Ejections and Fatalities in Single-Vehicle Rollover Crashes: A Question of Restraint

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Abstract

In recent years, due to initiatives such as Road Safety Vision 2010, and the National Occupant Restraint Program, Canada has seen reductions in casualties resulting from motor vehicle collisions. Indeed, the most recent collision statistics, published in 2012, show the lowest death toll on the nation's roads in almost sixty years. Furthermore, the most recent seat belt surveys, conducted in 2009-10, indicate that Canadians are buckling up in motor vehicles more than ever, with an overall usage rate in excess of 95%. Despite these very encouraging signs, the percentage of motor vehicle occupants who are fatally injured while not using seat belts remains unacceptably high at more than 35%. This problem is particularly well exemplified by fatalities resulting from single-vehicle rollover crashes. Such collisions frequently occur as a result of loss of directional control on the part of the driver, and involve vehicle yaw and a lateral rollover, a crash mode that is often benign. Belted occupants are generally retained inside the vehicle and come to little harm. However, such may well not be the case for the unbelted who are in considerable danger of being ejected from the vehicle, with the consequent potential for serious or fatal injury. The present study looks at this latter issue, both from the perspective of the national collision picture, and from a series of in-depth investigations of fatal crashes.

Résumé

Ces dernières années, grâce à des initiatives comme Plan Stratégique Vision 2010 et le Programme canadien sur la protection des occupants, le Canada a observé une réduction des victimes de collisions automobiles. En fait, les plus récentes statistiques sur les collisions (2012) montrent le taux le plus bas d'accidents mortels sur les routes du pays depuis presque 60 ans. En outre, les sondages les plus récents sur le port de la ceinture de sécurité, menés en 2009-2010, montrent que les Canadiens attachent plus que jamais leur ceinture de sécurité, avec un

taux global de port de la ceinture de plus de 95 %. Malgré ces indications très encourageantes, le pourcentage des occupants de véhicule qui sont blessés mortellement parce qu'ils ne portent pas leur ceinture reste à un taux élevé inacceptable : plus de 35 %. Ce problème est particulièrement présent dans le cas du capotage d'un véhicule. Ce genre d'accident se produit fréquemment à la suite de la perte de contrôle de direction de la part du conducteur. Le véhicule fait alors une embardée et un ou plusieurs tonneaux, accident qui est souvent bénin. Les occupants qui portent la ceinture sont généralement retenus à l'intérieur du véhicule et s'en sortent presque indemnes. Cependant, ce n'est pas le cas de ceux qui ne portent pas leur ceinture car ils risquent d'être éjectés du véhicule, ce qui peut entraîner une blessure grave ou mortelle. La présente étude examine cette dernière question, tant dans la perspective des statistiques nationales sur les accidents que des résultats d'une série d'enquêtes approfondies sur les accidents mortels.

INTRODUCTION

The magnitude and nature of the road safety problem in Canada has seen dramatic changes over the past four decades. In particular, there has been a significant decline in fatalities associated with motor-vehicle collisions. Traffic fatalities peaked in 1973 when a total of 6,706 individuals were killed in road-related collisions. Since this peak, the number of individuals killed has seen a steady decline. For the currently-available data series, the minimum occurred in 2011 when the Canadian fatality total was 2,023 [1], representing a total reduction of 70% relative to the peak 1973 value. While this decline has resulted from a number of different factors, including the reduction in vehicle travel in recessionary times, the Canadian road safety community can take credit for the success of many important safety initiatives (see Figure 1.)

Not the least important safety programmes undertaken in Canada have been those related to enhancing the effectiveness and convenience of occupant restraints in motor vehicles, particularly three-point seat belts, and in promoting the use of these systems. Technological developments and regulatory initiatives have provided very effective seat belt systems that are convenient to use. Country-wide mandatory seat belt usage laws have been developed, and concerted programmes of public education and enforcement have proven effective in convincing the vast majority of Canadians to buckle up. The historical rates of seat belt use in Canada are shown in Figure 2. Presently, belt use is at an all-time high of almost 96% [2].

While these statistics nominally provide a rosy view of road and motor vehicle safety in Canada, we must not lose sight of the fact that there are still approximately 2,000 people killed in crashes on an annual basis. Clearly, there is much to be done to reduce the death toll on our roads from these still unacceptably-high levels.

In particular, while national seat belt use as determined by observational surveys is high, it has long been appreciated that usage in the collision-involved population is considerably lower. For example, analysis of data from the National Collision Data Base (NCDB) shows that the percentage of fatally-injured passenger vehicle occupants not using seat belts has been in the range of 35-40% for more than a decade (see Figure 3).

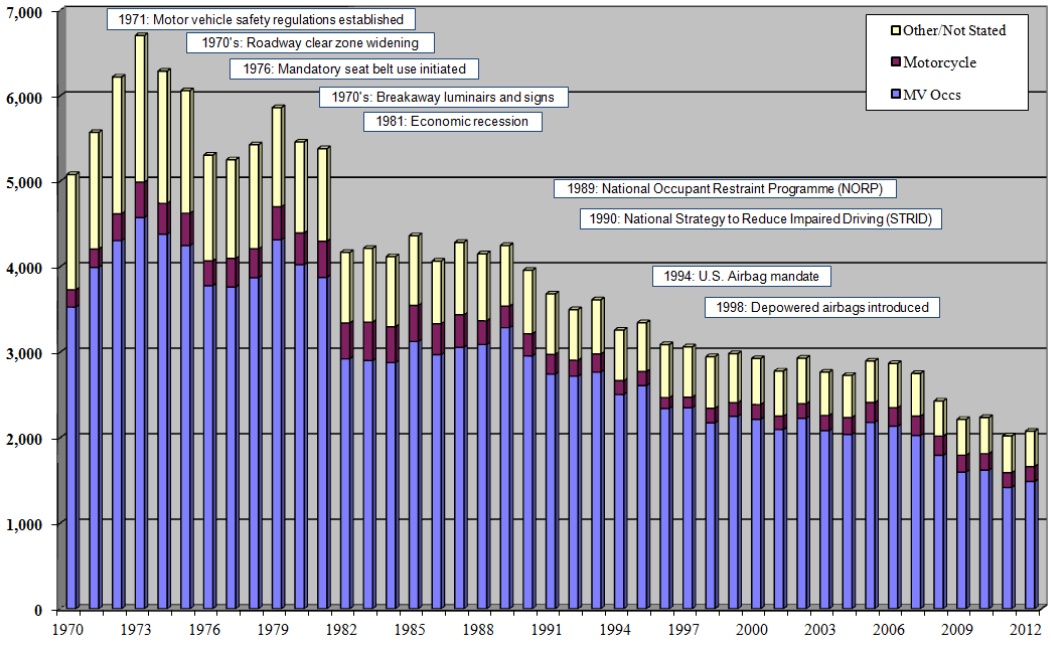


Figure 1. Road Traffic Fatalities in Canada 1970-2012

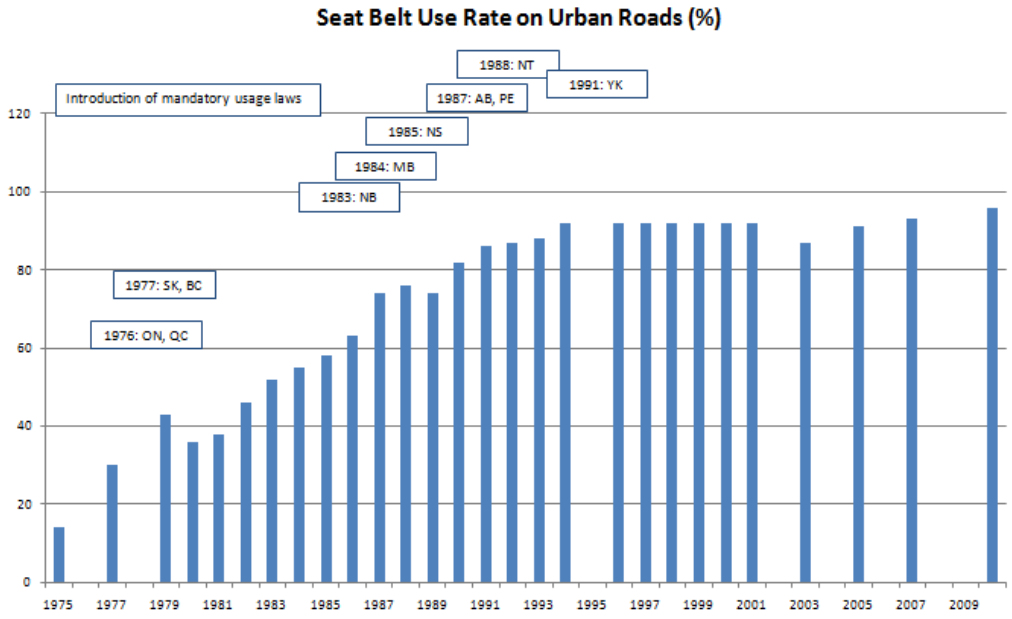


Figure 2. Seat Belt Use in Canada 1975-2010

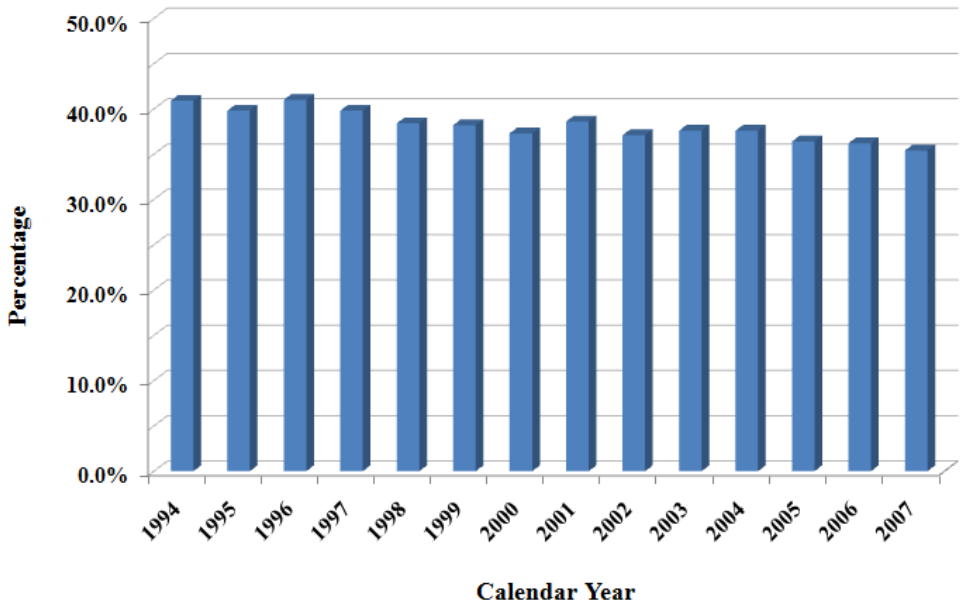


Figure 3. Percentage of Passenger Vehicle Occupant Fatalities Reported as Unrestrained

This situation is even worse when one considers only single-vehicle collisions and, in particular, when such crashes involve rollover events. In single-vehicle crashes, the percentage of fatally-injured passenger vehicle occupants not using seat belts has remained close to 57% during the above-noted time frame, while 80% of unrestrained passenger vehicle occupants who were fatally injured in single-vehicle rollovers were ejected from their vehicle.

Considerably greater insight into the nature of this latter problem, and the potential for additional countermeasures, can be obtained from a review of in-depth investigations of subject crashes. The present work undertakes this task using case studies drawn from Transport Canada's Causes of Fatal Collisions study.

CASE STUDIES

Real-world collisions involving single-vehicle rollovers resulting in fatalities to ejected occupants have been drawn from Transport Canada's Causes of Fatal Collisions Study. Conducted by the Collision Investigation and Research Division (ASFCA) this research programme commenced in October, 2004 and underwent three distinct phases of data collection, the last of which was completed at the end of 2009.

The first phase of the study was a pilot (CFCP) that captured data for fatal collisions within the boundaries of the City of Ottawa, Ontario and from in and around the City of Saskatoon, Saskatchewan. The second phase of the study (CFC2) used these same two sampling centres, supplemented by specific cases from the cities of Fredericton, New Brunswick; Montreal, Quebec; and London, Ontario. The final phase of the study (CFC3) was conducted by the teams in Montreal and London.

A total of 358 fatal collisions were documented in the study database. These crashes were filtered for single-vehicle incidents where the harmful event was a rollover collision, and at least one unrestrained occupant was completely ejected from a light-duty vehicle (passenger car, light truck or van) resulting in fatal injuries. A total of 26 cases were identified as meeting these criteria.

The crashes frequently involved a loss of directional control on the part of the driver after the vehicle had initially run off a paved roadway surface onto a soft shoulder. Loss of control also resulted from drivers travelling at high speed on loose gravel surfaces, or from abrupt lane-change manoeuvres. Inadequate recovery techniques and, in particular, over-steering in an attempt to correct the vehicle's trajectory, often resulted in vehicle yaw and subsequent rollover. While the majority of the cases consisted of vehicles tripping and entering into lateral rollovers, a few incidents involved impacts with poles or trees forward or aft of the occupant compartment resulting in the vehicle spinning away from the impact, tripping, and then rolling over.

CFCP-9617: The 30-year-old male driver of a 1990 GMC Sierra pickup truck was unrestrained and alcohol impaired, with a blood alcohol concentration (BAC) of 132 mg%. The pickup was westbound on a two-lane rural highway and rounding a gentle curve to the right. It was dark, under clear skies, and the asphalt-paved roadway was dry. As the vehicle exited the curve, it ran onto the gravel shoulder on the left side of the road. The driver steered back onto the roadway, over-corrected the steering to the left, and placed the vehicle in a counter-clockwise yaw. The vehicle ran onto the gravel shoulder on the right side of the road, tripped, and rolled through two complete revolutions. The driver was completely ejected through the right-front window. He was found approximately 27 m beyond the vehicle's final rest position with fatal head injuries.

CFCP-9633: A 2003 Nissan Xterra SUV was travelling westbound along the driving lane of a six-lane median-divided provincial highway. The driver intended to move into the centre travel lane; however, on performing a shoulder check prior to this manoeuvre, she observed a vehicle in this lane in the process of overtaking her vehicle. During this time, traffic ahead of the case vehicle had slowed suddenly. In order to avoid colliding with the vehicle directly in front of her, the driver steered abruptly to the right, into the adjacent bus lane. The driver then over-corrected the steering, and placed the vehicle in a counter-clockwise yaw. The vehicle rolled over across the driving and centre lanes of the westbound carriageway.

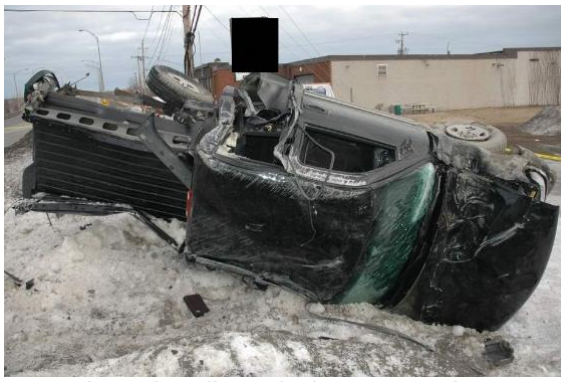
The driver, a 38-year-old female, was fully-restrained and suffered only minor injuries. She was accompanied by seven children. A 15-year-old female was fully restrained in the right front seat. A 5-year-old female and a 7-year-old male were sharing the available lap-torso seat belt in the

2003 Nissan Xterra (CFCP-9633)

2003 Nissan Xterra (CFCP-9633)

left-rear seat. A 13-year-old male was lap belted in the centre-rear, while a 14-year-old male was unrestrained in the right-rear seat. None of these occupants was injured. The two additional children, both 13-year-old males, occupied the cargo area of the SUV, behind the rear seat and were consequently unrestrained. Both of these occupants were completely ejected from the vehicle. One child sustained fatal head injuries, while the other suffered a fractured leg and serious facial injuries.

CFC2-1304: The unrestrained 47-year-old male driver of a 2001 Chevrolet Silverado pickup truck had spent the evening drinking with his nephew and was alcohol impaired with a BAC of 300 mg%. After leaving the bar, the two males were northbound in separate vehicles, racing along a four-lane undivided urban roadway that had a posted speed limit of 50 km/h. The asphalt pavement was dry, the sky was clear and the roadway was artificially illuminated. The Silverado's event data recorder (EDR) recorded a speed of 193 km/h prior to the driver losing directional control.



2001 Chevrolet Silverado (CFC2-1304)

2001 Chevrolet Silverado (CFC2-1304)

The pickup entered into a counter-clockwise yaw and ran off the right side of the road. The right side of the truck's box struck a lamp standard that broke away from its mounting. The truck then ran over a snow bank and rolled over. A second lamp standard was struck and detached from its mounting as the vehicle tumbled to its final resting position. The truck's driver was completely ejected and sustained fatal injuries.

CFC2-1602: A 2000 Chevrolet Cavalier was westbound on a two-lane gravel road. It was dark, the weather was clear, and the roadway was dry. The posted speed limit was 80 km/h; however, the vehicle's EDR indicated a pre-crash speed of 159 km/h. Tire marks on the gravel road showed that the vehicle entered into a clockwise yaw. The vehicle ran off the right side of the road, tripped in the grass-covered ditch, and rolled through one complete revolution. The EDR confirmed that the 18-year-old male driver was unrestrained. He was completely ejected from the vehicle and sustained fatal head injuries.

CFC2-1803: A 2002 Kia Sedona minivan was travelling along the passing lane of a four-lane, median-divided, rural highway with a posted speed limit of 110 km/h. It was dawn. The asphalt paved road was dry and the weather was clear. The vehicle's speed was in excess of 150 km/h when the left-rear tire failed, resulting in the driver losing directional control. The vehicle entered into a counter-clockwise yaw, ran off the road into the central median, and rolled over. Two 25-year-old males occupied the left-front and right-front seats of the vehicle, while a 20-year-old male was located in the centre-rear seat. All three occupants were unrestrained. All were completely ejected during the rollover and sustained fatal injuries.

CFC2-1830: A 1996 Ford Explorer SUV was westbound along a two-lane rural roadway. There was daylight and the weather was clear. The gravel-covered roadway was dry with some loose gravel. The 17-year-old female driver had been drinking and failed to maintain directional control. The vehicle entered into a counter-clockwise yaw. The driver over-corrected, putting the vehicle into a clockwise yaw. The vehicle ran off the right side of the road, tripped and rolled over.

Collision Scene (CFC2-1830)


1996 Ford Explorer (CFC2-1830)

The fully-restrained driver was accompanied by a fully-restrained 17-year-old right-front passenger. Both of these occupants remained in the vehicle and received non-life threatening injuries. A 17-year-old female in the right-rear seating position was unrestrained. She was ejected from the vehicle during the rollover. She came to rest underneath the vehicle and sustained fatal neck injuries.

CFC2-1833: A 2002 Ford F150 pickup truck was travelling in excess of 100 km/h along a two-lane rural street with a posted speed limit of 50 km/h. The asphalt-paved road was dry. There was daylight and the weather was clear. As the vehicle rounded a curve to the left, the driver lost directional control. The pickup entered into a counter-clockwise yaw, ran off the left side of the road, and rolled over. The 19-year-old male driver was accompanied by a 17-year-old male in the right-front seat and a 16-year-old male in the rear seat. The driver and the rear-seat passenger were both fully restrained and sustained minor to moderate injuries. The right-front occupant was unrestrained. He was completely ejected and received fatal injuries.

CFC3-1315: The 16-year-old male driver of a 2000 Chevrolet Silverado pickup truck was travelling around a gentle curve to the left on a collector road adjacent to a multi-lane highway. There was daylight and the asphalt pavement was dry. The posted speed limit for the road was 70 km/h. The vehicle's EDR recorded a travel speed of 104 km/h. Independent witnesses observed the case vehicle change lanes, with an abrupt steering manoeuvre to the right, as it rounded the curve. The vehicle entered into a clockwise yaw, ran off the right side of the road, and rolled over. The truck's driver was unrestrained. He was ejected from the vehicle and sustained a fatal skull fracture. There was a 20-year-old male passenger in the right-front seat, and a 17-year-old male in the rear seat. The right-front passenger was using the available lap-torso seat belt while the rear seat passenger was unrestrained. Both passengers remained in the vehicle and suffered moderate injuries.

CFC3-1603: A 2003 Dodge Durango sports utility vehicle (SUV) was northbound, at night, along a two-lane rural road. The roadway was freshly surfaced with gravel and there was a light frost. The vehicle was travelling at approximately 80 km/h even though the road had a posted speed limit of 50 km/h.


2003 Dodge Durango (CFC3-1603)


2003 Dodge Durango (CFC3-1603)

The vehicle ran onto the grass-covered shoulder on the west side of the road. The driver steered back onto the roadway, but then over-corrected to the left, putting the vehicle into a counter-clockwise yaw. The vehicle ran off the west side of the road and into the ditch where it tripped and rolled over.

The 16-year old female driver was accompanied by five 16-17 year-old friends. None of the vehicle occupants was restrained. The driver and four of the passengers remained inside the vehicle and sustained no more than minor injuries. A 16-year-old female was completely ejected from the left side of the third row seat. She was trapped underneath the vehicle at its final resting position and sustained fatal crushing injuries to the head and chest.

CFC3-1619: A 2004 Chevrolet Avalanche pickup truck was eastbound along a two-lane rural highway. It was dark; the weather was clear and the asphalt-paved roadway was dry. The vehicle ran off the right side of the roadway, tripped and rolled over.

The 16-year-old female driver did not have a driving license. The truck belonged to a 24-year-old male occupying the right-front seat. Two other unrestrained males, one 24 years old and the other 20 years old, were in the rear seat.

The posted speed limit on the road was 80 km/h. The truck's EDR recorded a travel speed of 88 km/h. The pre-crash data retrieved from the EDR further showed that the vehicle's brakes were never applied; however, the throttle was fully open (100%) for each of the three seconds prior to algorithm enable. This suggests that the inexperienced driver, when losing directional control of the vehicle, evidently hit the accelerator instead of the brake pedal.

All four unrestrained occupants were completely ejected. The three males received non-life-threatening injuries. The female driver was found 22 m east of the vehicle's final rest position. She was fatally injured.

2004 Chevrolet Avalanche (CFC3-1619)

2004 Chevrolet Avalanche (CFC3-1619)

CFC3-1669: The 23-year-old male driver of a 2003 Acura RSX two-door hatchback was westbound along a two-lane gravel road in the late afternoon. The posted speed limit was 80 km/h, The vehicle's speed was in excess of 100 km/h when it travelled onto the southern gravel shoulder. The driver steered back onto the road, and then over-corrected to the left, putting the vehicle into a counter-clockwise yaw. The vehicle ran off the left side of the road, tripped, and rolled through two complete revolutions. The unrestrained driver was ejected and sustained fatal head injuries.

DISCUSSION AND CONCLUSIONS

Single-vehicle crashes are almost always the sole responsibility of individual vehicle drivers. The incidence of factors beyond the direct control of the driver, such as a catastrophic vehicle component or system failure, is extremely low. Unfortunately, some individuals continue to drive irresponsibly. Driving at high speed, while impaired by alcohol and/or drugs, and failing to use seat belts were very common factors in many of the cases studied in the present work. Light trucks were more frequently involved in these rollover crashes than were passenger cars. Males were more frequently the driver than were females, and both genders consisted of mostly young adults.

Passenger cars were involved in 8 of the crashes, while the remaining 18 cases involved light trucks and vans. This is no doubt a result of an LTV being more likely to rollover than a car, given the same collision environment, due to the LTV having a higher centre of gravity. Driver age ranged from 16 to 54 years, with an average age of 26.2 years. Male drivers outnumbered female drivers by 18 to 8.

Vehicle speed in excess of the posted speed limit was noted in 23 of the 26 collisions. The pre-crash travel speed was calculated by collision investigators from physical evidence and/or using information retrieved from vehicle event data recorders (EDR). The average vehicle speed exceeded the posted speed limit by 38 km/h. The range of excess speeds was between 5 and 143 km/h, the latter being the pre-crash speed of a vehicle recorded on its EDR as 193 km/h on a roadway with a 50 km/h speed limit.

The drivers' blood alcohol concentrations were measured in eight of the cases. The BAC's ranged from 110 to 380 mg%, with an average BAC of 227 mg%. Three of these drivers were reported to have been using drugs (cannabis, cocaine and Ecstasy, respectively) in combination with the alcohol.

Many of the loss of control situations resulted from hard-steering manoeuvres, either over-steering by the driver while attempting to return to the travelled portion of the roadway after running onto the shoulder, or abrupt steering inputs while changing lanes. Where loss of control initially resulted while driving down straight stretches of road, high speed and loose gravel surfaces were generally involved.

As noted, in many of the cases, excessive speed and/or driver impairment were major factors in collision causation. However, the dominant factor in the occurrence of the fatalities was the non-use of seat belts and the consequent ejection of vehicle occupants.

Despite the occurrence of at least one fatality in each incident, a number of the case studies exemplify the benefits that seat belts offer in these types of relatively simple lateral rollovers. For example, in CFCP-9633 five occupants were belted and one additional passenger, although unbelted, was occupying a bench seat with three others. All of these occupants were retained in the vehicle during the rollover event and sustained either no or only minor injuries. In contrast, the two unbelted occupants in the rear cargo area of the vehicle were both ejected; one being fatally injured as a result, and the other receiving serious injuries. Similarly, in CFC2-1830 and CFC2-1833, two fully-restrained occupants in each of the case vehicles sustained minor to moderate injuries, while an unbelted individual was ejected from each vehicle and was fatally injured.

The broad similarities in many of the case studies identified in this study provide considerable insight into the primary areas where countermeasures are needed. From a road user perspective, the two most important contributions are strategies to promote restraint usage by motor vehicle occupants and measures to reduce the levels of driver impairment by alcohol and drugs. With respect to vehicle-related factors, enhanced collision avoidance systems and improved occupant protection measures are required.

Road User Countermeasures

Restraint use in Canada has been strongly affected by regulations for vehicle seat belts and child restraint systems, mandatory usage laws related to these devices, public education and enforcement programmes. Similarly, occurrences of drinking and driving have been reduced over time through a combination of legislative changes, public awareness and police enforcement campaigns.

Canada's motor vehicle safety regulations were established in the early 70's and included the requirement for the installation and crash performance of seat belt systems. Mandatory seat belt usage legislation was first introduced in Ontario and Quebec in 1976, followed by British Columbia and Saskatchewan in 1977. The remaining provinces and territories followed suit such that, by 1988, mandatory seat belt usage was universal across the country. Also, child restraint legislation was being introduced by all of the jurisdictions over this same time period, such that all motor vehicle occupants were required to be protected by available restraint systems. [3] The combination of public education and awareness campaigns, coupled with police enforcement actions, such as Selective Traffic Enforcement Programmes (STEP), proved to be highly effective in raising and maintaining national seat belt usage levels above 90%. The most recent survey data show Canadian seat belt usage to be over 95%. Such levels of seat belt use are comparable with those of countries with the best traffic safety records and have thus served Canada well.

The first legislation relating to impaired driving was enacted in 1921 at a time when the number of vehicles on Canadian roads was extremely limited. In 1969, the Criminal Code was amended with respect to impaired driving to provide that a driver with a blood alcohol concentration greater than 80 mg of alcohol per 100 ml of blood was, per se, guilty of the offence of impaired driving.

This effectively removed the onus on the prosecution, and hence on the investigating police service, to demonstrate that a driver's actions were impaired along with a BAC in excess of the prescribed limit. It was also an equivalent offence for a suspect to fail to comply with the demand of a peace officer to undergo an appropriate test. [4] Most recently, in July 2008, the Criminal Code was further amended to prescribe testing for the presence of drugs.

Over the years, the legislation has been supported by a range of public education and awareness campaigns, and by targeted enforcement actions such as the Reduce Impaired Driving Everywhere (RIDE) programme. In addition, interventions such as administrative license suspensions, vehicle impoundment, and alcohol-ignition interlock systems have been implemented to provide additional enforcement tools. The results have been significant with, for example, alcohol usage for fatally-injured drivers dropping from approximately 70% in the 70's to the current rate of about 35%. [5] However, notwithstanding this positive trend, it should be noted that the absolute level still remains relatively high, and that the rate has essentially reached a plateau over the past five years.

Most recently, Canada has adopted a series of road safety visions, with multi-year goals for safety improvements and ambitious targets for casualty reductions. Commencing in 1996, Road Safety Vision 2001 had the goal of Canada having the safest roads in the world by 2001. [6] Specifically, the initiative aimed to: raise public awareness of road safety issues; improve communication, increase cooperation and collaboration among road safety agencies; toughen enforcement measures; and improve national road safety data collection.

The initiative integrated a wide range of safety countermeasures, such as the National Occupant Restraint Program 2001 (NORP) targeted at obtaining 95% seat belt usage and properly restrained children in vehicles by 2001, the Strategy to Reduce Impaired Driving (STRID) 2001, enhanced police enforcement of traffic laws through Operation Impact, and the adoption of graduated driver licensing systems in many provinces and territories. The combination of these and the other initiatives did indeed lead to reductions in fatalities and serious injuries in Canada over the term of the Road Safety Vision 2001 programme; however, a number of other countries realized even better performance with the result that Canada's international position worsened.

In October 2000, in an attempt to counteract this negative trend, the Council of Ministers for Transportation and Highway Safety approved Road Safety Vision 2010 as a longer-term successor plan. [7] This programme, while carrying forward the original vision and strategic objectives, implemented a series of casualty reduction targets for the period 2001-2010. The overall goal was a national reduction in traffic fatalities and serious injuries by 30%, with sub-targets for casualties involving unbelted occupants, drinking drivers, speed and intersections, high-risk drivers, young drivers, commercial vehicles, vulnerable road users, rural roadways, and the goal of a national seat belt usage rate of 95% and proper use of child restraints.

The above-noted efforts to change user behaviour have been on-going for many years and, while they have had a positive effect, the process of change has been slow, and a current concern is that producing significant impact on the final groups of recalcitrants will prove even more difficult. However, since such groups are now small, it is time to pursue more aggressive measures, some of which may take the form of sophisticated vehicle-based technologies.

Motor Vehicle Countermeasures

Automotive technology and the attendant safety regulations will continue to be enhanced in the coming years, and such improvements will doubtless have an impact on both the frequency and consequences of motor vehicle collisions, including single-vehicle rollover crashes. A particular benefit afforded by vehicle-based systems is that, while not all road users will take advantage of the knowledge to be gained from public education programmes, or will necessarily be impacted by enforcement actions, many in-vehicle safety technologies are activated without any direct input from vehicle occupants.

For example, electronic technology is becoming all pervasive throughout the vehicle's control systems, and not the least of these are devices to promote collision avoidance. In particular, the inclusion of yaw sensors, and an electronic control system, to vehicles equipped with anti-lock brake systems (ABS) have given rise to electronic stability control (ESC) systems. ESC is designed to actively apply the brake at one or more of the vehicle's wheels, and may also reduce engine power, in order to counter any tendency of the vehicle to enter into a spin, and thus prevent the driver from losing directional control. [8] This technology has been available for some time as either standard or optional equipment on many vehicles. Recent changes to the safety regulations have implemented a new Canadian Motor Vehicle Safety Standard (CMVSS 126 - Electronic Stability Control Systems) such that ESC became mandatory equipment on every passenger car, multi-purpose passenger vehicle, truck and bus with a GVWR of 4,536 kg or less manufactured after August 31, 2011. [9] Since all of the case studies identified in this series of single-vehicle rollover crashes involved a loss of directional control and subsequent vehicle yaw, it is highly likely that the new standard will have significant future impact on this crash mode.

Some other safety systems that may have application to the prevention of single-vehicle rollover crashes are essentially still under development, or currently have very limited market penetration. For example, lane-tracking systems, that typically use on-board cameras and image processing systems to monitor roadway markings, can be used to detect if the vehicle is wandering out of its travel lane. [10] Such events can produce audible warnings or tactile feedback through the steering wheel to alert the driver to the potential hazard. Alternatively, a servo steering mechanism can be used to actively provide corrective steering action.

Seat belt systems have matured from simple lap belts to sophisticated occupant restraint systems featuring lap and shoulder belts with adjustable geometry, pyrotechnic pretensioners to eliminate slack [11], load limiters to moderate chest forces [12], and supplementary air bags to provide additional load distribution and particularly head protection. [13] Air bags have similarly evolved from simple, single threshold, single charge, deployment mechanisms to the so-called smart air bags for which either first stage or second stage deployment is based on occupant presence, crash severity and occupant proximity to the air bag module. [14] Occupant protection in side impacts is now promoted through sophisticated structural design, interior padding and side air bags, including both thoracic bags and head curtains. [15]

Further refinements to all of these systems are on-going. In particular, it is certain that the side head curtain will evolve into the “rollover curtain”, a side air bag that will be deployed when sensors determine that vehicle rollover is imminent. The rollover curtain will remain inflated for several seconds post-impact, thus providing cushioning against occupants striking portions of the vehicle interior, but also providing a barrier against potential ejection of unbelted occupants through the glazed areas of the vehicle. Additional measures, already implemented by some manufacturers, involve automatically closing side windows and the sun roof in the event that the possibility of vehicle rollover is detected. [16]

A specific impetus for the introduction of such systems was a recent change to the US regulations, notably the introduction of Federal Motor Vehicle Safety Standard No. 226 - Ejection Mitigation, which are being phased-in commencing September 1, 2013. [17] The associated test prescribes that an impactor, propelled from inside the vehicle, toward a side window, be prevented from moving more than a specified distance beyond the plane of the window. An associated change to the standards has seen more stringent requirements for Federal Motor Vehicle Safety Standard No. 216 - Roof Crush Resistance, these being phased-in commencing September 1, 2012. [18] This revised rule requires that a vehicle’s roof withstand a greater applied force than previously specified, with testing being conducted on both sides of the roof structure, and extends the range of vehicles that are subject to the new requirements.

Other relevant vehicle-based technologies that are currently mainly in developmental stages include aggressive seat belt reminder and interlock systems and passive alcohol sensors.

Seat belt-ignition interlocks were unsuccessfully used in the US in the 1970's when many of these systems were disabled by vehicle owners. More aggressive reminder systems, where audible warnings sound for an extended period, or some form of ignition and/or gearshift interlock prevents or delays the vehicle from being driven away have been the subject of much research. Recent advances in sophisticated automotive electronic systems could possibly be adapted to prevent enhanced reminder systems from being defeated.

There is some evidence that much more aggressive seat belt reminder systems are somewhat effective in promoting belt usage [19,20,21,22] and that such systems could be cost-beneficial [23]. Nevertheless, without regulation to mandate such systems manufacturers may well be influenced to reduce the level of intervention in order to assuage customer complaints. One possible countermeasure would be to provide incentives for manufacturers to install advanced seat-belt reminders. [24] Indeed the EuroNCAP new-car assessment program provides point scores for vehicles equipped with advanced seatbelt reminder systems, and scores front and rear occupant seating positions separately. [25]

Similarly to the above, in terms of affecting the behaviour of some drivers, slow progress has been made in addressing the undoubted problem of driving whilst impaired. Perhaps in-vehicle technologies can also be used to assist in this area. Various manufacturers have researched the installation of transdermal alcohol sensors and other passive sensing systems in concept vehicles [26,27] that are interfaced in an interlock mode to the vehicle’s ignition system.

As in the past, a combination of well considered and effective traffic safety programmes, together with a range of improvements in motor vehicle safety systems, is likely to provide additional benefits to the Canadian public. However, due to the implicit difficulty in affecting the behaviour of those motorists who seem willing to take the most risk, it may well be that new vehicle technologies will offer considerable potential to protect these vehicle occupants – despite themselves!

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