of Tables	ix
Chapter 1: INTRODUCTION	1
Purpose of this Study.....	1
Research Questions	2
Phase I – Driving Competence of Restricted License Holders	3
Phase II – Crash Reduction of Restricted License Holders.....	4
Phase III – Prolonging the Driving Life of the Elderly	5
Phase IV – Severity of Collisions	6
Scope	7
Importance of this Study	7
Chapter 2: BACKGROUND LITERATURE REVIEW	10
Aging of the Driving Population	10
Physiological Declines of Aging	11
Complex Driving Environments and Aging	22
Self-Regulation	25
Use of Restricted Licensing	26
Impacts of Restricted Licenses	27
Theoretical Framework	33
Application of the P-E Fit Model to Driving	37
Applications of the P-E Fit Model to Restricted Licensing	39
Hypotheses.....	40
Phase I: Driving Competence of Restricted License Holders	41
Phase II: Crash Reduction of Restricted Licenses	42
Phase III: Safe Driving Life Expectancy	43
Phase IV: Crash Severity	43
Chapter 3: METHODS	45
Experimental Design.....	45

Data Source	46
Data Collection.....	47
Analysis	49
Chapter 4: RESULTS	69
British Columbia Older Drivers.....	69
PHASE I	73
Phase II	77
Phase III	81
Phase IV	92
Chapter 5: DISCUSSION.....	94
Chapter 6: CONCLUSIONS.....	110
Policy Implications	113
Future Work.....	115
REFERENCES	118
Appendix – Parametric Survival Analysis	129

LIST OF FIGURES

Figure 1. Number of crashes per mile travelled, 2001-2002	11
Figure 2. Lawton's Ecological Model.....	36
Figure 3. LML plots for proportional hazards	60
Figure 4. Boxplots of time-to-event for restricted versus unrestricted drivers.	62
Figure 5. LML plots for type of license	63
Figure 6. LML plots for gender.....	64
Figure 7. LML plots for age groups	65
Figure 8. Age distribution of restricted license holders.....	69
Figure 9. Survival function plot from KM analysis	84
Figure 10. Survival function plot for unadjusted Cox PH regression	86
Figure 11. Hazard function plot for unadjusted Cox PH regression	87
Figure 12. Survival function plot for adjusted Cox PH regression	89
Figure 13. Hazard function plot for adjusted Cox PH regression	90
Figure 14. Negative Log-survivor plot for exponential test.....	131
Figure 15. LML plot for Weibull test	132

CHAPTER 1: INTRODUCTION

Over the past several decades, use of the personal automobile has become firmly entrenched in the culture of North Americans. Large distances between services, suburban sprawl, and limited public transportation networks have made the private vehicle the most practical form of transportation for most Canadians. In addition, the ability to own and operate a motor vehicle has become a symbol of social status and of competence, since ownership of a vehicle requires financial resources, and operation of a vehicle necessitates both physical and mental competence.

Use of the private vehicle is particularly critical for individuals with physical limitations that make other forms of transport less comfortable and less accessible. As people age, they typically experience physical declines which makes them more dependent on their cars for their transportation needs. However, driving is a complex task. The physical and cognitive declines associated with aging may therefore threaten the abilities of older drivers to safely operate a vehicle, especially during high-demand situations such as heavy traffic, bad weather, poor road conditions, and long distances.

Purpose of this Study

The primary purpose of this study is to examine the effect of restricted licenses on the crashes of older drivers. The policy of placing restrictions on driver's licenses has been used in some jurisdictions in an attempt to reduce the demands of the driving task, thereby allowing older drivers to continue to use

their vehicles in a safe manner. However, the use of this policy is controversial. Many older drivers argue that they should be allowed to continue driving in situations appropriate to their level of physical and mental abilities by avoiding situations that are too challenging for them. Opponents argue that the demands of driving are too unpredictable to guarantee that the senior will not encounter a situation that is too challenging, and that permitting older drivers to continue driving, who cannot safely operate a vehicle under all conditions, will result in increased risk to others on the roads.

Person-Environment fit theories state that, since the complexity of the road environment varies considerably, the demands of driving also vary such that a highly complex driving environment will demand greater resources from the individual than a less complex environment. It is assumed that restricted licenses are successful in allowing an individual to drive safely under some conditions (e.g. within a restricted radius) by controlling the complexity of the environment and thus the demands of the driving task. However this assumption has not previously been empirically proven. The purpose of this study is to provide quantitative evidence on the crash risk of older drivers who hold restricted licenses. Results are discussed within the context of Person-Environment Fit theory.

Research Questions

The main research question addressed in this study is whether or not the use of restricted licenses for older drivers in British Columbia results in a change in the number and characteristics of crashes involving these drivers. Whereas

supporters of restricted licenses believe crashes will remain the same or even decline because drivers will be exposed to fewer hazards, opponents believe crashes will increase because it will permit those who would otherwise be unable to renew their license to continue driving.

In studying the crashes of elderly drivers with restricted licenses, several questions will be addressed, specifically:

1. Do older drivers who are issued restricted licenses have lower levels of driving skill than those who are not restricted?
2. Are restricted licenses successful in reducing the number of crashes for at-risk seniors?
3. Do restricted licenses help prolong the crash-free driving of aging adults?
4. Do restricted licenses reduce the severity of collisions involving seniors?

A brief discussion of the importance of each of these questions follows.

Phase I – Driving Competence of Restricted License Holders

In examining the effectiveness of restricted licenses for reducing crash risk, it may be tempting to simply compare the crash rates of drivers with restricted licenses to those with unrestricted licenses. However, studies have demonstrated that involvement in one collision increases the likelihood of subsequent crashes (Daigenault, Joly & Frigon, 2002), so that direct comparisons between groups of drivers may be misleading if prior crash involvement is not known. The elevated risk of crash-involved drivers occurs in part because different driving styles and skill levels render certain drivers more susceptible to specific types of crashes (De Raedt & Ponjaert-Kristoffersen, 2000). Involvement in a collision may thus signal the existence of a risk-related driving style or behavior.

Restricted licenses are issued to older drivers when the licensing authority believes a driver is safe to drive in some situations but not in others. Such conclusions arise from the licensing authority's identification of a physical and/or mental limitation in the individual. Because of their limitation, it is likely that at least some of these drivers have been involved in prior crashes, and it follows that subsequent crashes would be expected if they continued to drive. Simply comparing the crash rates of restricted to unrestricted drivers would therefore result in significant error since older drivers with limitations would be expected to have a higher crash risk than healthy individuals driving under the same circumstances. The first phase of this study addresses this issue by examining the crash rates of older drivers prior to having restrictions imposed on their licenses to determine if those with restricted licenses have higher predicted crash rates. This is important because, although the restriction may not reduce the crash risk to zero, it may result in a significant decrease.

Phase II – Crash Reduction of Restricted License Holders

The second question addressed in this study is, for each individual driver with a restricted license, is the driving restriction successful in decreasing the number of crashes caused by that individual. The answer to this question represents a key area of knowledge for those involved with older drivers, including health care practitioners, licensing agencies, policy makers, and relatives and friends of the driver, as well as other drivers and pedestrians within the driver's community. Examining crash rates of drivers before and after restrictions are imposed will address this question. However, an important consideration in examining the change in crash rates of restricted drivers is the positive correlation between age and increasing risk of crash, especially for

drivers over age 70 years (Lyman, Ferguson, Braver, & Williams, 2002). This problem will be addressed by comparing the change in crashes of older drivers who are driving under restrictions, to the change in crashes for those who have no restrictions. This provides a reference point to assess patterns of crash rate change in the restricted group.

Phase III – Prolonging the Driving Life of the Elderly

Since aging is ultimately accompanied by declines in functional ability over time, the individual's ability to operate a private vehicle gradually diminishes. A third consideration in this study is whether or not driving restrictions can be used to mitigate the effects of such declines and extend the safe driving life expectancy of the elder. For older drivers and their caregivers, this is a critical question. Although the loss of a driver's license is psychologically catastrophic for many elders and may lead to isolation and depression (Fonda, Wallace, & Herzog, 2001), continued licensure should not be allowed at the expense of increased risk to the older driver or to the community in which they drive. To address this issue, the third phase of this study will examine the length of crash-free driving for older drivers after a restriction is placed on their license.

Most drivers who have unrestricted licenses have not been referred for a driving re-evaluation, so it is likely that this group do not have health concerns significant enough to affect their driving. Therefore in this phase of the study, only older drivers who were recalled for a road test will be examined, since these drivers are more likely to have demonstrated physical and/or cognitive declines. By comparing the crashes of older drivers recalled for testing and subsequently issued restricted versus unrestricted licenses, it will be determined whether or not

restricted licenses delay the involvement in collisions in a group known to have declining skills.

Phase IV – Severity of Collisions

Statistics show that crashes caused by senior drivers are more likely to involve multiple vehicles and to result in death than crashes caused by younger drivers (Lyman, Ferguson, Braver, & Williams, 2002). Publication and distribution of these statistics, especially the U-shaped curve showing fatal crash involvement by age (Figure 1), has raised alarm among road safety administrators and among members of the general public. Researchers have noted that “frailty bias” is a substantial contributor in these statistics. Because older people are more easily injured from physical impact, they are more likely to die in collisions (Hakamies-Blomqvist, Siren, & Davidse, 2004). In fact some researchers have concluded that older drivers are a serious threat primarily only to themselves, and that they do not increase the risk to other road users (Insurance Institute for Highway Safety, 2001). Furthermore, these statistics include all elderly drivers and do not differentiate between those who drive in all situations and those who restrict their driving. The high mortality/severity of crashes among older drivers may therefore reflect primarily a group of frail elders with declining skills who continue to drive in situations that are too demanding for their abilities.

An important question in examining the effects of restricted licensing is whether restrictions affect the severity of crashes involving the elderly, and whether older drivers are at higher risk of injury to themselves and others. The fourth phase of this study will compare crashes involving restricted and

unrestricted drivers by examining the number of vehicles involved, the number of injuries and fatalities, and the value of material damage in each collision.

Scope

Three types of restricted licenses were addressed in this study:

- maximum speed allowed
- driving within a specified geographical region only
- driving during daylight hours only.

These types of restrictions were chosen because they are most likely to be used with aging drivers and represent restrictions due to the effects of aging, such as slowed reflexes and declining vision, rather than the effects of permanent disabilities such as amputations or hemiplegia acquired at younger ages.

Importance of this Study

Compared to younger drivers, older drivers are involved in more multiple-vehicle crashes and are more likely to be legally at fault for the collisions (Hakamies-Blomqvist et al., 2004). As the number of older drivers increases over the next few decades, this could have significant impacts on the safety of others using the roadways. Licensing agencies are challenged to identify those who are likely to pose less risk, and those who are likely to endanger others. Currently it is assumed that restricted licenses do not significantly increase the crash risk of elderly drivers, but there has been little evidence to support or refute this assumption. Results of this study may therefore have significant implications for policies regarding the issuing of restricted licenses to elderly drivers in British Columbia and in other jurisdictions. If restricted licenses are found to increase the crash risk of older drivers, licensing authorities may discontinue their use with

the result that more older drivers will lose their driver's license. Conversely if restricted licenses are found to be beneficial in mitigating the crash risk of elders, regulators should continue this policy and consider more wide-spread use, with the result that a greater proportion of older drivers will retain their driver's license for longer.

Potential influences of the results of this study on the licensing policies of regulators may in turn have important consequences for the psychological health and well-being of our aging population. The negative effects of driving cessation are greatest among elderly who have been forced to surrender their license, often resulting in social isolation and worsening depressive symptoms (Fonda et al., 2001). This is frequently followed by physical declines and increased health care costs, especially among those who live alone and are forced to move into long-term care facilities (Freeman, Gange, Munoz, & West, 2006). If restricted licenses are not endorsed, more drivers will face an abrupt end to their driving life and an increase in social isolation and depressive symptoms among a greater proportion of our elderly may be noted.

Results of this study may also have profound effects on the friends, family and caregivers of the elderly. Since ability to access services such as medical appointments and grocery shopping is essential, others become obliged to assume a caregiver role when the older individual loses their independent transportation. In some instances, relatives or others may be inadequately equipped to suddenly assume this role, resulting in increased burden and stress affecting other family members and workplaces.

Taylor and Tripodes (2001) found that most older drivers who lost their license because of dementia depended heavily upon family members to provide

transportation. Among caregivers, 42% had to miss work frequently or occasionally to provide transportation and 13% had to give up work entirely. In another study, 45% of family members reported a moderate to severe increase in their workload after their relative was advised to cease driving (Azad, Byszewski, Amos, & Molnar, 2002). Formal transportation support systems are rarely used by former drivers because they are considered to be less safe and less convenient (Talbot et al., 2005).

Finally, results of this study have significance for the physical health of both the older population, and for the community at large. Through examination of driving records it will be determined whether or not older drivers who were allowed to continue driving under restricted conditions cause more collisions and injuries to themselves, as well as to others in the community.

CHAPTER 2: BACKGROUND LITERATURE REVIEW

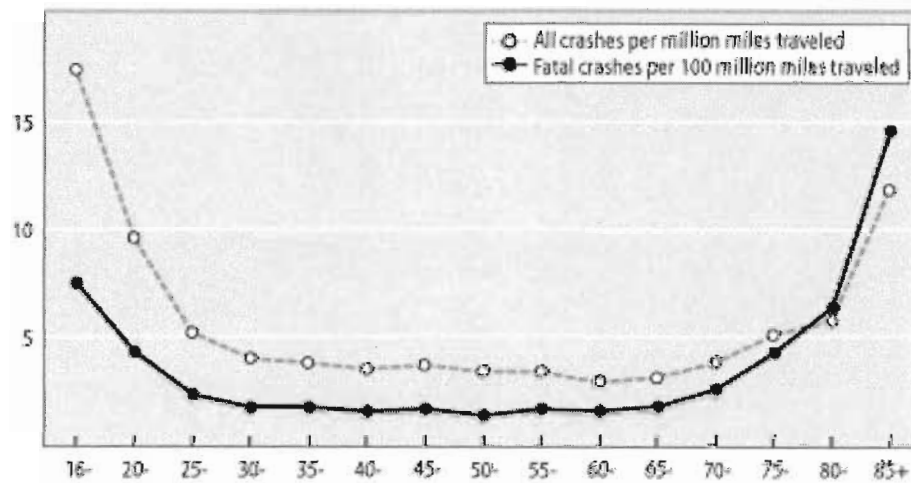
Aging of the Driving Population

In British Columbia, older adults make up an increasing proportion of the driving population. In 1920, older drivers aged 65 and older represented 5% of the population. Today, they represent 12.5%, and by mid-century they are expected to double that proportion (Statistics Canada, 1997). By 2010, it is projected that there will be 668,500 people over age 65 in BC, and 192,300 over age 80 (Statistics Canada, 2001). As the baby boom generation ages, older drivers are also expected to drive more kilometers per year than past generations. It has been conservatively estimated that between 1990 and 2020, the total annual kilometers driven will increase by 465% for elderly men and almost 500% for elderly women (Burkhart, Berger, Creedon, & McGavock, 1998). Baby boomers are also expected to continue driving to an older age than previous cohorts. In fact, the number of drivers over age 75, and especially those over age 85 is increasing more dramatically than the younger age categories (Griffin, 2004). Suburban sprawl, rising affluence, and inadequate public transit has resulted in a rate of increase in private vehicles six times the rate of population increase, reflecting the ubiquitous use of vehicles among household individuals (McGuckin & Liss, 2005). Today there are 255,000 older drivers age 70 and older in BC who are actively driving (ICBC, unpublished data).

Crash statistics show that as people age beyond age 65, their crash rate per kilometer increases. By age 75 they are involved in as many crashes per

kilometer driven as 16 year olds (Figure 1) (Insurance Institute for Highway Safety, 2003). Older drivers themselves are most at risk of injury or death during motor vehicle crashes, necessitating the development of strategies to protect them from disability and premature death from their own road collisions.

Figure 1. Number of crashes per mile travelled, 2001-2002



Physiological Declines of Aging

Physiologic changes occur with aging that affect the driving of older adults. Benekohal, Resende, Shim, Michaels, and Weeks (1992) surveyed 664 senior drivers about their driving difficulties. Reading street signs, negotiating intersections, finding the appropriate lane, following pavement markings, and responding to traffic signals were the main problems cited by older drivers. They stated that intersections with too many islands were confusing, and raised curbs that were unpainted were difficult to see. Since they experienced difficulty judging distances and gap, the elders expressed a clear preference for a left turn

protected arrow phase, and rumble strips to warn of upcoming medians, signals, and lane boundaries.

Since about the 1970s, researchers have studied how declines associated with aging impact the driving skills of older adults. Although earlier studies on fitness to drive took primarily a disease-based approach, focusing on the effects of medical conditions such as diabetes, epilepsy, and cardiovascular events on driving, more recent studies have looked at how individual factors of disease and the 'normal' aging process affect driving skills. A significant body of literature now exists on topics such as visual processing, divided attention, cognitive processing speed, peripheral nerve conduction, and muscular strength. Although a detailed discussion of these topics is beyond the scope of this study, a brief presentation of some key issues that are particularly relevant to this thesis is presented.

Vision

Driving has been described as primarily a visual task. In general, the visual performance of drivers begins to progressively decline after the age of about 45 years. In the US, the prevalence of visual acuity less than 20/40 is about 3% in the total population, and these impairments are caused primarily by cataracts (35.8%), age-related macular degeneration (14.2%), diabetic retinopathy (6.6%), glaucoma (4.7%), and other retinal disorders (7.3%) (Rahmani et al., 1996). The prevalence of eye diseases increases significantly with age. Among adults age 65-74 years, slightly more than half (58%) have age related macular degeneration, and this increases to 84% of adults age 85 years

and older. In addition, 37% of men and 40% of women age 65 years and older have a secondary diagnosis, especially cataracts (57%), and glaucoma (13%) (Elliott et al., 1997).

Visual defects that may affect driving include reduced static and dynamic visual acuity, reduced visual field including blind spots (scotoma), reduced contrast sensitivity, slowed accommodation reflexes (shifting from near to far vision), increased glare sensitivity and recovery from glare, and reduced visual field sensitivity (peripheral vision). The pupil of an 80-year-old allows only about two-thirds of the light allowed by the pupil of a 25-year-old, and adults over age 85 can take up to 2.5 minutes to recover from glare compared to less than 10 seconds for young adults. Presence of central scotoma is highly prevalent in macular degeneration, and reduced contrast sensitivity and acuity is particularly relevant for individuals with cataracts.

Although visual acuity in itself is not well correlated with crashes, it has been suggested that it is predictive of driving errors when combined with the slowed reflexes of aging and higher speeds of travel (Fonda, 1989). Even among elders with relatively well-preserved visual acuity under high light conditions, there is a marked decline in acuity under low light conditions, acuity in glare, depth perception, and glare recovery (West et al., 2002). Low performance on tests of contrast sensitivity have been highly correlated with driving performance (Wood & Troutbeck, 1995) and self-reported difficulties in both daytime and night driving (Rubin, Roche, Prasada-Rao, & Fried, 1994), and results of glare

sensitivity and glare recovery studies have shown correlations with on-road accidents (Brabyn, Schneck, Haegerstrom-Portnoy, & Steinman, 1994).

The influence of visual field defects on driving varies, depending on the nature of the defect. Johnson and Keltner (1983) found that drivers who had field loss deficits in one eye had accident and moving violation rates equal to a control group, but drivers with binocular field losses had crash and violation rates double those of the controls. Drivers with glaucoma that have significant visual field defects and have been shown to be 3.6 times more likely to be involved in crashes, while those with cataracts have 2.5 times more crashes than controls (Wood, 2002).

The influence of vision on driving depends on much more than visual performance. It involves factors such as visual perception, the ability to handle multiple data inputs, interpretation, and decision making that occurs in a dynamic rather than a static environment. Latency time to initiation of eye movement toward a location increases with age, and the speed of eye movement declines, so that visual search for targets is delayed (Kaneko, Kuba, Sakata, & Kuchinomachi, 2004). Although O'Neill et al. (1992) reported that a test of visuospatial *ability* did not discriminate impaired versus non-impaired driving among mildly demented drivers, Fitten et al. (1995) found that a visual *tracking* test was highly correlated with on-road performance. Older individuals demonstrate poorer visual search skills by allocating a larger percentage of their visual scanning time to a small area, and by revisiting the same areas during

their visual searches, indicating decrements in processing visual information (Maltz & Shinar, 1999).

Ability to attend to the salient features of the environment is also critical while driving. Over the past two decades, significant research has been done using the UFOV (Useful Field of View) test, a computer-based test where both central and peripheral stimuli are presented simultaneously (Ball & Owsley, 1993). The foundation of the test is that if the “attentional window” of drivers is small, they cannot adequately divide their attention between central and peripheral tasks, and the probability of accident involvement increases. Richardson & Marottoli (2003) showed that declines in visual attention had a significant effect on 25 driving items including scanning the environment, interaction with traffic and pedestrians, yielding right of way, responding to other vehicles, proper lane selection, steering recovery, making intersection turns, monitoring speed, and judging distances. Also, as the road environment becomes more cluttered with signage, traffic, pedestrians, and signals, older drivers take longer to search out, recognize, and respond to targets (Ho, Scialfa, Caird, & Graw, 2001). Ability to perceive and respond to multiple targets in a wide visual area has been shown to be one of the strongest predictors of crashes among older adults. In a study of 294 drivers age 55-90 years, the correlation coefficient between UFOV and prior crashes over a previous 5-year period was 0.52, while in the prospective study of the same group of drivers, the correlation with future crashes was 0.46 (Ball & Owsley, 1994). Other studies have

demonstrated that older drivers with 40% or more reduction in UFOV were 2.2 times more likely to have a crash compared with controls (Owsley et al., 1998).

Cognition

Early research with older adults consistently found age-related declines in verbal and performance intelligence beginning at about age 60, including declines in verbal meaning, spatial orientation, inductive reasoning, number manipulations, and word fluency. Evidence of such declines supported the generally held notion that cognitive decline is an inevitable consequence of aging. However, researchers now accept the model that intelligence is the product of two distinct types of skills, known as fluid intelligence and crystallized intelligence, each of which decline at different rates. Fluid intelligence refers to the capacity to process novel information where little or no prior knowledge is held, and it is involved in creative processes, identifying relationships, and drawing inferences. Crystallized intelligence, on the other hand, is based on the accumulation of information, skills, and strategies throughout the lifespan. Schaie (1996) demonstrated that patterns of decline vary by type of intelligence, by individual, and even between cohorts. As people age, declines in areas associated with fluid intelligence may occur with little or no decline in crystallized intelligence, and in fact, increases in crystallized intelligence may even be noted. Since crystallized intelligence increases with repeated experience and practise, for example in areas such as eating, playing a sport, or operating a vehicle, it becomes less susceptible to degradation, especially for those skills that are attained early in life. This has been verified by neuroimaging studies that

demonstrate prefrontal cortical activity is reduced in aging adults for tasks relying on controlled processes, but not for tasks relying on automatic processes (Anderson et al., 2000).

Beginning about age 50, neurons in the hippocampus of the brain are lost at a rate of about two percent per year. This area of the brain is involved in short-term memory, with the result that older people have greater difficulty storing and retrieving material. Substantial age differences appear when older adults are asked to manipulate information in short-term memory tasks, and although they can retrieve as many items from short-term memory as younger people, it takes them longer to do so (Quadagno, 2002, p. 188). Visual spatial processing also occurs in the hippocampus and therefore suffers age-related declines. Within the driving environment, short-term memory declines are relevant to tasks such as safe lane changes and way-finding, and visual spatial declines are particularly relevant to tasks such as lane adherence and parking.

Declines in prefrontal cortex activity that occurs with aging affect the ability to divide attention between tasks. Several studies have found that during a complex attention-demanding memory task, activity in the inferior left prefrontal cortex areas is reduced in older adults. Anderson et al. (2000) found that when subjects were required to divide their attention between a memory task and an auditory-motor response task, older adult performance was significantly reduced for memory encoding. For both young and older adults, addition of a secondary task also reduced performance on the accuracy, speed and eye movement involvement in visual search tasks, and the effect was increased with increasing

age. Similarly, McPhee, Scialfa, Dennis, Ho, and Caird (2004) found that compared to young drivers, older drivers were less accurate in searching for targets, slower to decide that a target sign was not present, and slower to react to the target when engaged in conversation.

The frontal lobes of the brain control “executive functions”, processes that activate, integrate, and manage other brain functions. These areas of the brain are most vulnerable to injury such as in car crashes, and to diseases such as Alzheimer’s. Beginning from age 45, substantial age-related changes can be seen in the size of neurons and blood flow in this area, and it is widely accepted that the frontal lobes of the brain show specific effects of aging earlier and more severely than other brain areas. Executive functions include working memory and recall, activation and decision-making, arousal and effort, response control, and complex problem solving including planning. However there is evidence that subregions within the frontal lobes are specialized for different types of function. Whereas dorsolateral frontal areas are largely involved in tasks of working memory, ventromedial areas are involved in social behaviour and goal weighting. It is the former areas that show accelerated deterioration with aging, followed much later by declines in the latter (Garden, Phillips & MacPherson, 2001). Results of the early declines in dorsolateral regions of the brain can be seen in older driver’s changes in tasks that require planning, paying attention, and responding, for example way-finding, proper lane selection, responding to traffic signals, and brake reaction time (Richardson and Marattoli, 2003), although such

behavioural changes are not likely to be manifested before about age 70 despite the physiological changes (Garden et al., 2001).

Identifying cognitive declines and classifying levels of decline have been an ongoing challenge for researchers and practitioners. Especially in areas such as driving, ability to recognize cognitive changes that are relevant to the task becomes critical in making decisions about who should and should not be driving. Although it is easy to make decisions for a diagnosis of moderate or severe dementia, decisions involving less severe cognitive changes are more difficult, especially since with aging, the pattern of cognitive changes becomes more heterogeneous (Schonknecht, Pantel, Kruse, & Schroder, 2005). In the early 1990s, a working party of the International Psychogeriatric Association introduced the concept of aging-associated cognitive decline (AACD). In contrast to most other definitions of cognitive decline that focused only on amnesic memory impairment, the working group's definition included difficulties in five key areas: 1) memory and learning; 2) attention and concentration; 3) thinking (problem solving, abstraction) 4) language; and 5) visuospatial functioning (Levy, 1994). In a German study of adults aged 60-64 years, the prevalence of AACD was found to be 13.4% and increased to 23.6% within a 4-year follow-up period, indicating cognitive age-related declines are common, even among those younger than age 70. These age-associated declines can remain relatively stable over several years (Schonknecht et al., 2002).

Impairments that exceed age-related cognitive decline but do not fulfil the criteria for dementia are referred to as mild cognitive impairments (MCI), and

have received substantial attention in recent driving literature, especially since about half of amnesic and one-quarter of nonamnesic cases convert to dementia within a few years (Fischer et al., 2007). Generally, a diagnosis of MCI does not immediately preclude an older adult from driving, but does signal a need to carefully manage the demands of the driving task. The more serious diagnosis of dementia affects 5-8% of all those over age 65 and a third of those age 85 or older (Evans, Funkenstein & Albert, 1989), and does signal the end of driving. Alzheimer's disease, the most common form of dementia, involves an overall shrinkage of brain tissue. In the early stages of the disease, short-term memory begins to decline when the cells in the hippocampus degenerate. These earlier changes may manifest themselves in driving as difficulties navigating unfamiliar areas, responding to road signs, and interpreting road cues. The ability to perform routine, practiced tasks later begins to decline, and is demonstrated in forgetting how to turn on the windshield wipers or how to start the car. As the disease spreads through the cerebral cortex, judgment is degraded, for example deciding to drive up a one-way street the wrong way because it is a shorter distance. Emotional outbursts may occur, for example in response to protests from passengers, and language eventually becomes impaired. The average length of time from diagnosis to death is 4-8 years, although it can take 20 years or more for the disease to run its course.

Physical

Aging is often associated with an accumulation of chronic diseases, such as arthritis and osteoporosis, which affect body positioning and physical

movement in a vehicle. But although older drivers report they have difficulties with physical movements in driving such as inability to turn the neck to perform adequate visual checks, or difficulties getting into and out of a vehicle (Herriotts, 2005; Cranney et al., 2005), most difficulties can be overcome by simple modifications to the vehicle (Jones, McCann & Lassere, 1991). On the other hand, diseases such as diabetes that result in peripheral nerve damage and slow motor conduction velocities, have been shown to increase the risk of collision by as much as a three-fold (Sagberg, 2006).

Neuronal changes in the brains of older adults result in increased effort needed to perform both physical and mental tasks. There are many studies that have demonstrated the increased mental workload that accompanies aging, but one simple example may be sufficient to demonstrate this effect. Voelcker-Rehage and Alberts (2007) compared the performance of younger (mean age 22) and older (mean age 71) adults in a dual-task study. Participants used a precision grip instrument to match their grip force to a target force line displayed on a screen, while simultaneously performing a cognitive (*n*-back) task. Even after a prolonged practice session where performance was improved for single tasks executed alone, the performance of the older adults deteriorated under dual-task conditions while that of the younger adults did not. Furthermore, when participants encountered an error in their cognitive task, there was significantly greater variability in their motor tracking of the target for older adults, while the motor tracking of younger adults remained smooth. Although this was a laboratory experiment, it demonstrates how motor movements such as braking

and steering in older drivers may require an increasing amount of cognitive resources, control, and supervision. Increased demands for processing complex visual, auditory, and tactile stimuli can thus erode motor responses, since the individual must divide attention between the two tasks.

With the cognitive changes that accompany aging, it is easy to understand how some elderly adults may react inappropriately, for example by over-steering or by compressing the brake instead of the gas, when confronted with demanding cognitive processing tasks such as visual clutter or unexpected presence of hazards that increase the environmental press. In a study of 180 normal and moderately cognitively impaired elder drivers, Freund, Colgrove, Petrakos, and McLeod (2007) found approximately one third of the drivers reacted to a driving simulator stimulus by depressing the accelerator instead of the brake. Low scores on the Clock Drawing test (CDT), a measure of executive dysfunction, was the best predictor of this maladaptive behaviour. Age was also a significant predictor, especially for those over age 84 years. The authors concluded that, “in the presence of executive dysfunction, the automatized and procedural skills learned over decades of daily driving are applied in an inflexible manner and thus do not protect the older driver from errors”.

Complex Driving Environments and Aging

Operation of a motor vehicle is conceptualized as the interaction between the driver, the vehicle, and the road environment, where errors in any one of these dimensions can result in a crash. Studies have shown that 80% of vehicle

accidents are due to driver error, 18% are due to the roads themselves, and 2% are due to vehicle malfunctions (BC Stats, 2000). Included in driver error is inexperience, poor judgment, lack of skill, and physical disabilities that limit the execution of responses to environmental demands.

The contribution of the driving environment to crashes is well documented. Complex and inappropriate roadway designs challenge the mental workload and abilities of all drivers to travel safely between destinations. For example, Flahaut (2004) found that divided highways with two lanes in each direction were associated with fewer collisions than two lanes of opposing traffic. They also found that roundabouts lowered crashes at major intersections, whereas the presence of roadway features such as sharp curves and narrowing roads that necessitated a change in speed limit was associated with higher probability of crashes. Karlaftis & Golias (2002) found that after total traffic volume, lane width was the most important variable in explaining crashes, followed by type of road surface. Pavement type and access control also affect crashes, as do other features of transportation networks such as lighting, parked cars, and traffic control devices. Bad weather adds yet another component, as well as the poor driving habits of other drivers sharing the road.

Elderly drivers frequently complain that the task of driving is becoming more complex and confusing. Older people suffer specific problems linked to divided attention performance which becomes particularly noticeable with complex roadways, heavy traffic, and more in-vehicle technologies. Mental workload is increased with the complexity of the task and the driving environment, and once the driver is no longer able to successfully respond to demands, performance declines. However, since mental workload also varies as

a function of the driver's state, the question of how much environmental complexity represents excessive workload remains largely unanswered (deWaard, 1996).

Studies on the contribution of roadway geometry and other environmental factors to crashes have only recently focused on older drivers. In 2001, the US Federal Highway Administration recognized the limitations of older drivers and published its updated handbook entitled *Highway Design Handbook for Older Drivers and Pedestrians* to provide designers and engineers with practical information in building roads that meet the declining functional capabilities of older drivers (Staplin, Lococo, Byington, & Harkey, 2001). The single greatest concern addressed in the guidelines is the ability of older drivers to negotiate intersections safely. The need for more time to react is considered a key factor. Seventeen different design elements were outlined, including items dealing with road and lane geometry, traffic control devices, signage, lighting, and fixed structures such as medians and curbs. By adjusting these features, road safety specialists hope to decrease the environmental demands of driving for the aging population.

Older adults themselves use a variety of techniques to attempt to reduce the mental workload required to safely operate a vehicle. In focus group interviews with elderly drivers, many older drivers report using cruise control to reduce their need to monitor their speed, turning off the radio to reduce auditory distractions, and not traveling with passengers who demand their attention while driving. Others report driving only in familiar areas where they do not have to rely on road signs for navigation, and avoiding left turns where there are "too many things to watch out for" (Nasvadi, unpublished). For drivers such as these, the

driving task has become highly automatized, allowing them to successfully operate a vehicle – at least under highly predictable situations (Summala, 1985).

Although older adults attempt to control their driving environment through self-regulation, and engineers have taken steps to reduce environmental demands, there is little evidence that these strategies are successful. Crashes per kilometer are higher for older drivers (Insurance Institute of Highway Safety, 2003), suggesting functional declines cannot be compensated for entirely. The issue of environmental complexity's contribution to crashes involving older drivers is addressed in this study. By examining the driving records of older drivers required to avoid specific environmental demands, some insight may be gained regarding how much is too much environmental demand for aging drivers.

Self-Regulation

The increase in number of elderly drivers and the subsequent increased risk of crashes may be at least partly mitigated by the adaptive behavior of older drivers themselves. Several studies have shown that many drivers begin to limit their driving as they age and as their physical abilities begin to decline. Some older drivers with visual and attentional impairments have been shown to avoid driving on high speed highways, in rush hour, in the rain, and alone (Ball et al., 1998). However, not all drivers adjust their driving habits in response to their declining skills. Charlton, Oxley, Fildes, Oxley, and Newstead (2003) revealed that 20% of drivers who did not adopt self-regulatory strategies failed an on-road driving test, highlighting the fact that some elderly drivers with diminished capacities continue to drive under circumstances beyond their abilities.

Furthermore, although many older drivers claim to restrict, for example, their nighttime driving, it has not been clearly demonstrated whether the highest risk drivers avoid night driving and if this decreases the number of crashes caused by older drivers. Hakamies-Blomqvist (1994) found that only 5.9% of crashes involving men over age 65 years occurred between 9pm and 7am compared to 26.1% of crashes for men aged 26 to 40 years. On the other hand, Mortimer & Fell (1989) found drivers over age 65 had higher nighttime crash rates than those age 25 to 65 years.

Use of Restricted Licensing

Motor vehicle administrators have permitted individuals with physical handicaps, who would otherwise be unable to operate a motor vehicle, to drive with specialized equipment or vehicle modifications such as hand controls, automatic transmissions, and extra mirrors. However, these restrictions were designed primarily to meet the transportation needs of young, handicapped individuals. The idea of using a restricted license for older drivers was initially proposed in the late 1980s by Dr. Patricia Waller (TRB, 1988). In recognizing that beginning drivers, because of their limited skill, should be introduced gradually to driving, Dr. Waller proposed that most older drivers also should not be abruptly removed from driving as their skills decline.

Although many jurisdictions have the authority to place restrictions on the driving of any applicant, the policy has not been uniformly applied when dealing with older drivers. Some examiners, particularly those in rural areas, continue to issue full licenses to older drivers who have no other means of transportation. Other driver examiners recognize seniors' needs to access medical and personal

services, and are open to the idea of permitting older drivers to drive in conditions excepting those in which they have demonstrated difficulty. Still other examiners feel strongly that all drivers should have equal capabilities, and therefore fail any senior who demonstrates reduced skills.

Despite the inconsistencies, restricted licenses are now being used more frequently to allow older drivers who have developed functional disabilities due to illnesses such as arthritis to continue driving with adaptive equipment similar to that of physically disabled drivers. In addition, as the driving environment has increased in complexity and as more older drivers are driving to an older age, licensing authorities have expanded the definition of restricted licenses to include limitations that address functional declines associated with normal aging. For example, many jurisdictions limit the speed a senior with decreased visual acuity is permitted to drive, limit the time of day the senior with decreased contrast sensitivity may drive, or restrict the geographical region to familiar areas in recognition of declining cognitive abilities. However, the efficacy of this practice has not yet been clearly demonstrated. The current study addresses this gap in knowledge.

Impacts of Restricted Licenses

Very little research work has been directed towards understanding the impacts of restricted licensing for seniors. An extensive search of published literature was conducted using Medline, Ageline, Academic Search Elite, ISI Web of Science, SocInfo & Google. Key words used in the search, included: restricted license, delicensing, graduated delicensing, driving restriction, and older drivers driving. Only two studies, discussed below, were found that addressed the

effectiveness of issuing restricted licenses to seniors. The first of these studies was conducted in the United States, and the second in Canada.

US Study

Stutts, Stewart & Van Heusen-Causey (2000) reported results of a population cohort study commissioned by the North Carolina Governor's Highway Safety Program. In the study, crash data for drivers age 65 and older with various license restrictions were compared with those who had no restrictions or restrictions requiring corrective lenses only. Telephone surveys were also conducted to assess knowledge and attitudes towards driving restrictions, as well as self-reported compliance.

All licensed North Carolina drivers aged 65 years and older as of December 31, 1999 were included in the study. Of the 771,269 senior drivers, only 25.3% had no restrictions on their license, and 72.6% had only one restriction, most often a requirement for corrective lenses. This was particularly true for women who were more likely than men to be restricted only for corrective lenses. Only 2.1% of senior drivers had two or more restrictions, usually for corrective lenses plus a restriction for speed or daylight travel. Men were more likely than women to have additional restrictions such as special equipment, but men were also more likely to have no restrictions at all.

Retrospective analysis of crash data for the 3-year period 1997-1999 revealed that drivers with restrictions involving more than just the requirement for corrective lenses were more likely to be involved in crashes, after controlling for age, gender, and population density. Average crash rate for restricted drivers was calculated at 0.165, compared to 0.117 for unrestricted drivers. The highest

risks were associated with drivers restricted to a maximum speed of 45 mph/no interstate driving in addition to corrective lenses, and drivers with 'other' restrictions such as special equipment, remaining within a certain radius of home, or being accompanied by a passenger.

Phone survey results in the study indicate that knowledge of restricted licensing was poor, even among drivers with restrictions on their own licenses. Only 20% of the sample knew that drivers could be restricted to daytime driving only, 4.5% knew about 45 mph/no highway restrictions, and 4.2% knew about restricted radius of travel. None of the respondents were aware that a driver's license could stipulate a requirement for extra mirrors, power brakes, automatic transmission, or an accompanying passenger. Of drivers with restrictions for daytime travel or 45 mph/no interstate travel, only two-thirds were aware of their restriction. Most of these (83.5%) said they always complied with the restriction, and 12% said they usually complied. Among drivers with extra restrictions in addition to corrective lenses, 22% felt the restriction was inappropriate and 29% said it made transportation more difficult. However, 77% of all drivers strongly agreed, and an additional 19% somewhat agreed that they would rather have a restricted license than no license at all.

This study appears to be the first population-based study to examine the crash rates of senior drivers with restricted licenses. As a population-based study, it represents a stronger research design by including all licensed elderly drivers compared to a study examining only restricted drivers. However, several limitations make interpretation of the results difficult. A primary weakness is that the study involved a 3-year retrospective analysis of crash data for older drivers, but the authors do not report consideration for the time at which the restriction

was imposed. It is therefore possible that a portion of drivers identified as restricted were involved in collisions prior to having the restriction placed on their license. Furthermore, lack of detail on the time the restriction was imposed did not allow for calculation of exposure time until a crash while under the restriction. The higher crash rate of these drivers compared to drivers without restrictions may not, therefore, represent an increased risk of crash involvement resulting from allowing these older drivers to continue driving. Rather, it may actually reflect the fact that elderly drivers involved in crashes are more likely to have a restriction placed on their license as a result of the crash. Analysis of crashes prior to and subsequent to imposing the restriction would be needed to address the effect of restricted licenses on crash rates.

A second weakness of the study is the method used to categorize restricted drivers. Restrictions for slower speed and/or daylight driving included only those drivers who also had restrictions for corrective lenses. Although the authors report most speed and daylight restrictions were issued to those with restrictions for corrective lenses, it is unclear what proportion did not. Also, all other driving restrictions were combined into a single category, including driving within a certain radius from home, various vehicle modifications, requirement for a licensed passenger, and other licenses (no air brakes, school bus only, conditional license). This broad range of categories may represent significantly different reasons for restrictions that have less to do with elderly driving. For example, depending on the time the restriction was imposed, a requirement for hand controls could represent a recent onset of physical challenges due to stroke or advanced arthritis, or else a long-standing physical disability.

Third, as with many studies attempting to determine crash risk, this study presents other limitations. The authors do not specifically cite the source of the crash data used, but imply that it is taken from state motor vehicle crash statistics. In most jurisdictions, reporting of crashes is restricted to police-attended crashes involving significant material damage, injury, or fatality. State or provincial data are therefore not representative of the true crash risk of drivers, since they significantly under-report the total number of crashes that occur on roadways (de Leur & Sayed, 2001).

Canadian Study

A recent research study on older drivers with restricted licenses addressed some of the weaknesses of the previous study. In a population-based cohort study, Marshall, Spasoff, Nair, and van Walraven (2002) used insurance claims records and traffic violations of all licensed drivers in the province of Saskatchewan. Saskatchewan Government Insurance provides insurance to all drivers in the province, and therefore records all police-attended crashes as well as those not recorded by police. In addition, the researchers identified the date all driving and licensing restrictions were imposed, as well as dates of license suspension or cancellation. Time series analysis was then conducted to determine whether rates before and after the restrictions were imposed differed significantly.

Unlike the previous study that focused on elderly drivers, the Saskatchewan study included drivers of all ages. Its main purpose was to compare crashes and violations of drivers with restrictions imposed for medical reasons, including those not strongly related to aging such as epilepsy, psychiatric conditions, amputations, etc. Restrictions were grouped into 3

categories: no restrictions; driving restrictions (e.g., daylight only, restricted radius); and licensing restrictions (e.g. periodic eye exams required).

Marshall et al. found that as a group, restricted license holders had a higher crash rate during the study period (1992-1999) than drivers without restrictions, but that this rate was lower than the rate for male drivers alone or for urban drivers. Compared to unrestricted drivers, those with restrictions were more likely to be male and live in rural locations. Crude rates of crashes and traffic violations four years before and four years after driving restrictions were imposed decreased. A relative rate reduction of 12.8% for crashes and 10.0% for violations was calculated when both driving and licensing restrictions were combined. Driving restrictions alone resulted in a relative rate reduction of 31.8% for crashes, but no change in traffic violations. Licensing restrictions alone resulted in a small reduction in crashes and a 10.7% relative rate reduction in traffic violations.

The main limitation of this study is its broad inclusion of all types of restricted licenses. Age-related restrictions are not differentiated from restrictions imposed for other causes. The authors also provide only 3 examples of restrictions (daylight only, restricted radius, periodic eye exams), and present no data on the other types and numbers of restrictions for each age category. For example, it is unclear whether drivers whose only restriction is for corrective lenses are included in the restricted driving, restricted licensing, or no restrictions category.

A second major limitation of this study is that the time series analysis of crash rates before and after imposing license restrictions was conducted for the entire population and not for different age groups, or for males and females

separately. Furthermore, no effort was made to measure driver compliance with the restrictions which may vary considerably by age, gender and type of restriction. As such, applicability of the results to the older driving population is limited.

Gaps in Knowledge

Overall, previous studies on the use of restricted licenses still do not clarify the efficacy of issuing restricted licenses to older drivers. Specifically, they do not unequivocally determine whether or not restrictions can be used to allow older adults to continue driving with a lower risk of causing a crash than if they were to continue driving unrestricted. They also do not clarify if the collisions of older drivers on restricted licenses are more serious or less serious than those caused by older drivers with unrestricted licenses. Results of the current study will attempt to provide a clearer understanding of the effectiveness of restricted licenses in mitigating the crash risk of an aging population.

Theoretical Framework

The main assumption in issuing restricted licenses to older drivers is that by controlling the environment in which the older adults drive, the task of driving will be simplified and more closely matched to the skills of the driver. In other words, proponents of restricted licenses are attempting to fit the demands of the environment to the skills of the person. In general, this practice is congruent with person-environment (P-E) fit frameworks used in other disciplines where the success of a behavior or program is considered a function of the compatibility of the individual with the demands of the environment. For example, P-E fit in older senior's housing attempts to match the functional limitations and ADL

dependence of the aging individual to the physical design and support of the living environment (Iwarsson, 2005). Similarly, person-job (P-J) and person-organization (P-O) fit in employee recruitment campaigns attempt to match the skills and personality of the applicant with the job demands and culture of the company (Livingston, Nelson & Barr, 1997).

Person-environment fit frameworks are developed from the work of Lewin (1951) who suggested the individual interacts with a 'life-space' defined as the person, the physical environment, and the 'psychological space' of the individual. Lewin conceptualized the behavior of individuals (B) as a function of personal characteristics (P) and environmental characteristics (E), represented by the equation $B = f(P,E)$. In his definition, 'life-space' was seen as a subjective appraisal by the individual rather than as anything that occurred independent of human interpretation. Later, Lawton and Nahemow (1973) included the importance of not only personal and environmental characteristics but also the interaction between the person and the environment (P^*E), and the behavior equation was expanded to include all three components: $B = f(P,E, P^*E)$.

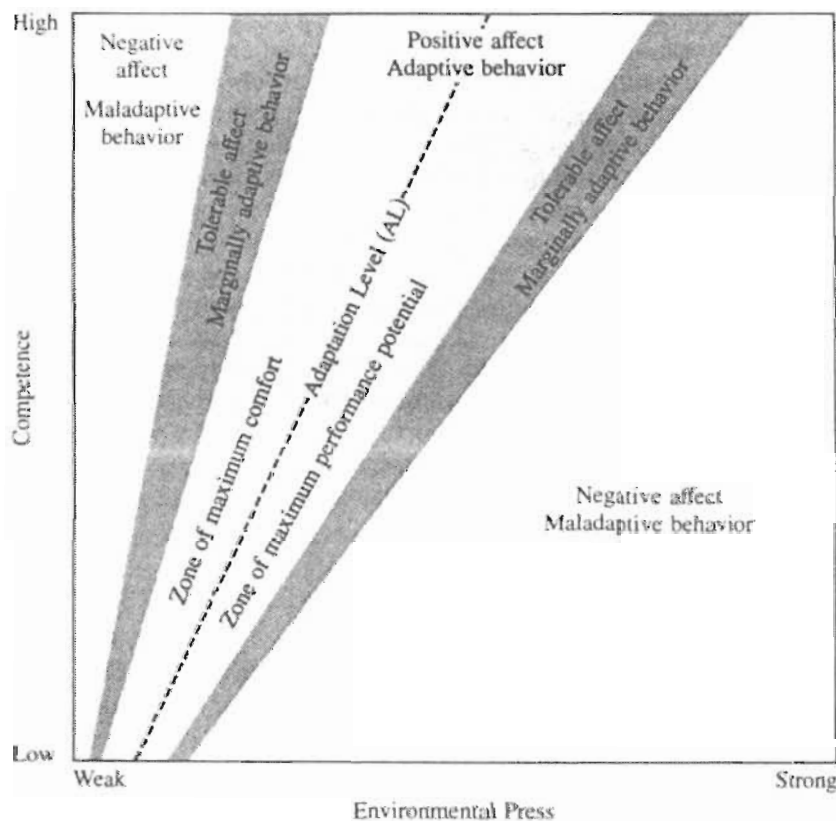
Lawton's (1980) development of an Ecological Model of Aging has defined the person term as a set of competences in the domains of biological health, sensorimotor functioning, cognitive skill, and ego strength. Environments are classified on the basis of the 'demand character' of the context in which the person behaves, such that some environments make large behavioral demands on people while others do not. The term "environmental press", coined by Murray (1938), was also incorporated into the Model. According to Murray's definition, press was composed of a combination of forces in the environment, plus personal need, that evoke a response. The press could be an objective demand

(alpha press) or one construed by the individual (beta press). However in Lawton's definition, the positive or negative quality of press was defined by the individual, such that the outcome when a person behaved within an environment could be placed on a continuum, from positive to negative. Outcome was also seen as manifested on two levels: as behavior, and as affect.

In his model, Lawton (1980) proposed that an individual's response to the environment depends on his own resources. Symbolized graphically (Figure 1), the vertical axis represents the competence of the individual (from low to high resources), and the horizontal axis represents the level of environmental press (from weak to strong stimulus). In this framework, adaptive behavior of the individual may result from a wide variety of combinations of personal competence and environmental press, but a neutral level of behavior ('adaptation level') occurs with a particular combination wherein the individual becomes unaware of any stimulus. Most of the time people are minimally aware of the environment, and behavior is appropriate. However, if the press of the environment increases or decreases beyond this neutral 'adaptation level', awareness returns. Within a moderate level of increase or decrease behavior remains adaptive and affect remains positive. A slight increase in press stimulates an increased level of performance, while a slight decrease in press allows the individual to relax and feel more comfortable. But as the press level falls or rises beyond a certain level, the limits of the person's competence are under-met or surpassed, the stress level is exceeded, behavior becomes maladaptive, and affect becomes negative. Greater mismatches between competence and press are associated with increasingly more negative outcomes. There is always a point of too low or too high press where behavior and affect deteriorate.

Aging is generally associated with a decrease in resources. The P-E Fit Model postulates that the effect of an environmental press of a given magnitude on outcome is greater as personal competence diminishes. In other words, people with lower levels of competence have a narrower range within which they are able to adapt to changes in environmental press. As the competence of the individual decreases, smaller variations in environmental press will result in negative outcomes as illustrated by the decreasing width of the bands to the left and right of the adaptation level in Figure 2.

Figure 2. Lawton's Ecological Model



Application of the P-E Fit Model to Driving

The demands of driving can vary significantly, depending on the vehicle and the circumstances of travel. Driving in a small car with automatic transmission across an open space is much less demanding than driving a pickup truck pulling a trailer down a steep icy highway, or rushing through a busy city to get to a medical appointment on time. The environmental press associated with driving is therefore made up of a number of factors, including those associated with the type of vehicle, the outside surroundings, and the environment within the vehicle. In general, increasing complexity in any of these factors will result in increased environmental press. For example, environmental press increases with increasing number of in-vehicle controls, number of distracting passengers, number of roadway objects to avoid, number of distracting stimuli outside the vehicle, and poor weather conditions. The press associated with each factor varies as a function of its magnitude: a roadway with many tight curves represents greater press than a roadway with few gentle curves. A speed dimension further increases the environmental press such that an increased frequency of occurrence results in increased press. This speed dimension may arise either from the frequency with which targets themselves appear (e.g., the number of other vehicles on the road) or by the relative speed of travel of the driver (e.g., road signs appear more frequently at a higher speed of travel). In fact, it is the speed component of driving that is perhaps the most critical in determining the impact of the environmental press (Stelmach & Nahom, 1992). As speed increases, it has the effect of increasing the level of competency needed for adaptation, and reducing the width of adjacent zones, so that a relatively small additional increase in environmental press will put the individual outside the zone of adaptive behavior and positive affect. Most circumstances

that occur while driving could be dealt with successfully if there were enough time to assess, plan, and execute an appropriate response.

In addition to describing the immediate behaviour of drivers, the P-E Fit Model can be used to understand driving behavior and the occurrence of motor vehicle crashes over the lifespan. Because new drivers have low levels of competence, driving students are at higher risk of crashes and are therefore not usually exposed to complex driving environments that exceed their skill levels. Rather, new drivers are first introduced to driving through relatively simple situations such as driving in a straight line through an empty parking lot. As their skill level increases additional tasks are added and the complexity of the driving environment is increased from empty open spaces, to busy streets, and later to highways with fast-moving traffic. In this way driving instructors manipulate the driving environment to match the competence level of the student, thus reducing the chances of maladaptive behavior, i.e. crashes.

New drivers find the driving task to be very complex and both physically and cognitively demanding. However, over time, most drivers develop highly-practiced skills that reduce the cognitive workload and allow them to drive in situations of higher environmental demand. Automation of predictable driving tasks such as steering, braking, and adjusting in-vehicle controls allows drivers to attend to unpredictable tasks such as visually searching for targets, making judgments about speed and gap, and responding to hazards. It is this automation of driving tasks that characterizes older, experienced drivers and allows them to adapt to the higher environmental demands of the roadways (Summala, 1985).

Although older drivers are able to rely on their highly-practiced skills for many driving situations, as their physical and cognitive abilities begin to decline

with age the environmental press begins to exceed their competence. For example, reduced nighttime acuity results in an increase in the environmental press for night driving, and reduced divided attention and visual scanning increases the environmental press for driving in complex environments. The speed component becomes a particularly salient feature of environmental press. Like new drivers, the elderly frequently adopt adaptive behaviors such as avoiding nighttime driving where vision declines prevent sufficient reaction time, driving slower, and avoiding busy roads that demand fast responses. They are attempting to reduce the pressures of the driving environment to match their own competencies. The P-E Fit Model predicts that lack of crashes signals successful adaptation, that is, the driver has maintained a balance between competence and press, whereas collisions signal greater mismatches between competence and press.

Applications of the P-E Fit Model to Restricted Licensing

Obtaining a driver's license in British Columbia depends on the ability of the driver to pass a road test. Road tests are administered by ICBC, and are standardized in that all individuals regardless of age, gender, ethnicity, health, or any other characteristic, are required to perform an equivalent set of maneuvers such as reversing a vehicle, negotiating intersections, highway driving, and parking. In theory, all drivers are expected to be able to deal with equivalent amounts of environmental press, although in practice the environmental press of driving in a large city is greater than that of a small town. Regardless, inability to cope with the driving environment during the test results in failure and loss of license. In this way, older drivers who are considered to be at high risk of

crashing under conditions presented in the standardized road test are removed from the driving population, thus reducing the crash rate of this population.

The environmental press of the road test itself may be manipulated to more closely match the competence of the elderly driver. For example, although the standardized road test includes highway driving that represents a high level of environmental press, it may be eliminated from the test for older drivers and a restriction placed on the license for highway driving. Or, if a senior shows reasonable driving skill during the low-speed portion of the driving test but uncertainty at high speeds, a restriction may be placed on the license rather than revoking the license altogether. Permitting older drivers to continue driving under restricted conditions therefore represents an attempt to re-establish a balance between the competence of the elderly drive and the press of the environment.

Hypotheses

The purpose of this study is to examine whether restricted licenses may be used successfully to reduce the demands of driving for older drivers whose competence has declined as a consequence of aging. In this study, hypotheses about the efficacy of using restricted licenses to manage the crash risk of elderly drivers were formulated based on the principles of Person-Environment Fit.

Person-Environment Fit theory emphasizes the resources of the individual, the conditions of the environment, and the interaction between the person and the environment. Therefore in examining the driving of seniors, it is important to consider the abilities of the driver, the conditions of the driving environment, and the way in which the driver responds to the driving situation. The P-E Fit Model predicts that safe driving will occur only when the skills and

abilities of the driver are sufficient to meet the demands of the roadway, the vehicle, and the physical environment, and when the driver responds in a manner that is appropriate to the situation.

The main hypothesis of this study is that restricted licensing will be successful in re-establishing the balance between the environmental press of driving and the competence of drivers with some diminished capacities, but it will not be successful in reducing the environmental press for drivers with severely diminished abilities. As the resources of the individual decline, smaller fluctuations in press can be withstood. Inherent in the task of driving is a level of complexity that demands a threshold level of competence, below which safe operation of a vehicle on public roadways is not possible. Declines in physical and cognitive competencies occur with advanced age, so it is hypothesized that in the very old, the level of competence will decline below the minimum threshold required for operation of a vehicle, even under conditions of reduced environmental press. Examination of crashes by age will be carried out to address this question.

Since road crash risk is confounded by age, health status, and prior crashes, this study is carried out in four phases designed to address those issues. Hypotheses for each of the four phases of the study will be addressed next.

Phase I: Driving Competence of Restricted License Holders

The first question to be addressed in this study is whether older drivers who are issued restricted licenses differ from other drivers in terms of the number of crashes and moving violations they experience prior to having restrictions

placed on their licenses. The P-E Fit Model predicts that as driving competence declines, the relative increase in environmental press will result in an increased number of crashes.

Usually, older drivers are issued restricted licenses after being referred for examination because of concerns about their driving expressed by doctors, police, family members, or others. Concerns may include deviations from normal driving maneuvers, minor scrapes with stationary objects, or actual crashes involving other vehicles or pedestrians. This suggests that these drivers are facing increasing challenges with their driving. Since the P-E Fit Model predicts maladaptive behavior for individuals with insufficient resources to meet the demands of the environment, it follows that older drivers with higher crash rates suffer diminished capacities. It is therefore hypothesized that older drivers who are issued restricted licenses will differ from those who have not been referred for re-examination by having more crash claims in the period prior to having the driving restriction imposed.

Phase II: Crash Reduction of Restricted Licenses

The second question addressed in this study is whether imposing a restriction on a driver's license reduces the future crash rate of older adults. License administrators assume that the restriction will reduce the press of the environment to a level congruent with the abilities of the senior driver, but evidence supporting this assumption has previously been missing.

One of the most salient features of driving is the speed demands of the task, which requires rapid recognition of targets, processing of information, decision-making, and execution of maneuvers. These cognitive and physical

processes are slowed with aging which results in an increase in environmental press. Some restrictions placed on the licenses of older adults address this component while others may not. Restrictions to prohibit driving above a certain speed address the speed factor directly. Restrictions prohibiting driving at night address the speed factor indirectly since poor night vision increases the target detection time and subsequently shortens reaction time. Driving within a restricted geographical area may not address the speed issue since it may not prohibit driving at high speeds.

In keeping with the P-E Fit Model, it is hypothesized that driving restrictions will result in a reduction of crashes for the individual after restrictions are imposed compared to before the restrictions were imposed. It is further hypothesized that restrictions that include a speed component will be more successful in reducing the crashes of older drivers than restrictions that do not contain a speed component.

Phase III: Safe Driving Life Expectancy

The P-E Fit Model predicts that as the resources of the individual decline, they eventually fall below a threshold level where they can no longer meet the demands of the environment. Since restricted licenses reduce the environmental press, it is hypothesized that older drivers will be able to continue driving safely for a longer period than others of the same age who are also likely to have diminished capacities, but who continue to drive unrestricted.

Phase IV: Crash Severity

Severity of crash has been demonstrated to be related to the discrepancy between the skills of the driver and the complexity of the driving situation, as

demonstrated in crashes involving novice drivers (Lam, 2003). Restricted licenses address speed of travel, novelty of roadways, and lighting. Restrictions should thus reduce the complexity of the driving environment, and consequently reduce the severity of crashes for the aging driver. It is further hypothesized that older drivers who continue to drive with restricted licenses are involved in less serious crashes than those who continue to drive without restrictions.

Table 1. Summary of Hypotheses.

Hypothesis	
Phase 1	▪ older drivers with higher crash rates are more likely to have restrictions placed on their licenses
Phase 2	▪ driving restrictions, especially those with a speed component, will result in a reduction of crashes for the individual after restrictions are imposed
Phase 3	▪ older drivers with diminished capacities will continue driving safely for a longer period with restricted licenses compared to those who continue to drive unrestricted
Phase 4	▪ older drivers who continue to drive with restricted licenses are involved in less serious crashes than those who continue to drive without restrictions

CHAPTER 3: METHODS

Experimental Design

This study employs a population-based cohort design to determine if the crash and violation rates of older drivers with restricted licenses differs from that of their peers with full licenses. Population cohort designs follow a whole population of people with a known exposure to a specific outcome, and can be used to identify a number of factors that influence the outcome. Cohort designs are considered the strongest of all observational designs because they avoid selection bias. In cohort designs, exposure of subjects is evaluated before the outcome is known, so selection is not subject to the biases encountered in other designs where the selection of subjects by outcome may introduce investigator preferences. Furthermore, since this study is population-based it includes all older drivers with the exposure of interest, further reducing bias introduced in other studies by refusals and attrition. In cohort studies, exposure precedes the outcome, a condition necessary for causation (Wartenberg, Ramsey & Warner, 2000).

In this study the exposure of interest is driving, and the outcome of interest is crashes. Factors affecting the outcome included in this study are age, gender, and type of license (restricted/unrestricted).

This study focuses on elderly drivers aged 66 years and older. This age group was selected because:

- Crash rates per kilometer for senior drivers increase for drivers aged 65 years and older, and especially for drivers aged 70 and over (Lyman et al., 2002). Adequate sample size for statistical analysis was reached by including drivers age 66 years and older.
- Restricted licenses are more likely to be issued to older drivers over age 65 years than to older drivers under age 65 years.
- Restricted licenses issued to drivers over age 65 years are more likely to reflect recent age-related declines rather than lifelong health-related driving issues (e.g. amputations, hemiplegia).

Data Source

The Insurance Corporation of British Columbia (ICBC) is a provincial insurance agency that administers all basic vehicle insurance as well as vehicle and driver licensing. All drivers in the province must purchase a basic insurance package that covers material damage, bodily injury, and some third party liability before they can license and operate a motor vehicle. Additional optional insurance may be purchased from ICBC or from other vendors. Vehicle licensing is also administered by ICBC, and although decisions regarding driver's licenses are the responsibility of the Office of the Superintendent of Motor Vehicles (OSMV), driver license testing is conducted by ICBC. Therefore, unlike other jurisdictions where information may be held by numerous private insurance agencies, licensing authorities, and policing authorities, all licensing, insurance, and crash information for every driver in the province of British Columbia is collected and retained by ICBC.

Data Collection

ICBC databases were searched for all individuals who were age 66 years and older as of January 1, 1999, and who held a valid driver's license. Subjects were identified first by driver's license number (DL). No personal information (e.g., name, phone number, address) that could be used to identify the subjects was extracted. To ensure anonymity and to protect the privacy of the individual, the DL was replaced by a unique sample number after all relevant data was extracted.

For each DL, the following driver licensing data were extracted from the database:

- date of birth
- gender
- death date
- date of driving license renewals
- dates of driving license expiry
- dates of driving license cancellation
- dates of driver road tests
- reason for driver road tests
- results of driver road tests
- date driving restriction was applied to a license
- type of driving restriction applied to a license.

Only driving restrictions most likely to be associated with the effects of aging were included in this study:

1. Restricted speed:

- not to exceed 80 km/h
- not to exceed 60 km/h

- no driving on specified highway
2. Restricted geographical radius – permitted area of travel specified
 3. Restricted time of day – daylight hours only.

The ICBC database contains information on all police-attended crashes as well as information on all insurance claims made to the Corporation. In each record, the type of claim (e.g. collision, theft from auto, vandalism), the role of the individual (driver, passenger), and the culpability of the individual for the incident is recorded. For culpability, the Corporation evaluates each claim based on information received from police, witnesses, and drivers, and assigns a value ranging from 0 – 100%. For each collision, a 4-level severity code is also assigned:

1. crash involves minor material damage only, value \leq \$1,000
2. crash involves major material damage, value $>$ \$1,000, but no injuries
3. crash involves injuries (value of material damage not stated)
4. crash involves a fatality (value of material damage/presence of injuries not stated).

For each DL, data was extracted concerning crashes that occurred between January 1, 1999 and June 30, 2006, where the senior was identified as the driver, and where culpability was assessed as at least 50%. Data that was extracted concerning crashes for each DL included:

- date of crash
- culpability %
- severity code
- number of vehicles involved.

Analysis

Statistical analysis of data was carried out using SPSS version 15.0 and SAS version 9.1.3. Since vehicle crashes are relatively rare events and do not follow normal distribution, non-parametric statistical analysis was used.

Since each phase of the study addressed a separate hypothesis, the design of each phase was unique and an appropriate subsample of the original extracted database was used (Table 2). A description of methods and samples for each phase follows.

Table 2. Sample characteristics for each study phase.

Phase	Sample Size	Description	Mean Age	% Male
Full Sample	151,284	All licensed drivers age 66 years and older	74.2	53.4
Phase I A	147,519	All drivers who were not already restricted at the start of the study	74.1	54.1
Phase IB	128,085	All drivers who were not already restricted at the start of the study <i>and</i> who did not stop driving before 2002	73.5	53.1
Phase IIA	2,661	Drivers who drove unrestricted at least 1 year prior to receiving a restriction	79.1	59.2
Phase IIB	3,266	Drivers who received their first restriction after the start of the study	79.5	59.3
Phase III	125,313	Only drivers who had licenses re-issued between January 1, 1999 and June 30, 2006	73.5	54.6
Phase IV	35,560	All drivers involved in a crash	74.2	60.4

Phase I

Phase I of the study was designed to address the question of whether or not older drivers with restricted licenses are more likely to have higher crash

rates than other drivers prior to the restriction being imposed. In comparing drivers who eventually became restricted versus those who were never restricted, two approaches were used. The first approach included all drivers, so that healthy, safe drivers were included with those who eventually became restricted or lost their license. The second approach used recall for a road exam as a signal of declining skills, so included only apparently “frail” drivers who were either issued a full license, issued a restricted license, or had their license revoked.

Phase IA – Healthy and Frail Drivers

This phase of the study compared crash rates during the unrestricted driving phase between January 1, 1999 and June 30, 2006. From the total sample of all older drivers, only those who were not already restricted at the start of the study (January 1, 1999) were selected. This produced a sample of 147,519 drivers. The crash rate (number of crashes per 100 days) for the period of unrestricted driving was determined for each individual as follows:

- For never-restricted drivers – from January 1, 1999 until the driver died, license was cancelled, or the study ended (30 June, 2006).
- For restricted drivers – from January 1, 1999 until the date the restriction was applied.

Independent sample *t* tests were used to compare mean crash rates between groups.

Phase IB – Frail Drivers Only

This phase of the study compared crash involvement from January 1, 1999 until recalled for a road exam in 2002. A sample of 2,940 previously

unrestricted drivers who were recalled for a road exam in 2002 was identified. These drivers were compared with those not recalled for a road exam. Only drivers who retained a valid license for the entire period prior to 2002 were included. Independent sample *t* tests were used to compare mean number of crashes between groups over the 3-year period. Non-parametric analysis was used to compare groups for crash involvement and to predict road exam recall and license restriction. Chi-square analysis was used to determine if drivers recalled for a road exam in 2002 were significantly more likely to be involved in a prior collision than drivers not recalled for a road exam.

Binary logistic regression was used to calculate the odds of being called for a re-exam after controlling for age and gender. Binary logistic regression is a nonparametric statistical technique used to determine the predicted probability of an outcome based on the combination of predictor variables. It is used when the dependent variable is dichotomous and independent variables are dichotomous or continuous. Logistic regression is appropriate in this study to determine the probability of being recalled for a re-exam or for receiving a license restriction (Yes/No) based on gender (dichotomous variable), age (continuous variable), and number of crashes (continuous variable).

Phase II

This phase of the study was designed to determine if crash rates of older drivers change after driving restrictions are imposed. All restricted drivers who had been driving at least one year without a restriction from the beginning of the

study were identified. Among this sample of 2,661 drivers, crash rates (number of crashes per 100 days) before the restriction was applied were compared with crash rates for the same driver after the restriction was applied, using Wilcoxon signed rank tests. The Wilcoxon signed rank test is the non-parametric counterpart of the paired *t*-test and corresponds to a test of whether the median of the differences between paired observations is zero in the population from which the sample is drawn. This test was appropriate because crashes do not typically follow a normal distribution and because the before-after observations were paired for each driver.

It was hypothesized that restrictions containing a speed component would have a greater impact on reducing crashes of elderly drivers. In BC, three types of speed-related restrictions may be applied: no highway driving; not to exceed 80 km/h; and not to exceed 60 km/h. In this phase of the study, codes for these three restrictions were combined into a single category. Comparisons were made for speed versus other types of restrictions.

The Mann-Whitney test was used for pairwise comparisons of categories of restrictions since the categories were independent of each other (i.e. not paired). For three or more categories, Kruskal-Wallis tests were used. Kruskal-Wallis is a non-parametric test used to compare three or more groups. It is similar to Wilcoxon in that it uses ranks, but the average rank in each group is compared using one-way analysis of variance.

To control for newness of the driving restriction, only drivers who had their first restriction applied on or after 1 January, 1999 were included in the analysis.

Phase III

This phase of the study determined whether drivers who are issued a restricted license remain crash-free for a longer period of time than drivers who continue to hold an unrestricted license. Survival analysis was used to address this issue.

Survival analysis is a class of statistical methods for studying the occurrence and timing of events, and is applied to longitudinal data to predict the probability of survival and the hazard of experiencing an event at time t . Although originally designed to study death in medical patients, its use has been expanded to include many different kinds of social and natural science events such as disease onset, equipment failure, traffic crashes, job terminations, recidivism, and stock market crashes. Survival analysis has benefits over other statistical methods in that it does not assume the rates of event occurrence are constant over the period of study by using a log-linear rather than a linear Model. Another key benefit is that survival analysis uses all data about a subject, and not just event data. In many longitudinal studies individuals are enrolled in the study over a period of time and are followed until they experience the event of interest (crash) or until the study ends. Often, individuals do not experience the event, either because the study ends beforehand or else the individual leaves the study. Rather than ignoring the data collected on these “censored” individuals, survival

analysis includes their data but gives them a different weight in the analysis. In this way, exposure is also controlled for by the analysis.

There are several different methods of survival analysis (Allison, 1995; Kleinbaum & Klein, 2005). Life tables (actuarial method) are used to display the survival pattern of a community when we do not know the exact survival time of each individual, but we do know the number of individuals who survive at a succession of time points. In this method, survival times are divided into discrete periods. In studies when we know the exact follow-up time for each individual in the study, Kaplan-Meier (KM) methods are appropriate. KM methods are non-parametric and may be used to compare the survival of two or more groups. However if the effects of other factors need to be explored, parametric or semi-parametric methods are needed. Parametric methods are used if the data are known to follow one of several underlying distributions including exponential, Weibull, log-logistic, gamma, and log-normal. These are known as accelerated failure time (AFT) models and represent rates that either increase, decrease, or are bimodal. Semi-parametric methods, known as proportional hazards methods (Cox PH), make no assumptions about the underlying distribution but do assume the hazards between groups being studied remain proportional. Since Cox PH has the least stringent assumptions and is therefore more robust (Tabachnick & Fidell, 2007, p. 535), it has become the most popular method of survival analysis and is used unless the underlying distribution is clearly demonstrated (Bradburn, Clark, Love, & Altman, 2003).

Models for survival data are fundamentally concerned with the timing of events, and include a scale and an origin. In this study, the presence of precise dates allowed for a scale unit of days to be used. This provides maximum accuracy in estimating group survival times.

Choice of origin is critical to the validity of survival analysis results, and should be the time marking initial exposure to risk. For drivers, initial exposure to the risk of crash occurs as soon as an individual begins to drive. In this study we are not interested in the risk of crash since the individual began driving, but only in the individual's risk of crash as an older adult. Therefore, choosing the origin as the time of first licensure would not be appropriate. On the other hand, choosing the origin as the date of data extraction, or even as a specific age for an individual, would also not be appropriate since the key question is whether a restricted license affects the crash risk, and restricted licenses are issued at any time for any age of driver. It might be possible to model the risk of crash beginning at a certain age with the occurrence of a restricted license as a time-dependent covariate similar to modelling the effect of surgery on the survival of cancer patients. However, unlike cancer patients who die only once, the outcome in our study may be repeated: drivers may crash multiple times both before and after receiving a restricted license. Statistical methods and programs have not yet evolved to adequately model repeated events, especially for large data sets. For example in the WLW method (Wei, Lin, & Weissfeld, 1998), problems with dependency between repeated events introduce significant biases in the results. On the other hand, fixed-effects methods that may control for such biases are

most appropriate when covariates vary across intervals for each individual and when each individual has at least two events (Allison, 1995, p. 245). In this study, the covariate of interest (type of license) does not vary for a significant proportion of the sample, and most individuals experience only one event (crash) or else they experience no events at all.

For survival analysis, the time of origin in this study was set as the latest date that a driving license was re-issued for each driver. In British Columbia, a driver's license must be renewed every five years. Re-testing of knowledge or on-road driving assessment is not generally required to renew a license: driving skill is assumed to be satisfactory. At age 80 and every two years thereafter, the driver must provide a medical report ensuring there are no medical problems that might interfere with their driving ability. However, license re-issue is still done only every 5 years unless the individual is referred for re-testing by a doctor, police, or other. Many elders choose not to renew their license when it expires or when they receive notice for re-exam. For this study, the date of re-issue was chosen as the time origin because it was reasoned that re-issuing a license signalled the start of renewed exposure to the risk of a crash from driving.

The total sample of all older drivers in BC was reduced to include only drivers who had licenses re-issued between January 1, 1999 and June 30, 2006. Some of these drivers had new restrictions placed on their license during this period so for these drivers the time of origin was set at the date the restriction was imposed, representing exposure to risk for that particular type of license. For drivers who were already restricted prior to 1999, the date of origin was set at the

date of re-licensing (with the restriction). Therefore time analysis involved time from re-licensing until crash (or censor) for unrestricted drivers and drivers who were already restricted at the beginning of the study, and time from restriction to crash (or censor) for drivers who received their first restriction during the study period. Censoring allows the use of information for all cases, even if they do not experience the event.

For drivers who did not experience a crash, date of censor was set as the earliest of, end of study date (June 30, 2006), license expiry date, or death date. Time was therefore calculated as days from license renewal or restriction to crash or censor date. Since licenses are valid for five years, the maximum time was five years (1,825 days).

Non-Parametric Analysis

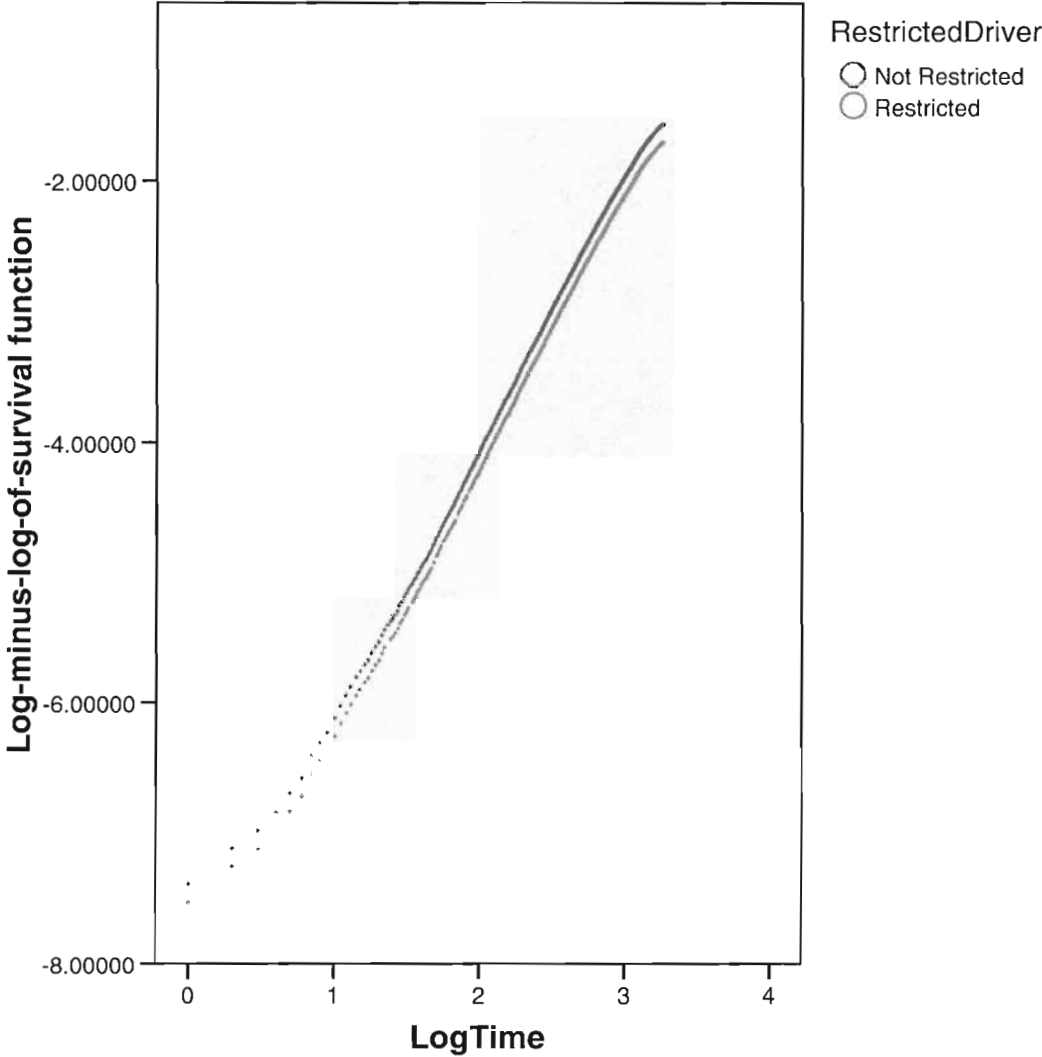
The first step in survival analysis is to compute and plot the estimate of the distribution of the survival time using non-parametric methods. Since in this study the exact date of event times was known, the KM method was used. The KM method is equivalent to the maximum likelihood estimator in comparing groups. Several statistics are used to test for differences between groups of a predictor variable. Choice of the most appropriate statistical test to determine if the difference exists between groups depends on the characteristics of the data (Table 3). Examination of the data for this study revealed a large proportion of censored cases (88%) and it was assumed that the differences between groups was likely to increase over time. Furthermore, (as discussed in more detail later)

log-minus-log plots (Figure 3) showed parallel lines indicating proportional hazards assumption is true. Therefore the Log-rank test was considered most appropriate in interpreting the difference between restricted and unrestricted drivers, and is reported in this document.

Table 3. Characteristics of statistical tests for survival analysis

Statistic	Test Efficiency
Log-rank	More likely to detect later differences (rates deaths equally) – best if proportional hazards is true
Wilcoxon (Breslow, Gehan)	More likely to detect earlier differences (weights earlier deaths heavier) but if % of censor is large, this has very low power More powerful than log-rank when distribution of event times is log-normal
Likelihood Ratio [-2Log(LR)]	An inferior test – assumes the hazard function is constant in each group (implying exponential distribution for event times)
Tarone-Ware	Weights are square root, so this test represents an intermediate strategy

Figure 3. LML plots for proportional hazards

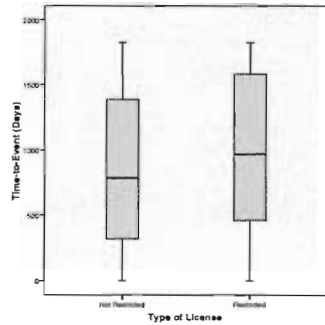


Data

In comparing groups, the tests of equality depend on the groups having similar patterns. Difficulties arise when the proportion of censored subjects in one group differs markedly from another (Norusis, 2007 p 113). In this study, 88.8% of restricted drivers were censored and 88.7% of unrestricted were censored. A plot of the censoring times between restricted and unrestricted groups showed similar censoring patterns that is, censoring for one group did not show a cluster different from the other group. In addition, censoring times were distributed evenly across the time of the study indicating censoring was independent of survival. If the pattern of censoring is not independent of the survival times, then survival estimates may not be accurate.

Finally, it is important to determine whether or not influential cases are affecting the results of the analysis, especially in parametric analysis. Boxplots of time-to-event for restricted and unrestricted drivers are presented in Figure 4. No outliers were detected. As a further check, dfBeta statistics were examined by saving the residuals from Cox regression. DfBeta statistics are the number of standard errors by which the coefficient changes when that observation is removed from the analysis. A negative value means that the coefficient increases when the observation is removed. An arbitrary cutoff for criteria for cases with poor fit is those with $dfBeta > 1.0$. or if $|dfbeta| > 2/\sqrt{n}$ (Garson, 1998). Results of the analysis demonstrated dfBeta residuals ranged from $-.00029$ to $.00162$, confirming there were no highly influential cases in the data set.

Figure 4. Boxplots of time-to-event for restricted versus unrestricted drivers.



Proportional Hazards

One of the assumptions of the semi-parametric Cox PH regression Model is that the ratio of the estimated hazard across time between any two cases is a constant. There are several ways to examine the proportional hazards assumption. Log-minus-log (LML) survival versus log-time plots are a graphical method for evaluating whether the proportional hazards assumption is reasonable for categorical variables. If the baseline hazard functions are proportional the lines should be parallel. If the lines cross or differ significantly, then the proportional hazards assumption is not valid. LML plots were created for type of license, for gender, and for three age categories (66-74 years, 75-84 years and 85+ years). As shown in Figure 5, Figure 6, and Figure 7, the proportional hazards assumption appears to be valid for type of license and for gender. For age categories, the large group sizes and almost identical baseline hazard for two of the age groups makes it impossible to confirm that the lines do not cross during the mid-portion. However, since the lines run parallel at the extreme portions, since they do not obviously deviate, and since the third line runs

parallel, it seems reasonable to conclude that the proportional hazards assumption is met.

Figure 5. LML plot for type of license

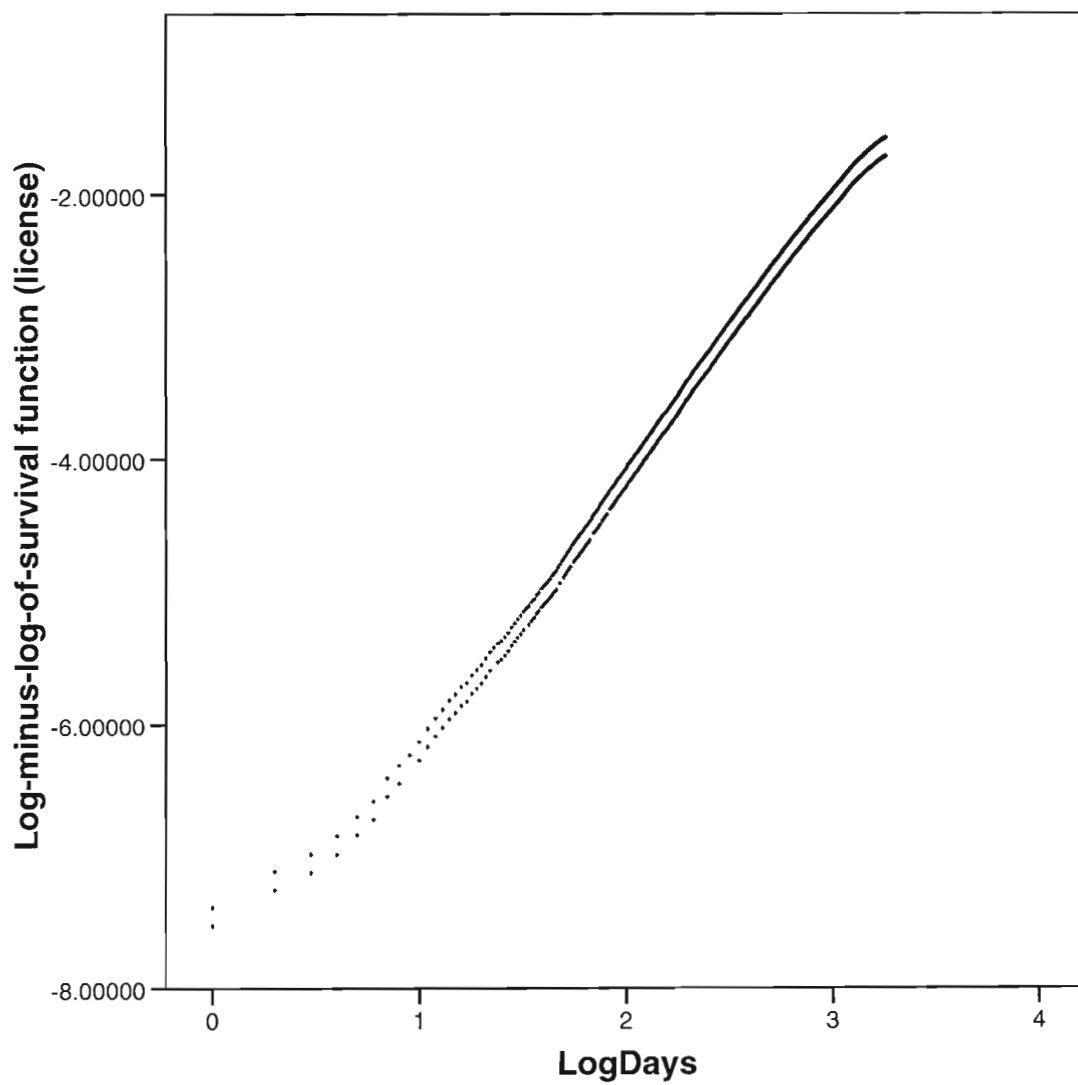


Figure 6. LML plot for gender

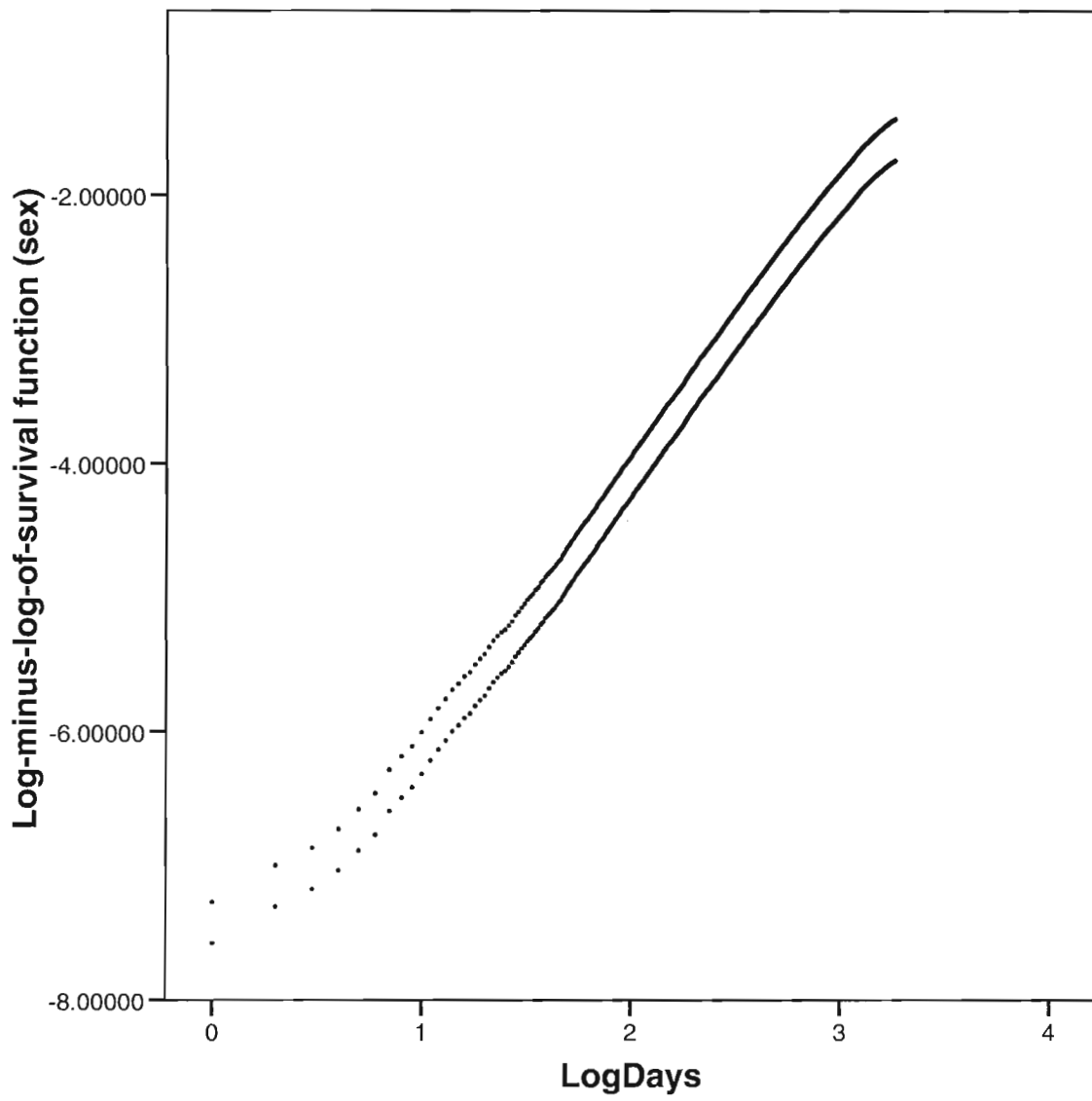
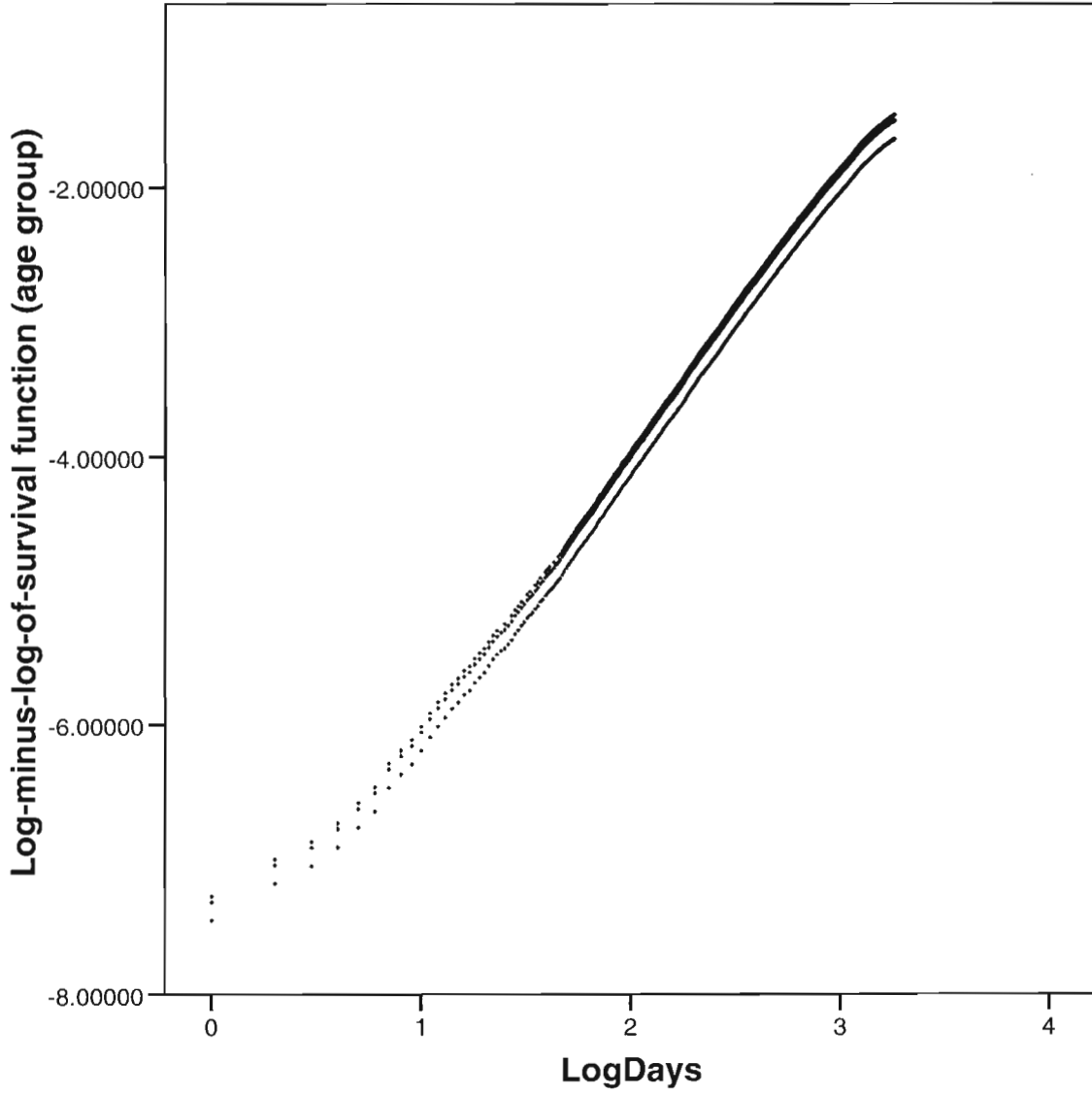


Figure 7. LML plots for age group



Parametric Models

The next step in examining the survival function is to determine if the shape of the baseline hazard can be defined by a known distribution. This is done by evaluating the fit of the data to known parametric models, either graphically, statistically through goodness-of-fit tests, or logically through an understanding of the data. Parametric models are more precise in that they define the shape of the hazard rate function. They also assume that survival time accelerates (or decelerates) by a constant factor. Parametric analysis of the data is presented in Appendix 1.

Model Choice

Both the log-logistic and Weibull models appear to be candidates for the underlying distribution, but we cannot formally test which model is best. Parametric models make strong assumptions about the distribution of the underlying hazard, especially that the hazard is constant for each pattern of covariates. As an alternative to specifying the underlying distribution, the Cox PH model should be considered. The assumptions made about the underlying distribution in a parametric model are much stronger assumptions than the proportional hazards assumptions made by the Cox PH model (Kleinbaum & Klein, 2005 p. 264). The parsimonious choice would be to use the Cox model.

The Weibull and log-logistic models are both AFT Models but the Weibull model is also a PH model while the log-logistic model is not. In fact, the log-

logistic model is a proportional odds model wherein the odds ratio of survival is assumed to remain constant. If the Weibull Model holds, then the hazards are proportional. As shown in Figure 5, the parallel lines verify the proportional hazards assumption is valid for the data, and the choice of Cox PH is appropriate. Thus the decision was made to continue analysis using the Cox PH model.

Semi-parametric Analysis

Cox PH regression analysis was performed using SPSS version 15.0. Time was calculated in days from date of most recent license renewal/restriction until date of the event (crash) or censor. Predictor variables were entered stepwise, with type of license entered first followed by gender and age at the time license renewal/restriction.

Phase IV

In this phase of the study, crash severity of restricted drivers was compared to that of unrestricted drivers. Since most drivers were involved in only one crash, the first crash during the study period (for never-restricted drivers) or the first crash following license restriction was selected. Information about the number of vehicles involved and the severity code applied by ICBC (presence of injuries, fatalities, or material damage only) was used. The customary procedure in road safety studies is to assign the highest severity rank to crashes involving

fatalities. Crashes involving injuries are then ranked according to their costs, followed by crashes without injuries also ranked by cost (Campbell & Knapp, 2005). In the current study, classifications for the ICBC severity codes were similarly recoded as ordinal measures, with the most serious collision (involving a fatality) coded as 4 (Table 4). An overall severity score was then developed by multiplying the severity code value by the number of vehicles involved in the collision. Others have used similar methods, weighting severity codes by number of crashes (Campbell & Knapp, 2005), time of crash (Madsen & Wright, 1998), and number of people and vehicles (Rombro, 2001).

Table 4. Weighting system for severity

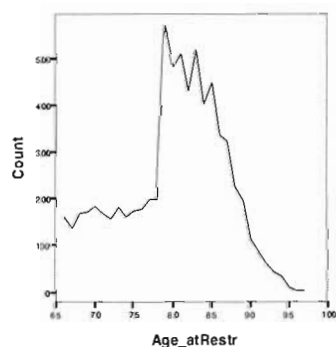
Severity Code	Applied value
Fatality	4
Injury	3
Material Damage > \$1000	2
Material Damage ≤ \$1000	1

CHAPTER 4: RESULTS

British Columbia Older Drivers

Results of initial data extraction revealed there were 151,284 individuals in British Columbia ranging in age from 63 to 103 years (mean 74.23, median 73.00) who held a valid driver's license between January 1, 1999 and June 30, 2006. Slightly more than half (53.4%) of the older drivers were men, and at the start of the study (January 1, 1999), 2.5% had an age-related restriction on their license. During the course of the study, an additional 3,266 drivers had restrictions placed on their license. Restricted drivers were more likely to be men (61.2% versus 54.1%, $\chi^2 = 73.65$, $p < .001$), and older (78.13 versus 74.13, $t = -33.08$, $p < .001$) than unrestricted drivers. As shown in Figure 8, age of restricted license holders follows a normal distribution with the greatest number being between 80 and 86 years of age.

Figure 8. Age distribution of restricted license holders



Number of drivers with different types of driving restrictions is presented in Table 5. Of the total 7,032 drivers who were restricted during the study period, the mean number of restrictions per person was not different for men compared to women. Significantly more men than women were restricted to daylight only (2.9% versus 2.3%, $\chi^2 = 48.40$, $p < .001$) and driving below 80 km/h (4.0% versus 2.9%, $\chi^2 = 154.86$, $p < .001$). More women than men were restricted to driving below 60 km/h which was marginally statistically significant (0.3% versus 0.2%, $\chi^2 = 3.75$, $p = .053$). There was no difference between the proportion of men and women restricted to a specific geographical area or restricted from highway driving.

Table 5. Number of drivers with restrictions

	Men	Women	χ^2	p
Daylight only	2347 (2.9%)	1581 (2.3%)	48.399	.000
No Highway	133 (0.2%)	115 (0.2%)	0.047	.849
Maximum 80 km/h	3309 (4.0%)	1974 (2.9%)	154.860	.000
Maximum 60 km/h	199 (0.2%)	203 (0.3%)	3.747	.053
Restricted area	720 (0.9%)	606 (0.9%)	0.000	1.000
Mean number of Restrictions	1.58	1.60	$t = -1.515$.130

Combinations of restrictions are presented in Table 6. The most commonly applied restriction was a combination of daylight only plus maximum

of 80 km/h, applied to 42% of the restricted drivers. Single restrictions for maximum 80 km/h and for geographical area comprised a third of the total restrictions.

Table 6. Number of drivers with restriction combinations

	Number of Restrictions							
	1	2		3		4		
	Daylight +	Area +	No Hwy +	Max 80 +	Daylight + No Hwy +	Daylight + Area +	No Hwy + Max 80 +	Daylight + No Hwy + Max 80 +
Daylight	312 (4.4%)							
No Highway	53 (0.8%)	27 (0.4%)	9 (0.1%)					
Max 80	2014 (28.6%)	2965 (42.2%)	46 (0.7%)	30 (0.4%)	26 (0.4%)	157 (2.2%)	11 (0.2%)	21 (0.3%)
Max 60	168 (2.4%)	65 (0.9%)	30 (0.4%)	22 (0.3%)	2 (0%)	12 (0.2%)	3 (0%)	1 (0%)
Geographical area	715 (10.2%)	232 (3.3%)				12 (0.2%)		7 (0.1%)
Total	3262 (46.4%)	3428 (48.7%)				297 (4.2%)		45 (0.6%)

PHASE I

This phase of the study addressed the hypothesis that older drivers who have been involved in an at-fault crash are more likely to have a restriction placed on their license. Since restricted licenses are often issued following a road exam, it is expected that crash involvement will also result in a higher likelihood of road exam recall.

Compared to never-restricted drivers, older drivers who eventually had a restriction placed on their license had a statistically significantly higher rate of crash (crashes per 100 days) than those who continued to drive unrestricted for the duration of the study (1.88 versus 0.17 crashes/100 days, $t = -3.015$, $p = .002$). Among both restricted and unrestricted drivers, men were more likely to be involved in a crash sometime during the entire study period (January 1, 1999 – June 30, 2006), and men were more likely to be involved in a crash prior to receiving a restricted license (21.0% of men versus 17.2% of women, $\chi^2 = 7.37$, $p = .007$) (Table 7).

Table 7. Proportion of men and women involved in a crash

	Men	Women	χ^2	<i>p</i>
Never-restricted drivers	26.1	20.3	669.86	.000
Restricted drivers	27.3	21.4	31.89	.000
Crashed before restriction	21.0	17.2	7.37	.007

Among drivers who retained a valid driving license for the three years prior to 2002, those who were required to undergo a road test were statistically significantly more likely to be involved in an at-fault collision prior to their road exam. Whereas 19.9% of those recalled for a road test were involved in a collision, only 13.2% of drivers not recalled had a crash ($\chi^2 = 99.60, p < .001$). The mean number of crashes per driver was also greater for those recalled for a road exam (0.51 versus 0.37, $t = -7.281, p < .001$).

Results of binary logistic regression to predict the likelihood of being recalled for a road exam are presented in Table 8. Drivers who experienced an at-fault crash in the three years prior to the exam were 1.64 times more likely to be called for a road test. Age and gender added significantly to the Model, and reduced the odds slightly to 1.45. The effects of age and gender were also statistically significant: men were 77% more likely to be recalled for a road exam than women, and with each year increase in age the odds of being recalled increased 8%.

Results of binary logistic regression to predict the likelihood of receiving a restricted license are presented in Table 9. Number of prior crashes alone did not predict getting a restricted license. When age and gender were added to the model, age reached statistical significance as a

predictor of license restriction, increasing the odds 7% for each year increase in age.

Table 8. Binary logistic regression results for prediction of road exam recall

	Model 1					Model 2				
	β	SE	Wald	Odds	p	β	SE	Wald	Odds	p
Crashed	0.49	0.047	109.63	1.64	<.001	0.37	0.047	61.05	1.45	<.001
Gender						0.57	0.040	202.20	1.77	<.001
Age						0.08	0.003	653.12	1.08	<.001
Model Chi-square	99.60				<.001	952.78				<.001

Table 9. Binary logistic regression results for prediction of license restriction

	Model 1					Model 2				
	β	SE	Wald	Odds	p	β	SE	Wald	Odds	p
Number of Crashes	-0.19	0.128	2.17	0.829	.141	-0.18	0.130	1.83	0.84	.177
Gender						0.27	0.164	2.63	1.32	.105
Age						0.07	0.016	19.49	1.07	<.001
Model Chi-square	2.36				.125	25.43				<.001

Results of this phase of the study demonstrate causing a crash increases the likelihood of being recalled for a road exam, and for receiving a restricted license, especially for drivers of advanced age. The first hypothesis of this thesis is supported by these findings.

Phase II

This phase of the study was designed to test the hypothesis that crash rates of individuals decline after restrictions are applied to a license. In this sample of 2,661 drivers who had been driving at least 1 year before a restriction was imposed, the drivers in the sample were involved in 805 culpable collisions before restrictions were added compared to 514 after restrictions were imposed. The mean number of crashes per driver before restrictions (0.31) was also greater than after (0.19) ($t = 7.66, p < .001$). More drivers remained crash-free after getting a restricted license: prior to a restriction, 2,050 drivers were not involved in a culpable crash whereas 2,265 drivers did not cause a crash after being restricted. Results of Wilcoxon signed rank test showed a statistically significant difference in total pre-versus post-restriction crashes (Table 10).

Table 10. Comparison of number of crashes before versus after restrictions: Wilcoxon signed rank test

	Time	Sample Size	Positive Ranks	Negative Ranks	Ties	z	p
Total Crashes:	Entire study period	396	297	30	69	-13.03	<.001
Crash Rate:	Minimum 1 year	2,326	336	449	1,541	-3.29	<.001
	Minimum 2 years	1,161	177	234	741	-3.44	<.001
	Minimum 3 years	411	66	107	238	-3.180	<.001

Although these results indicated fewer total crashes occurred after restrictions were imposed, it does not accurately indicate if the crash rate of drivers is reduced by formally restricting their driving. In other words, the number of crashes over a known period of time is needed to adequately compare restricted versus unrestricted travel. Therefore for each driver, the number of crashes per day was calculated for the period when they were unrestricted and for when they were restricted. Only drivers who had at least 1 year of unrestricted driving both before and after their first restriction was imposed were included in the sample. The sample included 2,326 drivers.

Mean crash rate per 100 days for the sample was greater before restrictions (0.023) than after restrictions (0.019) were placed on the license ($t = 3.25, p = .001$). When drivers who had a continuous license at least 2 years before and after the restriction were selected, the results were also statistically significant (mean 0.024 versus 0.017, $t = 3.64, p < .001$), and the

same effect was maintained for drivers who were licensed 3 years pre- and post-restriction (mean 0.027 versus 0.019, $t = 3.33$, $p = .001$). As shown in Table 10, results of Wilcoxon signed rank tests showed significantly more restricted drivers had lower crash rates after receiving a restricted license than when they were driving unrestricted, and this pattern continued for up to 3 years.

In examining the speed component of driving restrictions, the three types of speed-related restrictions were combined, resulting in categories of restrictions illustrated in Table 11. The number of drivers who had only a speed-related restriction represented merely 6.7% of the total number of restricted drivers. However, speed in combination with daylight restrictions were held by 66.1% of the restricted drivers, and a speed restriction alone or in combination with another restriction was imposed on more than three quarters (77.3%) of all restricted drivers.

Table 11. Combinations of speed and other restrictions for the sample

	Men	Women	Total
Speed only	115	103	218
	(5.9%)	(7.8%)	(6.7%)
Daylight only	124	80	204
	(6.4%)	(6.0%)	(6.2%)
Area only	212	143	355
	(10.9%)	(10.8%)	(10.9%)
Speed + Area	24	17	41
	(1.2%)	(1.3%)	(1.3%)
Speed + Daylight	1,297	862	2159
	(67.0%)	(64.9%)	(66.1%)
Area + Daylight	85	56	141
	(4.4%)	(4.2%)	(4.3%)
Speed + Area + Daylight	80	68	148
	(4.1%)	(5.1%)	(4.5%)
Total	1937	1329	3266

Pair-wise comparisons for total number of post-restriction crashes for drivers with speed only versus other types of restrictions was not statistically significant. When drivers with no speed-related restrictions were compared with drivers who had combinations of speed and other restrictions, no difference was found. When exposure was included by calculating crash rate per 100 days of licensure, there was still no statistically significant difference between speed-related and other restrictions (Table 12). Kruskal-Wallis

analysis of the seven combinations of restrictions also showed no significant differences.

Table 12. Results of non-parametric comparison of types of restrictions

	n	Test statistic	<i>p</i>
Number of post-restriction crashes:		K-W chi-square = 3.006	.808
Speed only vs Area only	574	Z = -0.207	.836
Speed only vs Daylight only	422	Z = -0.219	.827
Speed + other vs non-speed	3,267	Z = -0.329	.742
Post-restriction Crash Rate (crashes/100 days):		K-W chi-square = 3.060	.801
Speed only vs Area only	574	Z = -0.340	.734
Speed only vs Daylight only	422	Z = -0.397	.692
Speed + other vs non-speed	3,267	Z = -0.247	.805

Results of this phase of the study support the hypothesis that restricted licenses will result in a reduction of at-fault crashes. The hypothesis that speed-related restrictions will be more effective at reducing crashes was not supported.

Phase III

Phase III of this study used survival analysis to test the hypothesis that older drivers with restricted licenses remain crash-free for longer periods than drivers with unrestricted licenses.

A total of 125,313 older drivers who were re-issued a driver's license during the study period were identified. Of these, 5,533 (4.4%) held restricted licenses sometime during the study, with 2,266 (1.3%) being already restricted at the start of the study. The total sample was composed of 54.6% male, but a significantly higher proportion of drivers who were issued restricted licenses were men. Restricted license holders were also older and, whereas only 3.2% of unrestricted drivers were age 85 years and older, 13.3% of restricted drivers were in this older age category (Table 13).

Table 13. Sample characteristics

	Restricted	Unrestricted	Test statistic	<i>p</i>
Drivers (%)	4.4	95.6		
Male (%)	60.2	54.4	$\chi^2 = 72.969$	<.001
Mean age of sample (years)	77.84	77.29	$t = -55.894$	<.001
Mean age of men (years)	77.94	73.40	$t = -41.852$	<.001
Mean age of women (years)	77.70	73.15	$t = -37.013$	<.001
Proportion age 85+	13.3	3.2	$\chi^2 = 968.601$	<.001

An equal proportion (11%) of restricted and unrestricted older drivers experienced a crash during the study period (Table 14). More men than women caused collisions (12.4% versus 10.1%, $\chi^2 = 160.921$, $p < .001$). Among men who had a crash, an equal proportion held restricted versus unrestricted licenses, and the same was true for women. The mean number

of days from license renewal until a subsequent crash was significantly greater (i.e. longer) for drivers with restricted licenses (651.13 versus 533.99 days, $t = -5.453$, $p < .001$).

Table 14. Crash characteristics of restricted and unrestricted drivers

	Restricted	Unrestricted	Test statistic	<i>p</i>
Crashed (%)	11.6	11.4	$\chi^2 = 0.255$.605
Men who crashed (%)	12.7	12.4	$\chi^2 = 0.219$.630
Women who crashed (%)	9.9	10.1	$\chi^2 = 0.089$.798
Mean age at licensure (yrs)	77.72	73.93	$t = -15.850$	<.001
Mean days to crash (SD)	651.13 (536.13)	533.99 (533.99)	$t = -5.453$	<.001

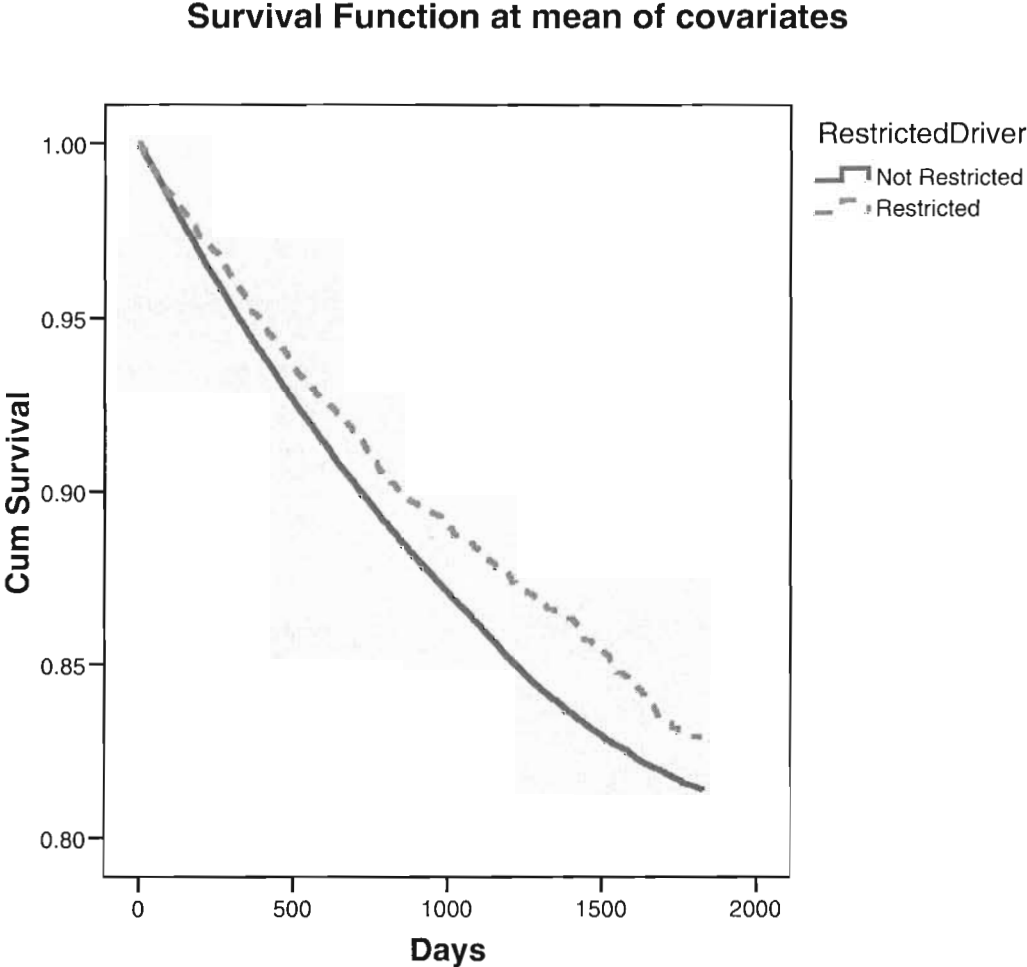
Non-parametric Analysis:

There were 619 events (crashes) for restricted drivers and 13,592 for unrestricted drivers. Results of KM analysis revealed a highly statistically significant difference in survival between restricted and unrestricted drivers, with restricted drivers having a higher survival (Chi-square = 11.61, $df = 1$, $p < .001$).

A plot of the cumulative survival (proportion of all cases that are crash-free at a certain time) obtained from KM analysis is presented in Figure 9. The graph demonstrates that the probability of survival for restricted drivers is higher than for unrestricted drivers, and appears to increase to about 5 years

(1,800 days), but then begins to converge. However, it must be noted that survival estimates can be unreliable towards the end of a study when there are relatively small numbers of subjects still at risk of having an event (Kahn & Prescott, 2004), so it is unlikely that the survival functions actually converge.

Figure 9. Survival function plot from KM analysis



Results of unadjusted Cox PH regression revealed a statistically significant difference between restricted and unrestricted drivers, with the crash rate for restricted license holders being 87% that of the unrestricted drivers (Table 15). Plots of the survival and hazard functions (Figure 10 and Figure 11) demonstrate the higher survival (lower likelihood of crash) for drivers with restricted licenses.

Figure 10. Survival function plot for unadjusted Cox PH regression

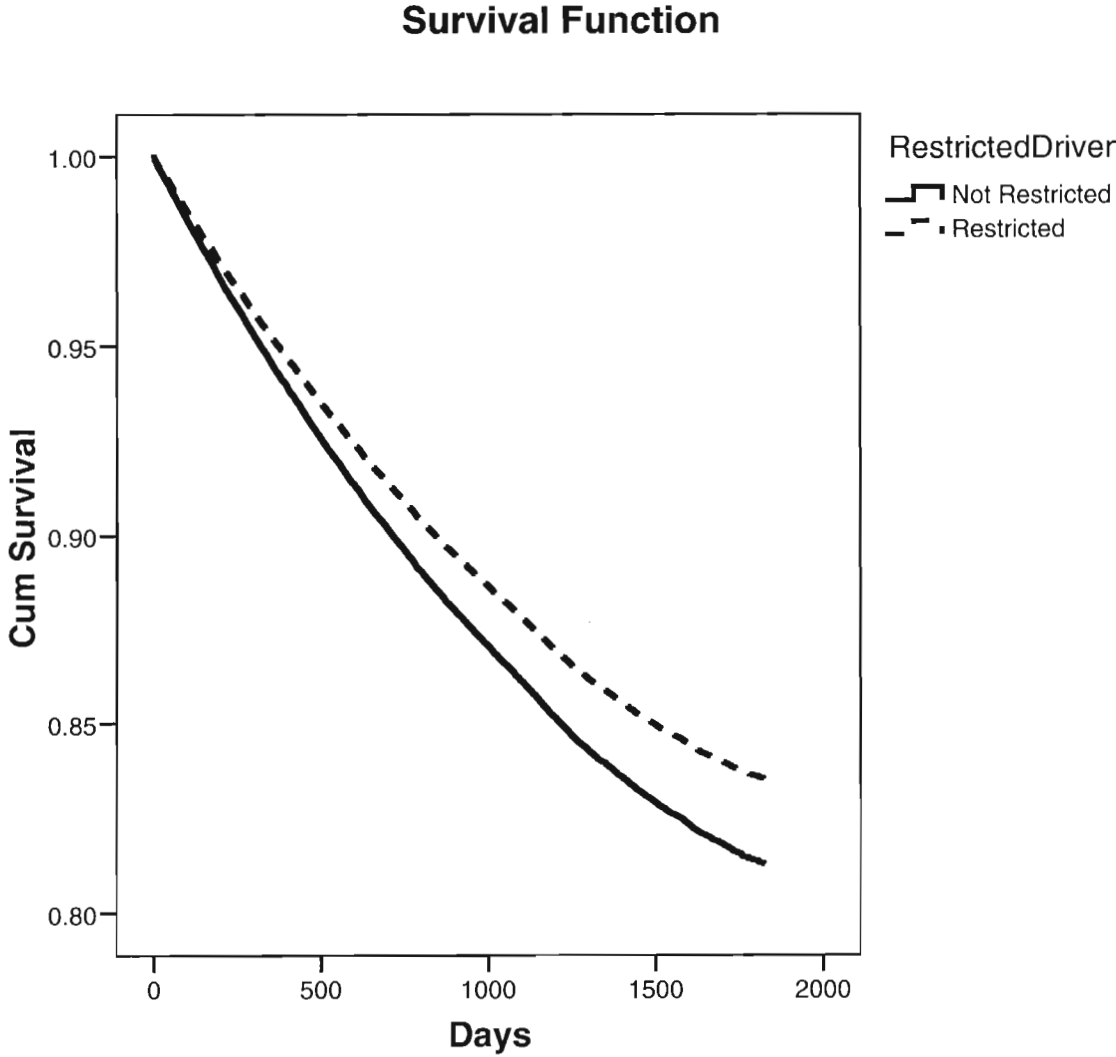
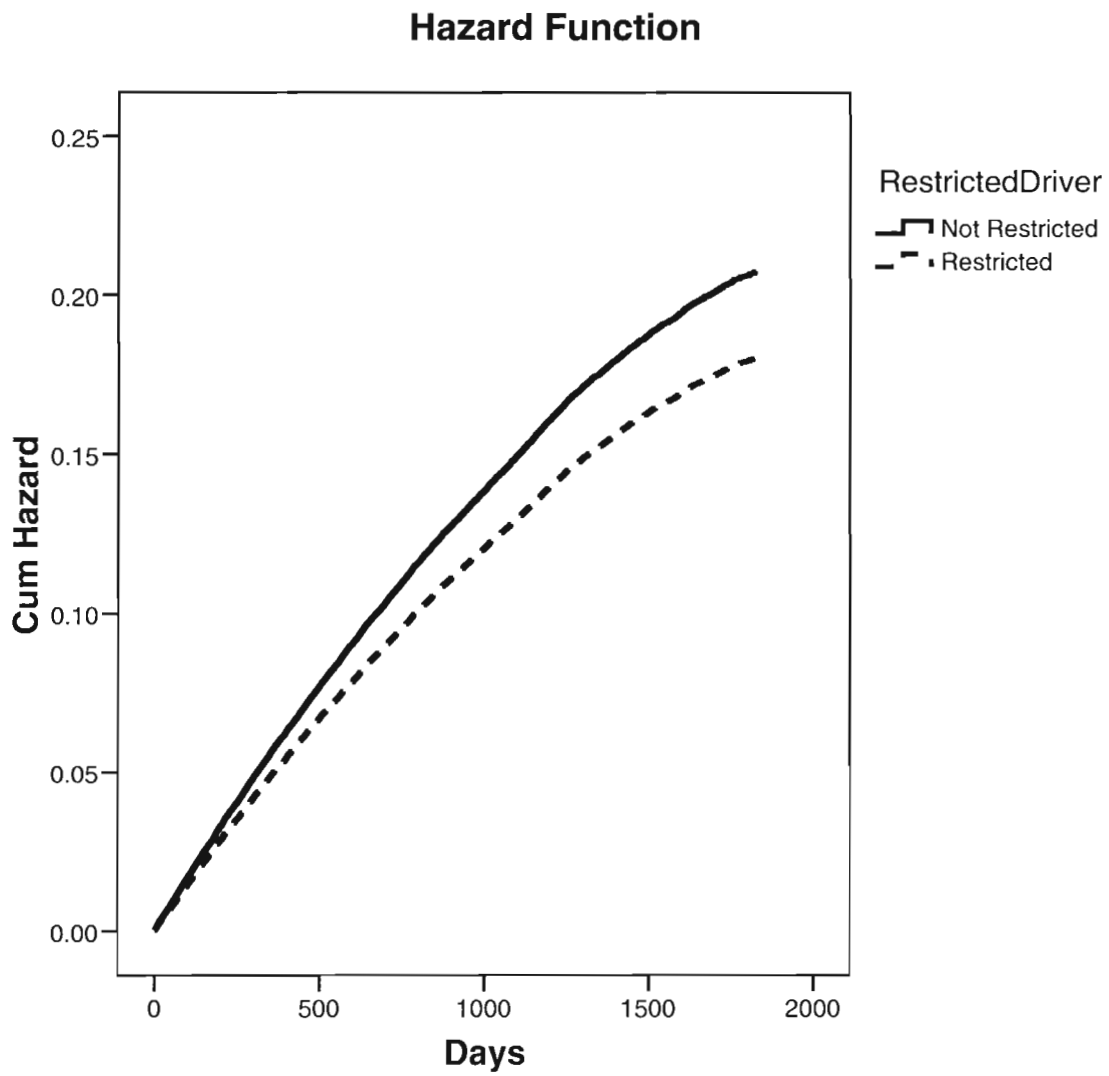


Figure 11. Hazard function plot for unadjusted Cox PH regression



Gender added significantly to the model but had little impact on the effect of license type on time-to-crash. Men were 36% more likely to experience a crash than women. Age at time of license renewal also added significantly to the model, with the risk of crash increasing 1% for each year increase in age. After adjusting for gender and age, the crash rate of restricted drivers was increased slightly to 89.3% that of unrestricted drivers. No correlations were found between variables, however interaction effects were found between age and type of license. Plots of survival and hazard functions for the adjusted model are presented in Figure 12 and Figure 13.

Figure 12. Survival function plot for adjusted Cox PH regression

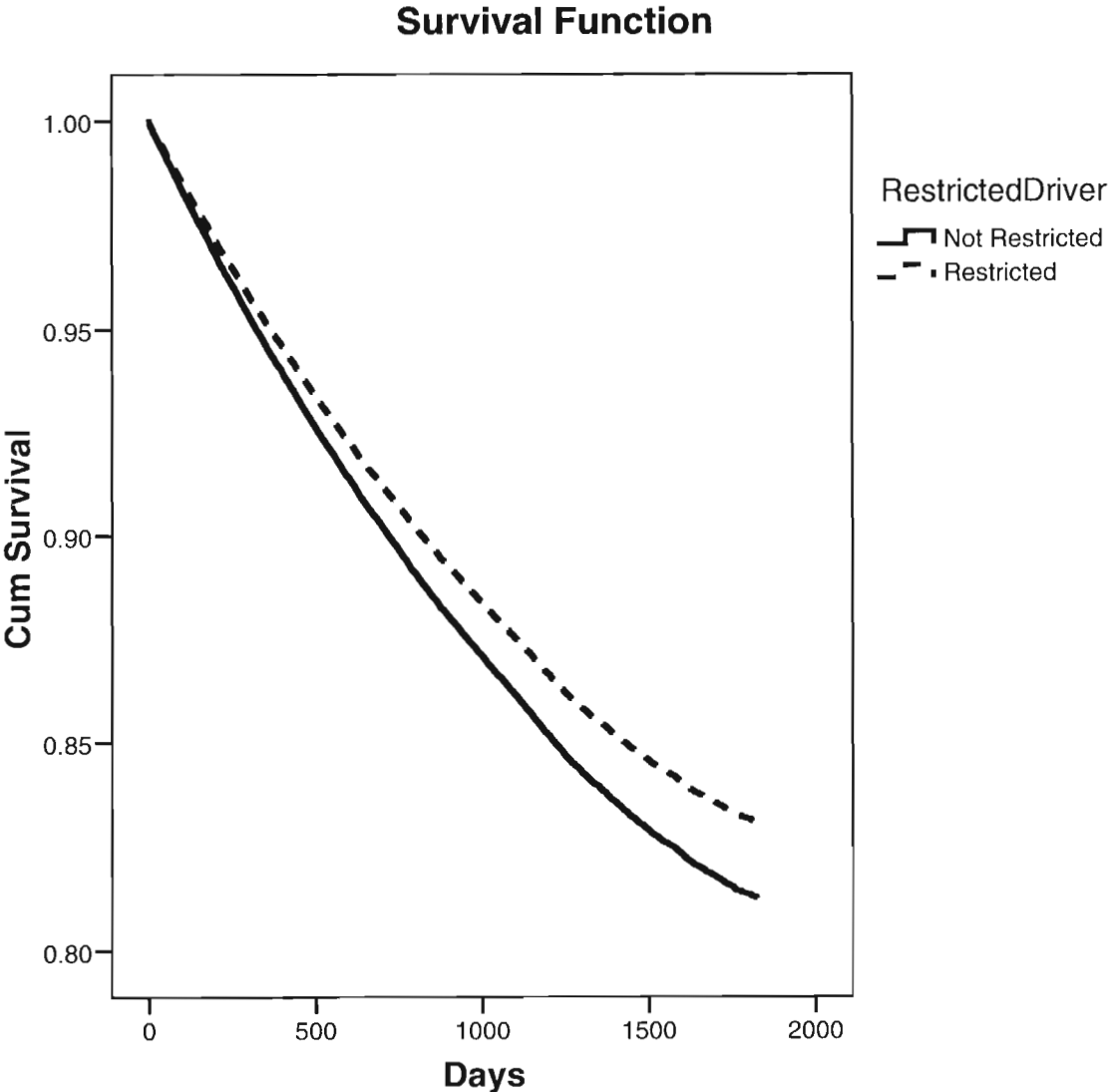


Figure 13. Hazard function plot for adjusted Cox PH regression

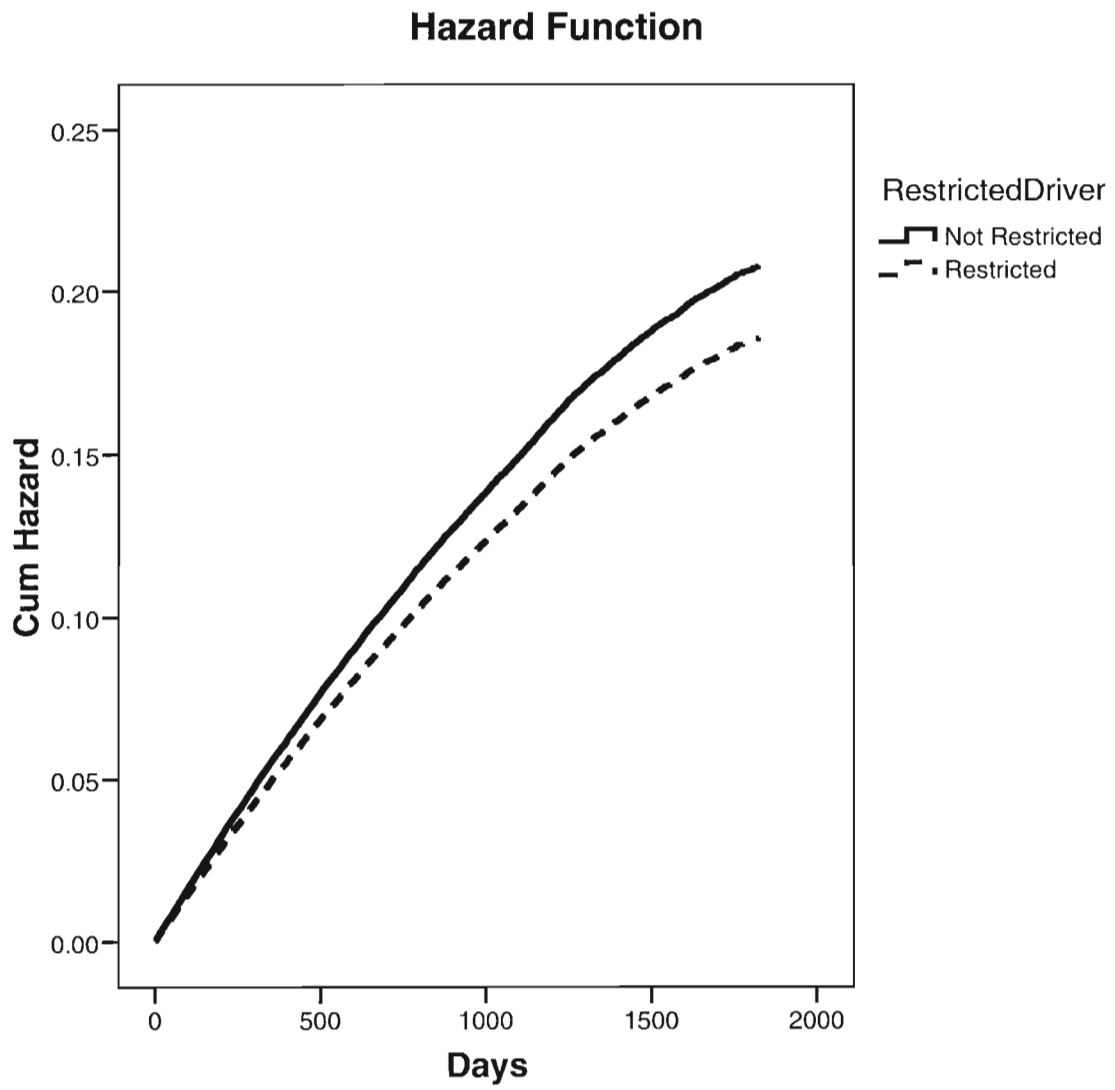


Table 1. Results of Cox PH regression

	Model 1			Model 2			Model 3					
	β	OR	p	CI	β	OR	p	CI	β	OR	p	CI
Restricted	-0.14	0.87	.001	0.802, 0.942	-0.16	0.85	.000	0.785, 0.922	-0.11	0.89	.007	0.824, 0.969
Gender					0.31	1.36	.000	1.318, 1.409	0.31	1.36	.000	1.317, 1.408
Age									0.01	1.01	.000	1.005, 1.010
Model Chi-square Score	11.61		.001		341.21		.000		384.2		.000	

Phase IV

This phase of the study tested the hypothesis that crashes caused by restricted drivers would be less serious than crashes caused by unrestricted drivers.

Classification of crashes involving restricted and unrestricted drivers in the study are presented in Table 16. For both restricted and unrestricted drivers, there were approximately equal proportions of major and minor material damage collisions, although it must be noted that extent of material damage is in large part a function of the value of the vehicles involved in the collision. When collisions involving injuries/fatalities were compared with non-injury collisions, there was no difference between types of license holders (Table 17). A comparison of mean severity scores, calculated by weighting severity by number of vehicles, also did not produce a statistically significant result.

There was no statistically significant difference between restricted and unrestricted drivers concerning involvement in single-vehicle versus multi-vehicle crashes, nor in the presence of injuries/fatalities versus material damage only. However, since restricted license holders were older, their projected crash severity would be greater. Consequently, it may be concluded that the levelling-off of crash severity supports the hypothesis that restrictions reduce crash severity.

Table 16. Severity classification of first collisions (% of collisions)

	Restricted Drivers	Unrestricted Drivers
Fatality	0.2	0.3
Injury	22.3	21.4
Material Damage > \$1000	38.4	38.9
Material Damage ≤ \$1000	38.6	39.9

Table 17. Comparison of severity for restricted versus unrestricted drivers

	Restricted	Unrestricted	Statistic	<i>p</i>
% Injury/fatality crashes	22.2	21.6	$\chi^2 = 0.392$.531
% single-vehicle crashes	24.9	26.2	$\chi^2 = 1.445$.229
Mean number of vehicles	1.80	1.77	$t = -1.780$.075
Mean Severity Score	3.34	3.27	$t = -1.539$.124

CHAPTER 5: DISCUSSION

The primary purpose of this study was to determine whether restricted licenses may be used successfully to reduce the incidence of at-fault crashes for older drivers whose competence has declined as a consequence of aging. This is an important question for both road safety policy makers faced with an increasing number of elderly drivers, and for older drivers themselves who are facing the possibility of losing the independence their automobile has afforded them. In a culture that is dependent upon the automobile for access to most daily activities, ability to acquire and retain a driver's license plays a key role in the social, physical, and psychological well-being of the individual. This is especially the case for older citizens who do not have access to other forms of transport because of deteriorating health, rural residence, cultural norms, or other issues, so that ability to drive becomes a key determinant in maintaining social connectedness and access to services. Loss of a license to drive represents for most, the loss of one of our most fundamental freedoms, the freedom to choose when and where to go. On the other hand, the crash per kilometre involvement of aging drivers has been shown to be as high as that of young drivers, and because of their frailty, elderly drivers are at

increased risk of death or injury in collisions. Strategies are needed to mitigate these risks.

The P-E Fit Model of behaviour predicts that crash-free driving will occur only when the skills and abilities of the driver are matched to the demands of the driving environment. Since aging is generally associated with declines in an individual's personal resources such as visual acuity, reaction time, divided attention, and executive functions, it follows that reducing the demands or 'press' of the environment may help to restore the balance between the individual's resources and the driving task. Restricted licenses that reduce the level of resources needed for driving such as visual processing, quick responses, and divided attention, may be a method for improving the match between the aging individual's resources and the driving environment, and consequently a method for allowing continued safe driving for seniors. Whether or not restricted licenses are able to meet these expectations was the focus of this thesis.

This study improves on the two previous studies that have addressed this question by specifically focusing on older drivers and age-related restrictions. In both prior studies, broad categories of driving restrictions were used, including restrictions such as corrective lenses and vehicle modifications that are less likely to be specifically related to advanced age. This study also improves on prior work by clearly defining the study

population regarding age, on-road driver testing, and crash claims history of restricted versus unrestricted drivers. It draws additional strength from the completeness of data obtained from provincial insurance databases: crash data were extracted from insurance claims crash records rather than from police-reported crashes used in most studies. In most jurisdictions, only severe collisions such as those involving injuries or significant material damage are reported to police, and in British Columbia, police-reported data represent only about 17% of all crash-claim events (Zheng, Cooper & Dean, 2007). Also, complete licensing data were available for each individual in the study including type of license, dates of license renewal, license expiry dates, and road test dates and results. This richness of data allowed for the use of advanced statistical techniques such as survival analysis that uses all data rather than just outcome data, and accounts for variation in exposure time.

The main findings of this study clearly demonstrate the positive effects of issuing restricted licenses versus unrestricted licenses for a particular segment of the older driver population. The probability of remaining crash-free was 13% higher for drivers issued restricted licenses. This represents the first evidence that the crash-free driving life of older drivers may be extended by this method. During the period of study, 611 out of 2,661 drivers caused a total of 805 crashes before being restricted; after restrictions, 396 of these same drivers caused 514 crashes. If these drivers had never received restrictions, it is reasonable to expect that at least an additional 291 crashes

involving 215 additional older drivers would have occurred during the study period. By comparison, other road safety initiatives in BC have seen reductions in total crashes for photo radar (7%), graduated licensing for new drivers (16%), installation of HOV lanes (25%), and traffic calming engineering improvements (40%). Similar to restricted licensing, photo radar and graduated licensing represent methods of changing driving behaviour to address the demands of the environment, and the reduction in crashes demonstrated in this study is in proportion to these other methods. Higher reductions in crashes were attained by the methods which directly manipulated the driving environment. However it must be noted that results in other jurisdictions and in other programs targeting the driver and the environment are highly variable. Likewise, restricted licensing applied to other groups of drivers in other jurisdictions may produce different results.

Another significant finding of this study is that drivers with restricted licenses actually retained their license for longer than drivers who were not restricted. That is, more unrestricted drivers had their license revoked while restricted drivers continued to be licensed. This is especially significant for the psychological well-being of these individuals. Rothe (1994) established that a license to drive is synonymous with self-respect, social membership, independence, and quality of life, and the loss of the right to drive creates a crisis in the older adult's life. Older men are particularly emotionally invested in their vehicles, and the loss of a license has been described in catastrophic

terms by many elderly drivers (Eisenhandler, 1993; Stutts, Wilkins, Reinfurt, Rodgman, & Van Heusen-Causey, 2001). Fonda, Wallace and Herzog (2001) showed that elderly drivers who stopped driving were at a greater risk of developing depressive symptoms, and this was not mitigated by having a spouse drive them. Even drivers who restricted their driving distances had a greater risk of worsening depressive symptoms, but less so than those who stopped altogether. The fact that restricted licenses can permit an elder to remain licensed, even though the driving must be reduced, is an important finding.

Results of Cox PH regression demonstrated that increasing age was a significant factor in the differential crash rates controlling for restrictions, increasing the odds of crashing by 1% for each year increase in age. In this study, drivers involved in post-restriction crashes were older, suggesting that age is an important prediction of crashes even among those with restrictions, and that a threshold level exists beyond which restrictions are not effective. Other studies have shown similar results. Daigneault et al. (2002) found that unrestricted drivers who were involved in 3 or more crashes over a 5-year period were older than crash-free drivers (mean age 69.4 versus 80.1 years), and that they demonstrated executive function declines such as reduced mental flexibility, decreased adjustment to environmental changes, and decreased planning capabilities. These drivers reported driving slower and intending to be more careful with their driving, but their higher crash rate

indicates this strategy was not effective and supports the hypothesis that there is a threshold beyond which declines cannot be compensated for. The authors concluded, "These drivers adopt behaviours that are generally more careful but not necessarily appropriate for every specific situation and/or sufficient to compensate for poor cognitive functioning". The finding that advanced age is a predominant factor for increased crash risk may have consequences for licensing administrators, especially in regards to the duration of a license. Whereas at age 70 years a restricted driver might be expected to continue driving relatively safely for say, 10 years, at age 85 a restricted driver might be expected to remain safe for only 3 years. With advancing age, administrators may be well advised to reduce the period of time between re-evaluations for license renewal among very old drivers.

This study addressed the hypothesis that older drivers who are issued a restricted license are more likely to have been involved in a recent crash than drivers who continue to drive unrestricted. This question is important in establishing the projected crash risk of the drivers in the study, as well as exploring what factors contribute to the issuing of restricted licenses. Results demonstrated that those who eventually became restricted had a higher at-fault crash rate prior to their restriction than drivers who never received a restricted license. Men were more likely to be involved in a crash, a result which is consistent with the findings of others (Chandraratna, Stamatiadis & Stromberg, 2006; Chipman, MacGregor, Smiley, & Lee-Gosselin, 1993). And

since prior crashes for elders are predictive of subsequent crashes (Daigneault et al., 2002), it would be expected that the projected crash rate of the restricted driver group would be higher than that of the unrestricted group if all individuals continued to drive unrestricted. This suggests that the positive impact of restricted licenses found in the survival analysis actually underestimates the effect. This finding also helps to establish a measure of success regarding crash reduction strategies. For restricted licenses to be considered successful, road safety administrators would need to carefully examine the costs and benefits of various levels of crash reduction in this at-risk population. For example, a zero crash rate would be possible if all driver's licenses were revoked, however the psychosocial consequences of revoking a license have been shown to be very negative (Fonda et al., 2001). On the other hand, if the number of crashes in this group of drivers is expected to increase over time, a strategy that resulted in the levelling-off of crashes while protecting the psychological well-being of the individual might be considered successful. Since this group of drivers was expected to have higher crash rates than the general population, and since restrictions resulted in a lower crash rate, the effect of restricted licenses is pronounced.

Results of this study partially supported the hypothesis that restricted license holders would cause less severe crashes than unrestricted drivers. Higher speeds of travel are generally associated with more severe injuries in collisions, and it was expected that restrictions forbidding high-speed travel

would therefore result in fewer injury collisions. No difference in the number of injury-related crashes was found between restricted versus unrestricted drivers. This may be interpreted as a positive finding. As drivers age, they are associated with more injury crashes, especially for drivers over age 70 years. This effect has been explained at least partly by the increased physical frailty that accompanies aging, such that older drivers are more likely to be injured in otherwise less severe collisions (Keall & Frith, 2004). Since the restricted group had a higher proportion of drivers over age 85, an increase in number of injury claims would be expected. Thus the levelling-off effect of number of injury claims represents an actual decline in projected injury claims for restricted drivers. No statistically significant difference was found between restricted and unrestricted drivers for the computed severity score, but this result may be due primarily to methodological problems. In computing the severity score, a weighting scale with equal intervals was used. Further studies may be needed to develop a weighting system that would better represent the incremental difference between minor and major material damage, between major material damage and injury, and between injury and death.

It was hypothesized that a speed component would add significantly to the environmental press of the driving environment by demanding not only accurate and appropriate responses, but also quick responses. Since older adults generally show a slowing of motor reflexes (Mano et al., 1992) as well

as perceptual processing (Macdonald, Hultsch, Strauss, & Dixon, 2003), time-dependent tasks become more difficult. Thus it was hypothesized that restrictions that targeted specifically a speed component would have a greater impact. Results of this study, however, showed no difference in effectiveness for speed-related restrictions compared to others. This may be explained at least partly by the fact that restrictions for geographical area of travel often limit the driver to a small area close to their residence, and so inherently eliminate highway or higher speed driving. Also, very few drivers had only one type of driving restriction. The most common restriction combination was for limited speed and daylight-only travel, held by two thirds of the restricted drivers. Both of these types of restrictions address visual processing declines which contribute substantially to the speed aspects of driving.

Among drivers in this study who retained a license for at least 3 years prior to 2002, those who had experienced an at-fault crash were 1.6 times more likely to be recalled for a road test, and both male gender and advanced age were significant predictors of road test recall. For older drivers then, it appears that causing a collision precipitates referral for a road exam, especially for drivers of advanced age. However, the finding that male gender is more likely to be recalled for a road test may be a partially spurious result. Other studies have shown that women are less confident of their driving skills and are more likely to cease driving prematurely (Stutts et al., 2001). It is

therefore possible that older female drivers who caused collisions were also referred for re-exam, but that they were more likely to give up driving rather than report for the test. Further studies that examine the refusal rate among older drivers would be required to verify this.

Among older drivers who do take a road test, neither gender nor the number of prior collisions predicted getting a restricted license; age was the only statistically significant predictor. Thus there appears to be no gender bias for issuing restricted licenses, so that road examiners are not more likely to pass an elderly man or elderly woman with restrictions. Instead, advanced age was found to be the only predictor of restricted licensing which suggests either an age bias, such that examiners believe driving is incongruent with advanced age, or else a correlation between age and declining driving skills demonstrated during the road test. The former explanation is less likely, since if an age bias existed amongst the examiners who tested these older drivers, they would be more likely to rescind a license altogether.

The above findings are consistent with the P-E Fit Model of behaviour that associates aging with a decline in personal resources available to meet the demands of the environment. In this study, the finding that age predicts both road exam recall and subsequent restricted licensing suggests that among a subset of older drivers in BC, advanced age is accompanied by reduced driving skills resulting in a crash, and this reduction of skills is verified

by on-road driving re-evaluation that ultimately results in issuing a restricted license. However there are likely numerous other important factors in addition to age, gender, and crash involvement that could predict who would receive a restricted license. Further studies could be designed to examine the influence of factors such as number of medical conditions, educational level, years of driving experience, area of residence, and even driver examiner characteristics.

The impact of restricted licenses on family and friends of elderly drivers warrants discussion. Several studies have examined the effect of the loss of a driver's license on the elderly, however less is known about the stress on family members who suspect their elderly relative is driving in conditions above their abilities. On the one hand, if the senior loses all driving privileges, then the stress of worrying about crash involvement of the relative or friend will be eliminated. On the other hand, all responsibility for transportation becomes the burden of someone else. Authorities are sometimes reluctant to rescind a license, especially in rural areas, because of the pressure it places on family caregivers to provide transport, or because there is no family able or willing to provide support. Taylor and Tripodes (2001) reported 42% of caregivers had to miss work frequently or occasionally, and 13% quit work altogether to provide transportation to dementia patients who had recently lost their driver's license. It has also been found that although many family members were able to recognize unsafe driving among their relatives, few

had the support of physicians, police, or licensing authorities, resulting in increased stress among family members. In many instances the physician did not agree with the family member about the seriousness of the problem, and the police and licensing officials often missed opportunities to intervene. Family members also sometimes did not intervene despite driving difficulties displayed by the elderly parent. Barriers to intervention included negative feelings due to conflicts over the anticipated role reversal with the child becoming the parent, guilt over causing loss of independence, fear of meddling in what might be perceived by others as a minor concern, being too busy to provide rides to the displaced driver, and fear of revenge or retribution (Sterns et al. 2001). Allowing limited use of a vehicle by an aging driver may substantially reduce the emotional and physical burdens of others.

Limitations

Results of this study were dependent upon the ways in which drivers in this province were selected for restricted licenses, and other jurisdictions may vary substantially in their selection processes. Jurisdictions that use restricted licensing may also differ in how they evaluate eligible drivers, and in what types of restrictions are used for different driver characteristics. For these reasons, results of this study may not be generalizable to other regions.

In this study, driving exposure data for number of hours or kilometres driven was not available. This may be considered by some to be a significant

weakness of the study since it does not allow for calculation of crashes per kilometre driven. It may be argued that the prolonged crash-free driving of the restricted driver group does not actually show reduced risk of crash while behind the wheel, but instead is a result of reduced exposure. In fact numerous studies have shown that as individuals age they typically reduce their amount of driving, especially in advanced years. However, encouraging reduced exposure is actually the purpose of restricted licenses. Rather than eliminating a license altogether, it is hoped that a mandated restriction of driving will result in a reduction in kilometres driven under high-demand situations, which may result in reduced total exposure, and ultimately in a reduction in crashes caused by these drivers.

Another argument put forth by restricted licensing opponents is that older crash-involved drivers, if left alone, would stop driving on their own and that restricted licenses only encourage them to continue. Prior evidence does not support this assumption. Although some studies have shown that drivers declare being involved in a crash or near-crash would make them consider giving up driving (Ragland, Satariano & MacLeod, 2004; Rudman, Riedland, Chipman & Sciortino, 2006), others have shown that crash involvement was a relatively minor contributor to actual driving cessation (Adler & Kuskowski, 2003; Carr, Shead & Storandt, 2005; Persson, 1993). Even if restricted licenses do encourage drivers to continue driving, results of this study show that they do so at a reduced risk of causing a crash.

A further component of driving exposure is the level of compliance which, of course, affects exposure to excess press and potentially results in maladaptive behaviour. In the worst case scenario all older drivers could ignore their restrictions and continue driving unrestricted, but the reduced crash rate of the restricted group in this study suggests this did not happen, and in fact suggests the majority comply with their restriction. Older citizens as a group tend to have a more negative view of others who commit traffic offences (Yagil, 1998), and are generally more compliant with regulations such as speed limits (Elliott, Armitage & Braughan, 2003). On the other hand, Yagil (1998) demonstrated that older drivers' motivation for complying with traffic regulations is predicted more by a perceived danger of getting caught than by a sense of obligation to obey the law. This may be addressed by the use of vehicle identifiers similar to those used by novice drivers. Especially among rural drivers, motivation to comply with certain restrictions may be undermined by practical needs. Furthermore, Azad et al. (2002) found that among patients referred to a memory clinic, only 7.6% continued to drive despite specific instructions to stop. In North Carolina, Stutts et al. (2000) found only 4.5% of older drivers said they never comply with their restrictions and an additional 12% said they sometimes do not comply. In the current study, it is therefore likely that at least some of the crashes caused by restricted drivers occurred when individuals were driving contrary to their restrictions. Further studies using in-vehicle driver recorders, driver logs,

interviews, or studies examining crash characteristics such as crash location and time of day for restricted drivers could provide more information on compliance with restricted licensing.

The question of compliance is salient to driver regulation policies. It seems reasonable that drivers are more likely to comply with restrictions that they consider are just, and that do not unreasonably reduce their autonomy or access to services. Marshall et al. (2007) interviewed 86 elderly licensed drivers in Ottawa, Ontario, where the only form of restricted licensing is for corrective lenses for visual acuity. Using a modified standard gamble technique where loss of license was assigned a value of 0 and an unrestricted license a value of 1, they asked each driver to rate the acceptability of 11 hypothetical types of driving restrictions. Restrictions receiving the highest utility scores were requirement for corrective lenses (0.98), vehicle adaptations (0.94), having to undergo regular assessments (0.94), driving during daytime only (0.93), and avoiding major highways (0.89). Lowest scores were found for driving restrictions limiting speed to 60 km/h or less (0.50), driving within a 10-km radius of home (0.45), driving to specific destinations only (0.45), and driving only when accompanied by another licensed driver (0.42). No differences were found between men and women, but limiting speed below 60 km/h was significantly less acceptable for rural drivers, presumably because it would limit their access to services. In the current study, 3.6% of drivers had a restriction for 60km/h and 11.9% had

restrictions for radius of travel, restrictions found to be poorly tolerated in the Ontario study. However results in the current study did not show any statistically significant difference in crashes for the various restrictions, possibly suggesting no differences in compliance between types of restrictions in this study. Further studies are needed to determine how, for instance, rural versus urban residence, gender, age, and other factors affect acceptability of, and compliance with specific driving restrictions.

This study was limited to an examination of three types of driving restrictions currently being used in the province of British Columbia: limited speed of travel, limited radius of travel, and limited daylight travel. These restrictions were chosen because discussions with road examiners and licensing administrators revealed they are most likely associated with age-related changes. However, there are other types of restrictions that could be (but are not necessarily) associated aging, such as corrective visual lenses and vehicle modifications. It is possible that if these restrictions could have been identified as age-related for each individual and included in the analysis, the results might have been different. This seems unlikely though, since ICBC road examiners stated most of the drivers who receive age-related restrictions for visual defects or physical disabilities also receive restrictions for daylight travel, speed, and/or geographical area, and so would already have been included in the analysis.

CHAPTER 6: CONCLUSIONS

Results of this study demonstrate that the crash-free driving life expectancy of older drivers may be extended through the use of restricted licenses. These results lend support to the P-E Fit Model of behaviour that affirms positive outcomes are possible only when the press of the environment can be matched by the resources of the individual. The findings of this study may be used to inform policy makers about strategies to mitigate the expected increase in crashes caused by the growing number of older drivers.

A critical factor in the results of this study is the method used in awarding restricted licenses. Especially when restrictions are based on road test evaluations, results are somewhat subjective in that the road examiner must make decisions on, for instance, whether the older driver appears to be aware of potential hazards, or whether the older driver could react quickly enough in a high-speed emergency. Significant inter-rater variability may exist, with some examiners being very strict about level of skill required, while others are more concerned about the tradeoffs between the risk of crash and the psychosocial wellbeing of the elder. In addition, the basic criteria used in determining eligibility for a restricted license may differ significantly between

regions. For example, in some regions a diagnosis of mild cognitive impairment may provoke evaluation for a restriction whereas in other regions it may result in automatic cancellation of the license. Since the success of restricted licensing rests on the appropriateness of its use, standardized methods of driver evaluation may be particularly useful.

Restrictions examined in this study represent one method of mitigating the crash risk of older drivers. It is possible that other types of restricted licenses could be developed that would lower crash rates further, for example a restriction on the length of each individual trip taken by the elderly driver. Such a restriction might be particularly useful in dealing with drivers of advanced age. The importance of declining ability to divide attention between tasks is evidenced in the earlier fatigue of older drivers. Freund and Colgrove (2007) found that a group of drivers they classified as *restricted* (safe under certain circumstances) did not differ from safe drivers over short periods of time. For the *restricted* category of drivers a list of 29 unique recommendations was developed to address the types of errors displayed by this group. Recommendations for restricted distance, area, and duration of trip were the most common categories of restrictions identified. The authors noted that identification of a need to limit driving time to a maximum of 30 minutes per trip arose out of the acknowledgement of increased workload experienced by aging drivers and the resultant fatigue after relatively short

periods. This finding identifies a possible new category of driving restriction that could help reduce crashes caused by elderly drivers.

Horberry, Anderson, Regan, Triggs, and Brown (2006) have presented some evidence that could support perhaps another category of driving restriction that may be appropriate for aging drivers. Participants in a driving simulator were challenged with an auditory question and answer conversation, with an in-vehicle entertainment/information system, and with complex external stimuli (billboards, buildings, vehicles) while attempting to avoid hazards such as pedestrians and backing vehicles. Mean speed and deviation from the posted speed limit were used as measures of mental workload. Older adults slowed more and deviated more from the posted speed limit when attempting to perform the entertainment/information system task, but not the auditory and external visual tasks. As personal resources decline with aging, restrictions regarding in-vehicle technologies such as computers and hand-held mobile phones that require the user to take their eyes off the road could be considered.

The key message that may be taken from this study is that allowing aging drivers to continue to hold a driver's license that appropriately restricts their use of a motor vehicle does not appear to increase the risk to the community or the older driver, and may contribute positively to the psychosocial well-being of the individual.

Policy Implications

Based on the findings of this study, it is recommended that licensing authorities include restricted licensing in programs aimed at reducing crashes for older drivers. Although restricted licensing alone cannot completely eliminate crashes involving older adults, its contribution to significantly reducing the crash risk, while supporting the psychosocial well-being of the individual and the society as a whole, should be acknowledged and acted upon.

Implementing a policy of issuing restricted licenses should be done on a case-by-case basis. Since advancing age is characterized by a high level of variability in the decline of personal resources, it would not be appropriate to apply restrictions based on factors such as age, gender, or geographical area of residence. Rather, driving restrictions should be tailored to the individual's level of resources that affect their driving. In order to accomplish this, administrators need to develop clear guidelines as to what levels of personal resources are appropriate for specific driving restrictions. Furthermore, these guidelines should be communicated to driver examiners, medical professionals, and licensing administrators, so that the restrictions are applied in a consistent and fair manner. This is needed to maximize the effectiveness of the policy, and to realize the potential gains in terms of reduced crashes.

In implementing policy, success is affected by the level of compliance with the policy. It is therefore recommended that a method of ensuring compliance with restrictions be developed. This should take two forms: enforcement and education. Enforcement could be accomplished by identifying vehicles driven by restricted drivers in a manner similar to how vehicles driven by novice drivers are identified by a letter N or L in British Columbia, or how proof of vehicle insurance is displayed as a license plate sticker. Penalties are assessed by enforcement officers against drivers who do not comply with the requirements of their license. An educational component should also be included, targeting both the restricted driver and the general public to raise awareness of the policy and its implications, and to encourage public support in reporting non-compliant drivers. Similar education campaigns have proven useful in enforcing drunk-driving and drunk-boating policies.

The issue of education is important in implementing a systematic restricted-licensing policy. Given that age-related restricted licenses are designed for older adults whose driving skills have declined, efforts should be made to maximize the use of the individual's remaining resources. It is recommended that all drivers who are issued age-related restrictions be required to attend a driver refresher program that targets not only road knowledge, but also compensatory driving skills such as adequate shoulder checks, scanning for hazards, and emergency braking.

Results of this study demonstrated that a large proportion of restricted licenses are issued at age 80 years. This highlights the effectiveness of the mandatory medical certificate at age 80 in identifying potentially high-risk drivers. However, the sudden increase in restrictions at age 80 years, coupled with the increase in crashes for those between age 70 and 80 years, suggests a significant number of drivers younger than age 80 may also be at high risk. It is therefore recommended that mandatory medical certification be considered earlier than age 80 years, and at least as young as age 75 years.

Future Work

Since the impacts of age-related driving restrictions on the crashes of older adults have not been previously studied, a significant amount of additional research needs to be carried out to answer key questions for policy makers. For example, studies should be conducted to identify factors such as specific driving styles or habits that may be used to predict drivers who would most benefit from restricted licenses; some drivers may be better able to adapt to changes than others. Types of crashes caused by both restricted and unrestricted drivers should also be examined to inform how restrictions change the driving patterns of older drivers, and to help in developing new or better categories of restrictions.

Further examination of ICBC data may reveal effects of other characteristics such as years of driving experience or area of residence

(especially urban versus rural) on restricted licenses and crashes.

Examination of crash records may also reveal the proportion of restricted drivers who have crashes while driving outside the boundaries of their restrictions, and the crashes of individuals who continue to drive despite having their license rescinded. Driver interviews may help in understanding why some drivers do not comply with the terms of their license, and may be used to develop materials to increase the level of compliance.

The effect of exposure on risk of crash has not been addressed in this study. Further research is required to determine the interaction between crash risk, reduced driving, and driving restrictions. Driving exposure may be measured through driver logs or in-car data recorders. However, to avoid recall bias, a prospective study must be designed to detect changes in driving prior to, versus after driving restrictions are imposed. Since it is difficult to predict which drivers will eventually become restricted, a large sample size would be needed, and these drivers must be followed for several years.

Finally, qualitative studies could be used to determine the attitudes of older drivers and the whole community towards restricted licenses.

Especially, the acceptability of the recommendations for reducing the age of requirement for a medical certificate, the identification of vehicles driven by restricted drivers, and penalties for non-compliance should be studied. Cost-

benefit analyses of these policies, including both financial and social aspects, would help in developing effective and acceptable strategies.

REFERENCES

- Adler, G., & Kuskowski, M. (2003). Driving cessation in older men with dementia. *Alzheimer Disease and Associated Disorders*, 17(2), 68-71.
- Allison, P. D. (1995). *Survival Analysis Using SAS. A Practical Guide*. Cary, NC: SAS Institute Inc. 292 p.
- Anderson, N. D., Ikadaka, T., Cabeza, R., Kapur, S., McIntosh, A. R., & Craik, F. I. M. (2000). The effects of divided attention on encoding- and retrieval-related brain activity: A PET study of younger and older adults. *Journal of Cognitive Neuroscience*, 12(5), 775-792.
- Azad, N., Byszewski, A., Amos, S., & Molnar, F. J. (2002). A survey of the impact of driving cessation on older drivers. *Geriatrics Today*, 5, 1710-174.
- Ball, K., & Owsley, C. (1993). The useful field of view test: a new technique for evaluating age-related declines in visual function. *Journal of the American Optometry Association*, 64, 71-80.
- Ball K, & Owsley C. (1994). Predicting vehicle crashes in the elderly: Who is at risk? In Johansson K., & Lundberg C. (eds). *Aging and Driving*. Stockholm: Karolinska Institutet, pp 115-127.
- Ball, K., Owsley, C., Stalvey, B., Roenker, D. L., Sloane, M. E., & Graves, M. (1998). Driving avoidance and functional impairment in older drivers. *Accident Analysis and Prevention*, 30 (3), 313-322.
- Benekohal, R. F., Resende, P., Shim, E., Michaels, R. M., & Weeks, B. (1992). *Highway Operations Problems of Elderly Drivers in Illinois*. Publication No. FHWA-IL-92-023, Springfield, IL: Illinois Department of Transportation.

- BC Stats. (2000). Road collisions. *Infoline: Highlights*, August 25, Issue 00-34.
- Brabyn, J., Schneck, M. E., Haegerstrom-Portnoy, G., & Steinman, B. (1994). Vision test performance and accident proneness in drivers over the age of 55. In *Vision Science and its Applications*, 1994 Technical Digest Series, Vol. 2, Washington DC: Optical Society of America, pp210-213.
- Bradburn, M. J., Clark, T. G., Love, S. B., & Altman, D. G. (2003). Survival Analysis Part III: Multivariate data analysis – choosing a model and assessing its adequacy and fit. *British Journal of Cancer*, *89*, 605-611.
- Burkhardt, J.E., Berger, A.M., Creedon, M., & McGavock, A.T. (1998). Mobility and independence: Changes and challenges for older drivers. Washington: National Highway Traffic Safety Administration.
- Campbell, J. R., & Knapp, K. K. (2005). Alternative crash severity ranking measures and the implications on crash severity ranking procedures. *Proceedings of the 2005 Mid-Continent Transportation Research Symposium*, Ames, Iowa, August.
- Carr, D. B., shead, V., & Storandt, M. (2005). Driving cessation in older adults with dementia of the Alzheimer's type. *The Gerontologist*, *5*(6), 824-82.
- Chandraratna, S., Stamatiadis, N., & Stromberg, A. (2006). Crash involvement of drivers with multiple crashes. *Accident Analysis and Prevention*, *38*(3), 532-541.
- Charlton, J., Oxley, J., Fildes, B, Oxley, P., & Newstead, S. (2003). Self-regulatory behaviour of older drivers. *Annual Proceedings of the Association for the Advancement of Automotive Medicine*, *47*, 181-194.
- Chipman, M. L., MacGregor, C. G., Smiley, A. M., & Lee-Gosselin, M. (1993). The role of exposure in comparisons of crash risk among different drivers and driving environments. *Accident Analysis and Prevention*, *25*(2), 207-211.

- Cranney, A. B., Harrison, A., Uhland, L., Vaidyanath, C., Graham, I., Man-Son-Hing, M., Jaffey, J., Towheed, T. E., Anastassiades, T. P., & Dwosh, II. (2005). Driving problems in patients with rheumatoid arthritis. *Journal of Rheumatology*, *32*(12), 2337-2342.
- Daigneault, G., Joly, P., & Frigon, J. (2002). Previous convictions or accidents and the risk of subsequent accidents of older drivers. *Accident Analysis and Prevention*, *34*, 257-261.
- de Leur, P., & Sayed, T. (2001). Using claims prediction model for road safety evaluation. *Canadian Journal of Civil Engineering*, *28*, 804-812.
- De Raedt, R., & Ponjaert-Kristoffersen, I. (2000). Can strategic and tactical compensation reduce crash risk in older drivers? *Age and Ageing*, *29*, 517-521.
- deWaard, D. (1996). The measurement of drivers' mental workload. PhD thesis, University of Groningen. Haren, The Netherlands: University of Groningen, Traffic Research Centre.
- Eisenhandler, S. A. (1993). The asphalt identikit: old age and the driver's license. *International Journal of Aging and Human Development*, *30*(1), 1-14.
- Elliott, D. B., Trukolo-Ilic, M., Strong, J. G., Pace, R., Plotkin, A., & Bevers, P. (1997). Demographic characteristics of the vision-disabled elderly. *Investigations in Ophthalmology and Visual Science*, *38*, 2566-2575.
- Elliott, M. A., Armitage, C. J., & Baughan, C. J. (2003). Drivers' compliance with speed limits: An application of the Theory of Planned Behavior. *Journal of Applied Psychology*, *88*(5), 964-972.
- Evans, D.A., Funkenstein, H. H., & Albert, M. S. (1989). Prevalence of Alzheimer's disease in a community population of older persons: higher than previously reported. *JAMA*, *262*, 2551-2556.
- Fisher, P., Jungwirth, S., Zehetmayer, S., Weissgram, S., Hownigschnabl, S., Gelpi, E., Krampla, W., & Tragl, K. (2007). Conversion from subtypes of mild cognitive impairment to Alzheimer dementia. *Neurology*, *68*(4), 288-291.

- Fitten, L. J., Perryman, K. M. Wilkinson, C. J., Little, R. J., Burns, M. M., Pachana, N., Mervis, J. R., Malmgren, R., Siembieda, D. W., & Ganzell, S. (1995). Alzheimer and vascular dementias and driving: a prospective road and laboratory study. *JAMA*, *273*, 1360-1365.
- Flahaut, B. (2004). Impact of infrastructure and local environment on road unsafety. Logistic Modeling with spatial autocorrelation. *Accident Analysis and Prevention*, *36*, 1055-1066.
- Fonda, G. (1989). Legal blindness can be compatible with safe driving. *Ophthalmology*, *96*, 1457-1459.
- Fonda, S. J., Wallace, R. B., & Herzog, A. R. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *Journal of Gerontology: Social Sciences*, *56B*, (6), S343-S351.
- Freeman, E. E., Gange, S. J., Munoz, B., & West, S. K. (2006). Driving status and risk of entry into long-term care in older adults. *American Journal of Public Health*, *96*(7), 1-6.
- Freund, B., & Colgrove, L. A. (2007). Error specific restrictions for older drivers: Promoting continued independence and public safety. *Accident Analysis and Prevention*, (in press).
- Freund, B., Colgrove, L. A., Petrakos, D., & McLeod, R. (2007). In my car the brake is on the right: Pedal errors among older drivers. *Accident Analysis and Prevention*, (in press).
- Fonda, S. J., Wallace, R. B., & Herzog, A. R. (2001). Changes in driving patterns and worsening depressive symptoms among older adults. *Journals of Gerontology B: Psychological and Social Sciences*, *56*(6), S343-S351.
- Garden, S. E., Phillips, L. H., & MacPherson, S. E. (2001). Midlife aging, open-ended planning, and laboratory measures of executive function. *Neuropsychology*, *15* (4), 472-482.
- Garson, G. D. (1998). *Multiple Regression*. Clearwater FL: Statistics Solutions, Inc. 82 pp.

- Griffin, L. I. (2004). Older driver involvement in injury crashes in Texas, 1975-1999. Washington: AAA Foundation for Traffic Safety.
- Hakamies-Blomqvist, L. (1994). Compensation in older drivers as reflected in their fatal accidents. *Accident Analysis and Prevention*, 26(1), 107-12.
- Hakamies-Blomqvist, L, Siren, A., & Davidse, R. (2004). Older drivers – a review. *Swedish National Road & Transport Research Institute VTI rapport 497A*.
- Herriotts, P. (2005). Identification of vehicle design requirements for older drivers. *Applied Ergonomics*, 36,(3), 255-262.
- Ho, G., Scialfa, C., Caird, J., & Graw, T. (2001). Conspicuity of traffic signs: the effect of clutter, luminance and aging. *Human Factors*, 43, 194-207.
- Horberry, T., Anderson, J., Regan, M.A., Triggs, T.J., & Brown, J. (2006). Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis and Prevention*, 38(1), 185-191.
- ICBC (unpublished). Data extracted from licensing database, September, 2007.
- Insurance Institute for Highway Safety. (2001). They aren't dangerous, except maybe to themselves. *Status Report 36(8)*, September 8.
- Insurance Institute for Highway Safety. (2003). Who poses the greater risk, older or younger drivers? *Status Report 38(3)*, March 15.
- Iwarsson, S. (2005). A long-term perspective on person-environment fit and ADL dependence among older Swedish adults. *The Gerontologist*, 45 (3), 327-336.
- Johnson, C. A., & Keltner, J. L. (1983). Incidence of visual field loss in 20,000 eyes and its relationship to driving performance. *Archives of Ophthalmology*, 101, 371-375.
- Jones, J. G., McCann, J., & Lassere, M. N. (1991). Driving and arthritis. *British Journal of Rheumatology*, 30(5), 361-364.

- Kaneko, R., Kuba, Y., Sakata, Y., & Kuchinomachi, Y. (2004). Aging and shifts of visual attention in saccadic eye movements. *Experimental Aging Research*, *30*, 149-162.
- Karlaftis, M. G., & Golias, I. (2002). Effects of road geometry and traffic volumes on rural roadway accidents. *Accident Analysis and Prevention*, *34*, 357-365.
- Keall, M. D., & Frith, W. J. (2004). Older driver crash rates in relation to type and quantity of travel. *Traffic Injury Prevention*, *5*, 26-36.
- Khan, I. H., & Prescott, G. J. (2004). A primer on survival analysis. *Journal of Nephrology*, *17*, 216-222.
- Kleinbaum, D. G., & Klein, M. (2005). *Survival Analysis. A Self-Learning Text*. 2nd Edition. New York, NY: Springer. 616 p.
- Lam, L.T. (2003). Factors associated with fatal and injurious car crash among learner drivers in New South Wales, Australia. *Accident Analysis and Prevention*, *35*(3), 333-340.
- Lawton, M. P. (1980). *Environment and Aging*. (pp 10-19) Monterey, CA: Brooks/Cole Publishing Company.
- Lawton, M. P. (1982). Competence, Environmental press, and the Adaptation of Older People. (pp 33-59). In: Lawton, Windley & Byerts (Editors) *Aging and the Environment, Theoretical Approaches*. New York: Springer Publishing Company.
- Lawton, M. P., & Nahemow, L. (1973). Ecology and the aging process. In: C. Eisdorfer & M.P. Lawton (Eds.) *The Psychology of Adult Development and Aging*. (pp. 619-674). Washington DC: American Psychological Association.
- Levy, R. (1994). Aging-associated cognitive decline. *International Psychogeriatrics*, *6*(1), 63-68.
- Lewin, K. (1951). *Field Theory in Social Science*. New York, NY: Harper & Row.

- Livingston, L. P., Nelson, D. L., & Barr, S. H. (1997). Person-environment fit and creativity: an examination of supply-value and demand-ability versions of fit. *Journal of Management, March-April*.
- Lyman, S., Ferguson, S. A., Braver, E. R., & Williams, A. F. (2002). Older driver involvements in police reported crashes and fatal crashes: trends and projections. *Injury Prevention, 8*, 116-120.
- MacDonald, S. W., Hultsch, D. F., Strauss, E., & Dixon, R. A. (2003). Age-related slowing of digit symbol substitution revisited: what do longitudinal age changes reflect? *Journals of Gerontology B: Psychological Sciences and Social Sciences, 58*(3), P187-P194.
- Madsen, D. G., & Wright, D. G. (1998). An effectiveness analysis of SafeStat (Motor Carrier Safety Status Measurement System). US DOT Paper No. 990448. Available at <http://ai.volpe.dot.gov/CarrierResearchResults/TextFiles/Effect2.txt>.
- Maltz, M., & Shinar, D. (1999). Eye movements of younger and older drivers. *Human Factors, 41*, (1), 15-25.
- Mano, Y., Nakamuro, T., Ikoma, K., Sugata, T., Morimoto, S., Takayanagi, T., & Mayer, R. F. (1992). Central motor conductivity in aged people. *Internal Medicine, 31*(9), 1084-1087.
- Marshall, S. C., Spasoff, R., Nair, R., & van Walraven, C. (2002). Restricted driver licensing for medical impairments: Does it work? *Canadian Medical Association Journal, 167*(7), 747-751.
- Marshall, S. C., Man-Son-Hing, M., Molnar, F., Wilson, K. G., & Blair, R. (2007). The acceptability to older drivers of different types of licensing restriction. *Accident Analysis and Prevention, 39*, 776-793.
- McGuckin, N., & Liss, S. (2005). Aging cars, aging drivers: important findings from the National Household Travel Survey. *ITE Journal, 75*(9), 30-37.
- McPhee, L. C., Scialfa, C. T., Dennis, W. M., Ho, G., & Caird, J. K. (2004). Age differences in visual search for traffic signs during a simulated conversation. *Human Factors, 46*(4), 674-685.

- Mortimer, R. G., & Fell, F. C. (1989). Older drivers: their night fatal crash involvement and risk. *Accident Analysis and Prevention*, 21(3), 273-282.
- Murray, H. A. (1938). *Explorations in Personality*. New York: Oxford University Press.
- Nasvadi, G. (unpublished). Results of focus group interviews with older drivers, September, 2005.
- Norusis, M. J. (2007). SPSS 15.0. *Advanced Statistical Procedures Companion*. Upper Saddle River, NJ: Prentice Hall. 418 pp.
- O'Neill, D., Neubauer, K., Boyle, M., Gerrard, J., Surmon, D., & Wilcock, G. K. (1992). Dementia and driving. *Journal of the Royal Society of Medicine*, 85, 199-202.
- Owsley, C., Ball, K., McGwin, G., Sloane, M. E., Roenker, D. L., White, M. F., & Overley, E. T. Visual processing impairment and risk of motor vehicle crash among older adults. *JAMA*, 279, 1083-1088.
- Persson, D. (1993). The elderly driver: deciding when to stop. *The Gerontologist*, 33, 88-91.
- Quadagno, J. (2002). *Aging and the Life Course, An Introduction to Social Gerontology*. 2nd Edition. New York NY: McGraw-Hill.
- Ragland, D. R., Satariano, W. A., & MacLeod, K. (2004). Reasons given by older people for limitation or avoidance of driving. *The Gerontologist*, 44(2), 237-244.
- Rahmani, B., Tielsch, J. M., Katz, J., Gottsch, J., Quigley, H., Javitt, J., & Sommer, A. (1996). The cause-specific prevalence of visual impairment in an urban population. *Ophthalmology*, 103(11), 1721-1726.
- Richardson, E. D., & Marottoli, R. A. (2003). Visual attention and driving behaviors among community-living older persons. *Journals of Gerontology A: Medical Sciences*, 58(9), M832-836.

- Rombro, C. (2001). Cost of large truck- and bus-involved crashes. *Analysis Brief, No. FMCSA-MCRT-01-005. March*. Available at <http://ai.volpe.dot.gov>.
- Rothe, P. J. (1994). *Beyond Traffic Safety*. New Brunswick and London: Transaction Publishers.
- Rubin, G. S., Roche, K. B., Prasada-Rao, P., & Fried, L. P. (1994). Visual impairment and disability in older adults. *Clinical Visual Science, 71*, 750-756.
- Rudman, D. L., Riedland, J., Chipman, M., & Sciortino, P. (2006). Holding on and letting go: the perspectives of pre-older drivers and older drivers on driving self-regulation in later life. *Canadian Journal on Aging, 25*(1), 65-76.
- Sagberg, F. (2006). Driver health and crash involvement: A case-control study. *Accident Analysis and Prevention, 38*, 28-34.
- Schaie, K. W. (1996). *Intellectual development in adulthood: The Seattle Longitudinal Study*. New York: Cambridge University Press.
- Schonknecht, P., Pantel, J., Kruse, A., & Schroder, J. (2005). Prevalence and natural course of aging-associated cognitive decline in a population-based sample of young-old subjects. *American Journal of Psychiatry, 162* (11), 2071-2077.
- Staplin, L., Lococo, K., Byington, S., & Harkey, D. (2001). *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*. McLean, VA: US Department of Transportation Federal Highway Administration. FHWA-RD-01-051.
- Statistics Canada. (1997). Medium Growth Projections. *Catalogue 89-519XPE*.
- Statistics Canada. (2001). BC Level Population Projection.
- Statistics Canada. (2001). Living Arrangements of Older drivers in BC. *BC Stats Issue 16*.

- Stelmach, G. E., & Nahom, A. (1992). Cognitive-motor abilities of the elderly driver. *Human Factors*, 34(1), 53-65.
- Sterns, H. L., Sterns, R., Aizenberg, R., & Anapole, J. (2001). *Family and friends concerned about an older driver*. Washington, DC: NHTSA Report No. DOT HS 809 307.
- Stutts, F. C., Stewart, J. R., VanHeusin-Causey, S. (2000). *An evaluation of restricted licensing for North Carolina's older drivers*. Chapel Hill, NC: University of North Carolina Highway Safety Research Center.
- Sutts, J. C., Wilkins, J. W., Reinfurt, D. W., Rodgman, E. A., & Van Heusen-Causey, S. (2001). *The Premature Reduction and Cessation Of Driving By Older Men And Women*. Chapel Hill, NC: University of North Carolina Highway Safety Research Center.
- Summala, H. (1985). Modeling driver behaviour: a pessimistic prediction? In L. Evans & R. C. Schwing (Editors). *Human Behaviour and Traffic Safety*, pp 43-65. New York: Plenum Press.
- Tabachnick, B. G., & Fidell, L. S. (2007). *Using Multivariate Statistics , 5th ed.* Boston: Allyn and Bacon.
- Talbot, A., Bruce, I., Cunningham, C. J., Coen, R. F., Lawlor, B. A., Coakley, D., Walsh, J. B., & O'Neill, D. (2005). Driving cessation in patients attending a memory clinic. *Age and Ageing*, 34, 363-368.
- Taylor, B. D., & Tripodes, S. (2001). The effects of driving cessation on the elderly with dementia and their caregivers. *Accident Analysis and Prevention*, 33, 519-528.
- TRB Transportation Research Board. (1988). *Transportation in an Aging Society: Improving mobility and safety for older persons – Volume 2 – technical papers*. Special Report 218. Washington (DC): National Research Council
- Voelcker-Rehage, & Alberts, (2007) Effect of motor practice on dual-task performance in older adults. *Journals of Gerontology B: Psychological Sciences and Social Sciences*, 62(3), P141-P148.

- Wartenberg, D., Ramsey, D., & Warner, J. (2000). The four most common types of epidemiological studies. *Epidemiology for Journalists*, Jan 24. http://www.facsnet.org/tools/ref_tutor/epidem/four.php3
- Wei, I., Lin, D. Y., & Weissfeld, L. (1998). Regression analysis of multivariate incomplete failure time data by modelling marginal distributions. *Journal of the American Statistical Association*, *84*, 1065-1073.
- West, C. G., Gildengorin, G., Haegerstrom-Portnoy, G., Schneck, M. E., Lott, L., & Brabyn, J. A. (2002). Is vision function related to physical functional ability in older adults? *Journal of the American Geriatrics Society*, *50*, 136-145.
- Wood, J. M. (2002). Aging, driving and vision. *Clinical and Experimental Optometry*, *85*(4), 214-220.
- Wood, J. M., & Troutbeck, R. (1995). Elderly drivers and simulated visual impairment. *Optometry and Visual Science*, *72*, 115-124.
- Yagil, D. (1998). Instrumental and normative motives for compliance with traffic laws among young and older drivers. *Accident Analysis and Prevention*, *30*(4), 417-424.
- Zheng, Y. Y., Cooper, P. J., & Dean, C. B. (2007). Modeling the contribution of speeding and impaired driving to insurance claim counts and costs when contributing factors are unknown. *Journal of Safety Research*, *38*(1), 25-33.

APPENDIX – PARAMETRIC SURVIVAL ANALYSIS

Using the SAS Lifereg procedure, log-likelihood ratio statistics were obtained for the various model distributions (Table 18). Since the log-likelihood values are negative, values closer to zero indicate a better fit. Statistically the log-normal model appears to be the best fit to the data, however since the U-shape of the distribution is inconsistent with the data, these results should be ignored and this model rejected. In the Weibull model the shape parameter less than 1 indicates the hazard is decreasing over time which is more consistent with the data.

Table 18 Log-likelihood statistics for restricted versus unrestricted drivers

	Log-likelihood	Scale	Shape
Exponential	-58364.324	1.000	1.000
Weibull	-58170.060	1.1524	0.8677
Log-logistic	-58119.355	1.1027	
Gamma	-58234.446**	0.6082	1.9834
Log-normal	-58096.829	2.3551	

** model did not converge

Taking the differences between nested models and multiplying by 2 yields likelihood-ratio chi-square statistics shown in Table 19 (Allison, 1995 p 89). The exponential model should be rejected ($p < .0001$) implying the

hazard is not constant over time. Caution is warranted in interpreting these results since the gamma model did not converge. However, the finding is consistent with the Lagrange multiplier test results from the SAS output (Chi-square 325.2197, $p < .0001$). The Lagrange multiplier statistic tests the hypothesis that the shape parameter is indeed equal to 1.0 so we reject the exponential model. The Weibull model differs significantly from the exponential model so may be a possible candidate for the distribution.

Table 19 Calculation of log-likelihood ratios

	Difference * 2	df	<i>p</i>
Exponential versus gamma	259.756	2	< .0001
Weibull versus gamma	128.772	1	< .0001
Exponential versus Weibull	388.528	1	< .0001

Graphical methods may also be used in evaluating the fit of a model. If the distribution of an event time is exponential, a plot of $-\log S(t)$ versus t should produce a straight line with origin at 0. For the Weibull model, the $\log(-\log)$ of $S(t)$ (LML) is linear with the log of time. Fit of the log-logistic model can also be tested graphically since the log odds of failure is a linear function of the log of time. A plot of $\ln(1-S(t))/S(t)$ versus $\ln(t)$ results in a straight line with slope equal to the shape parameter (Kleinbaum & Klein, 2005, p. 279).

The curves in Figure 14 confirm that the exponential model is a poor fit to the data. In Figure 15 and Figure 16 the lines are straight and in fact both

plots are almost identical, indicating both the Weibull distribution and the log-logistic distribution are reasonable approximations. This is consistent with the finding that the scale of the log-logistic model was greater than 1 (Table 18) so that the log-logistic model behaves like the Weibull distribution. However since the log-logistic model is not nested within the others, we can not formally test whether it is a better fit than the Weibull model (Allison, 1995, p 90).

Figure 14. Negative Log-survivor plot for exponential test

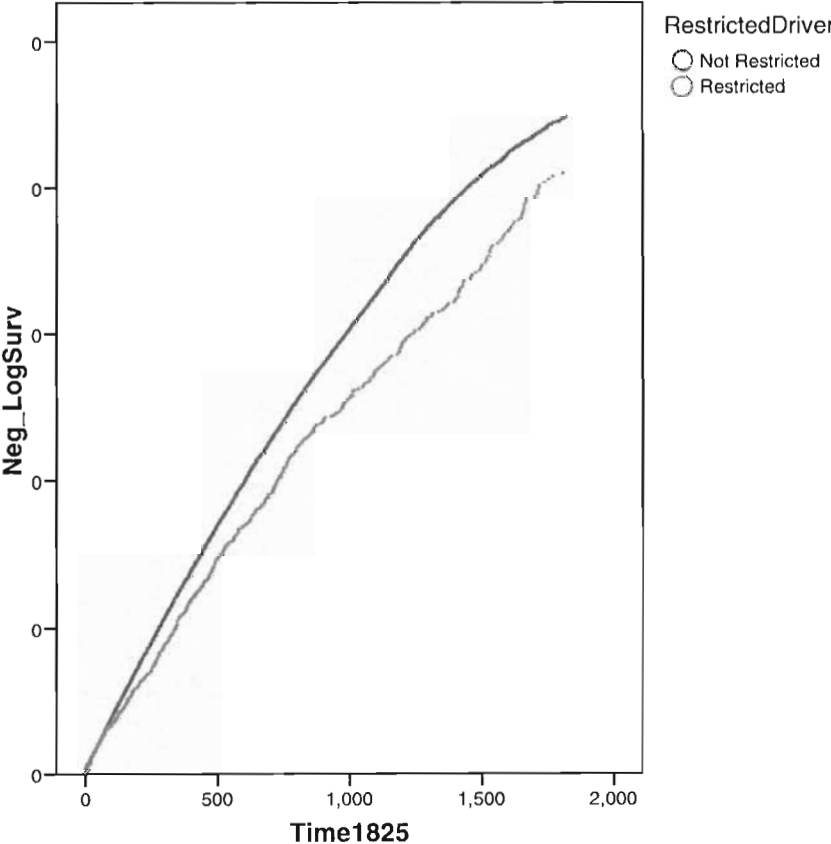


Figure 15. LML plot for Weibull test

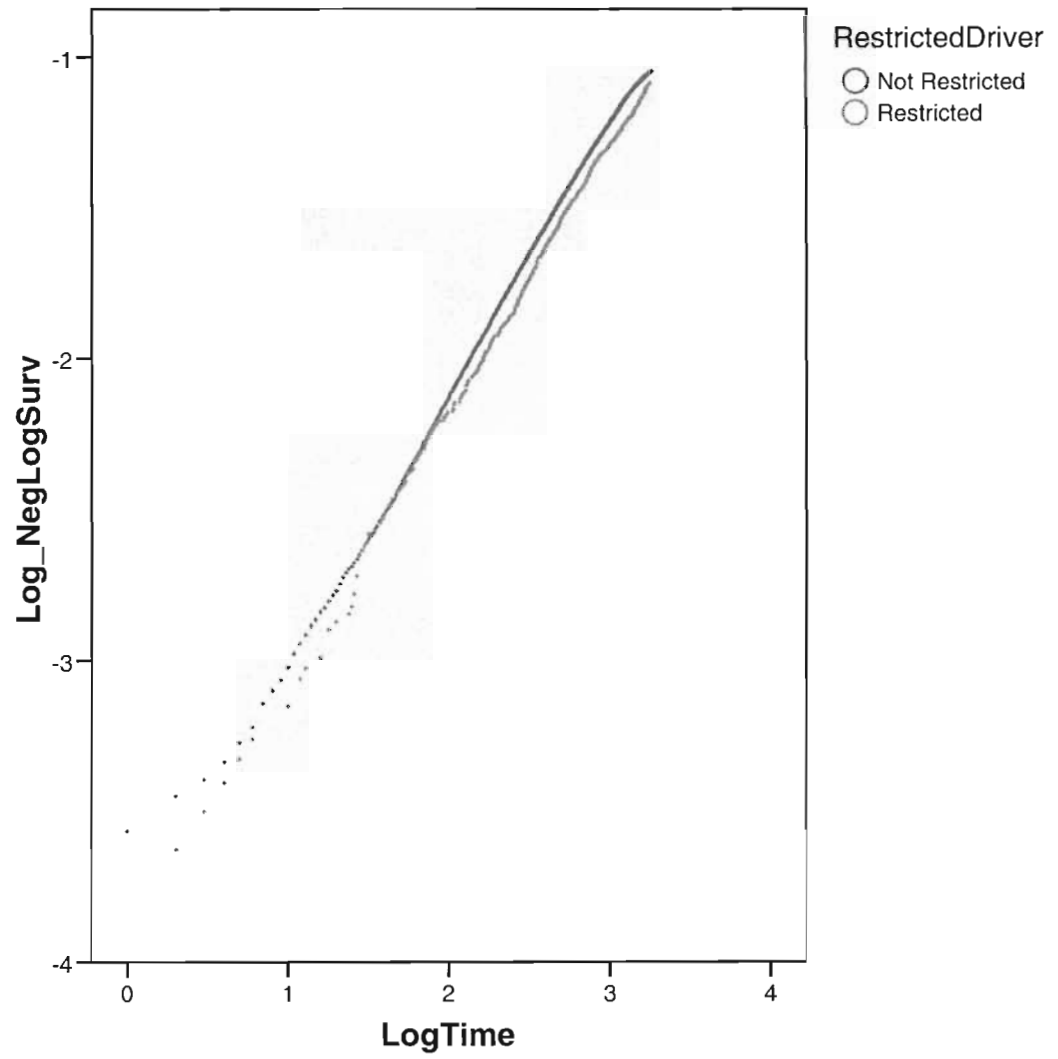


Figure 17. Log survival test for log-logistic model

