Multidisciplinary Study of the Causes of Fatal Collisions

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Abstract

Transport Canada, in conjunction with a number of participating agencies, has embarked on a pilot study to investigate the causes of fatal motor vehicle collisions and to identify potential countermeasures. The study is being undertaken on all fatal crashes occurring in the City of Ottawa, Ontario. In-depth investigations of such collisions consider the involvement of human, vehicle and environmental factors. The results of each investigation are reviewed by a multi-disciplinary panel composed of personnel from the participating agencies. The researchers include collision investigators, a physician, police officers, traffic engineers, psychologists, human factors specialists, research and regulatory engineers. In the first year of the programme, 27 collisions were investigated. In 18 single-vehicle incidents, pedestrian and pole impacts were the most common crash type, while 9 vehicle-to-vehicle crashes were predominantly side impacts. Human factors issues, including the use of alcohol and drugs, driver inattention and inappropriate driving behaviour were the most common causation mechanisms, while adverse road design and vehicle maintenance issues were also identified in certain crashes. In this paper, the study methodology is described, and the initial case series reviewed in terms of causal factors, collision consequences, and potential counter-measures that might be adopted to prevent or mitigate such incidents in the future.

Résumé

Transports Canada, en collaboration avec un certain nombre d'organismes participants, a débuté une étude pilote pour examiner les causes de collisions mortelles de véhicules automobiles et identifier des mesures possibles. L'étude couvre tous les accidents mortels qui sont survenus dans la Ville d'Ottawa en Ontario. L'examen approfondi de telles collisions implique les facteurs humains, automobiles et environnementaux. Les résultats de chaque enquête sont examinés par un groupe multidisciplinaire composé de membres du personnel des organismes participants. Les experts comprennent des enquêteurs sur les collisions, un médecin, des policiers, des ingénieurs de la circulation, des psychologues, des spécialistes des facteurs humains, et des ingénieurs en recherche et en réglementation. Lors de la première année du programme, 27 collisions ont fait l'objet d'une enquête. Dans 18 accidents impliquant un seul véhicule, les impacts avec des piétons et des poteaux étaient les types de collision les plus courants; alors que les 9 accidents entre véhicules étaient surtout des impacts latéraux. Les facteurs humains, dont la consommation d'alcool et de drogues, le manque d'attention du conducteur et les mauvaises habitudes de conduite, étaient les fautes les plus courantes; alors qu'une mauvaise conception de la route et un manque d'entretien du véhicule ont aussi été identifiés dans certains accidents. Dans le présent document, vous trouverez une description de la méthodologie de l'étude, la série de cas examinés en fonction des facteurs

déterminants, les conséquences des collisions et des mesures possibles qui pourraient être prises pour prévenir ou atténuer les risques de tels accidents à l'avenir.

Introduction

Deaths and injuries resulting from motor vehicle collisions continue to be the major transportation-safety problem in Canada with road fatalities accounting for nearly 90% of transportation-related deaths, and estimates of the associated economic losses ranging from $10 billion to $25 billion, on an annual basis.

In response, the federal, provincial and territorial governments have adopted Road Safety Vision 2010 [1], with a national target to decrease the average number of road users killed or seriously injured during the 2008-2010 period by 30% as compared to the period 1996-2001.

Road Safety Vision 2010 has a number of strategic objectives, namely to: raise public awareness of road safety issues; improve communication, cooperation and collaboration among road safety agencies; to enhance enforcement measures; and to improve national road safety data quality and collection. In addition to the specific national target for fatality and injury reduction, there are a number of sub-targets aimed at the use of seat belts and child restraints, the occurrence of driving while impaired, improving rural road safety, reducing speed- and intersection-related crashes, improving commercial vehicle safety, and reducing the collision involvement of young drivers, high-risk drivers, and vulnerable road users.

As an adjunct to the work being undertaken by partner agencies across Canada, and in-house activities focused on achieving specific targets, Transport Canada's Collision Investigation and Research Division has commenced a pilot study of the causes of fatal collisions occurring in the City of Ottawa, Ontario. The intention of this study is to identify specific aspects of causation related to human, vehicle and environmental factors, and to develop some appropriate countermeasures that might avoid similar collisions in the future or, at least, mitigate their consequences.

The seminal study of collision causation was conducted by Treat et al. [2] These researchers used a multi-level investigative approach that analyzed police-reported data, on-scene investigations and in-depth multi-disciplinary studies of individual collisions. The results showed that human factors were the principal causes of collisions and were involved in over 92% of the incidents captured. Environmental and vehicular factors were involved less frequently, these being associated with approximately 34% and 13% of collisions respectively. It is interesting to note that an almost identical level of human-factor involvement was found in a recent Canadian pilot study of pre-crash factors. [3]

In the present study, a number of partnering agencies were approached to assist in both the collection and analysis of data from real-world, fatal collisions. The area of operation was defined as the boundaries of the City of Ottawa. This involves the jurisdictions of two policing agencies, the Ottawa Police Service and the Ottawa detachment of the Ontario Provincial Police, the latter having responsibility for collisions occurring on provincial roadways running through the city. Both police agencies agreed to participate in the study. In addition, personnel from the City of Ottawa's Transportation, Utilities and Public Works department were willing to provide their expertise with respect to safety and traffic services. Similarly, the Regional Supervising Coroner for Eastern Ontario agreed to furnish information obtained as part of coroners' investigations into the incidents under study.

It should be noted that no identifying information was retained as part of the investigative files, and the resulting study data are completely anonymous.

Transport Canada provided a team of collision investigators who developed the data collection and reporting system used in the study. These personnel

also took the responsibility of assembling data on case incidents from the other agencies, and conducted follow-up investigations of collision scenes and involved vehicles. Some of Transport Canada's specialists in human factors, vehicle and highway engineering were tasked to participate in a multi-disciplinary review panel to consider the study findings. Similarly, members of the participating police services and the city's traffic engineering department, in addition to the Regional Coroner, were invited to attend each meeting of the review panel.

When all the data had been captured for any given collision, a draft report was produced by the collision investigation team and circulated to the members of the review panel. Subsequently, a round-table meeting of the panel was held to discuss the completed cases. The circumstances of each collision were presented, and illustrated by specific photographs associated with the points under discussion.

In this manner, the broad knowledge and expertise of the assembled specialists were brought to bear to determine the contributing factors for each collision, and to identify potential countermeasures that might prove effective in preventing similar incidents in the future.

Case Studies

For the purposes of this paper, summaries of the first twelve cases in the series are presented in some detail:

CFPC-9601

A 1991 Ford Tempo four-door sedan was travelling westbound in the passing lane of a four-lane, median-divided suburban arterial. The asphalt-paved road was dry and in good condition. Witnesses indicated that the vehicle was travelling in excess of the posted 80 km/h speed limit. As the vehicle rounded a curve to the right, its left side wheels ran onto the gravel shoulder. The driver, a 55-year-old, fully-restrained male, steered to the right in an attempt to regain the paved surface, then over-steered to the left placing the vehicle in yaw. The vehicle ran off the road and entered the median ditch.

The front end of the vehicle impacted the backslope of the ditch. The vehicle then rolled over, landing heavily on the rear end. The driver's seat back yielded under the occupant load. The driver slipped under the seat belt, ramped up the seat back and, during the rollover, was ejected through the left-rear window. The driver's head struck the road surface and he was pronounced dead at the collision scene.

The driver was a night-shift worker and was returning home after finishing his shift. A post-mortem toxicological screen indicated a blood serum concentration of tetrahydrocannabinol (THC) of 3.1 ng/ml, indicative of recent use of marijuana.

The driver's injuries included a basal skull fracture and associated brain injuries, fractures to the cervical vertebrae, and fractured ribs with pulmonary contusions.

CFCP-9602

A 1995 Dodge Neon four-door sedan was being driven westbound on a two-lane, gravel road. It was dark with artificial lighting. The gravel roadway was dry. The 18-year-old, male driver was accompanied by a 20-year-old female in the right-front seat and a 20-year-old male in the centre-rear seat. The driver and right-front passenger were both fully-restrained, while the centre-rear passenger was using the available lap belt.

The driver had a valid G2 licence and was in compliance with the associated restrictions. He had been licensed for approximately two years and had no infractions during this period.

He was the designated driver that evening and, prior to the crash, he and his companions had left a party to meet up with some friends. The passengers

indicated that, just prior to the crash, the driver was deliberately swerving the vehicle from side to side on the road. In this process, the driver lost directional control. The vehicle rotated clockwise and ran onto a grass lawn on the north side of the road. The left side of the vehicle struck a 25 cm diameter wooden utility pole which fractured at the level of the vehicle's roofline. The vehicle rolled over and came to rest on its wheels just west of the point of impact with the pole.

The impact with the pole was in the area of the vehicle's left B-pillar. Direct damage extended vertically from the sill to the roof side rail. At the point of impact, the vehicle was pitched so that its roof was leading into the impact. The maximum crush and intrusion was at the roof side rail, and the damage extended to the centre of the vehicle. The front air bags for both the driver and the right-front passenger deployed in the crash.

The driver was found severely injured and barely conscious. After a prolonged extrication, he was transported to hospital where he was noted to be tachycardic and hypotensive, with a Glasgow Coma Scale rating of 4. Despite appropriate fluid resuscitation, he suffered cardio-respiratory arrest. Resuscitation was unsuccessful. Toxicological analysis of post-mortem blood was negative for alcohol.

Injuries sustained by the driver included haemorrhagic contusions of the cerebral hemi-spheres, subarachnoid haemorrhage and edema, bilateral pulmonary contusions and haemothoraces, deep lacerations of the spleen, superficial lacerations of the liver, a tear to the right renal artery, a fracture to the left posterior lateral sixth rib, displaced fractures of the left sacroiliac joint, the mid-radius and cubitus of the right forearm

The right-front passenger was unconscious at the scene but regained consciousness when paramedics arrived. She sustained a fracture to the left orbital bone, multiple rib fractures, a ruptured spleen, and a fracture to the left shoulder.

The centre-rear passenger was conscious at the scene. He sustained an open fracture of left femur and fractures to the left tibia and fibula.

CFCP-9603

A 1995 Pontiac Grand Am 4-door sedan was south-bound on a two-lane, rural collector and passed an uninvolved vehicle at high speed. The Pontiac's driver negotiated a left hand curve and travelled along a short straight. The vehicle entered a second curve to the left, where the driver lost directional control. The vehicle rotated clockwise, egressed from the roadway, and ran down into the west ditch. The vehicle's left-front corner impacted the back slope of the ditch. The vehicle tripped onto the driver's side, and continued sliding and rotating across the base of the ditch. The Pontiac's left C-pillar impacted a metal I-beam fence post, set in concrete causing the vehicle to stop and roll upright. The vehicle came to rest at the bottom of the ditch, facing the roadway.

The driver was an alcohol-impaired, 19-year-old female. She claimed to have been using the three-point seat belt; however, there was no loading evidence on the restraint system. She sustained only minor injuries in the collision.

Her 20-year-old, male, right-front passenger was unrestrained and was partially ejected from the vehicle. He was found with his head and upper torso on the trunk lid, and his lower body draped over the rear seat. Occupant head contact was noted on the vehicle's C-pillar. The passenger sustained fatal head injuries.

CFCP-9604

A 1998 Nissan Maxima sedan was southbound on a four-lane, undivided urban arterial. It was dark with artificial illumination from streetlights. It was raining at the time of the collision and the roads were wet. The road had a speed limit of 50 km/h.

The vehicle was approaching an intersection on a green traffic light when a 43-year-old, male pedestrian ran out from between parked cars on the west side of the street. A witness accompanying the pedestrian stated that the pedestrian suddenly veered off the west sidewalk, with the intention of catching a bus on the opposite side of the street.

The 18-year-old, male driver braked hard, but the front bumper of his vehicle struck the lower legs of the pedestrian. The pedestrian wrapped over the vehicle's hood and his head struck the rear edge of the hood at the junction with the windshield. The pedestrian was alive on arrival at hospital but died in the emergency room.

A toxicological screen indicated a blood alcohol level of 269 mg% showing the pedestrian to be in a state of acute ethanol intoxication. His injuries included multiple fractures of the skull, bilateral cerebral and brain stem contusions, mild subarachnoid haemorrhage and bilateral subdural haematoma, bilateral acute pulmonary congestion and edema.

CFCP-9605

A 1998 Chrysler Sebring convertible was travelling westbound along a two-lane, undivided, rural collector. It was dark with no artificial illumination. The weather was clear and the roads were dry. The road had a posted speed limit of 60 km/h.

An elderly male pedestrian was crossing the road from the vehicle driver's left. The front of the Sebring struck the pedestrian who was thrown up onto the vehicle's hood. The pedestrian partially penetrated the left side of the windshield and then continued up onto the convertible's roof.

The driver, a 41-year-old female, was accompanied by her 18-year-old son in the right-front passenger seat. Neither vehicle occupant observed the pedestrian until immediately prior to the collision.

The pedestrian was an 80-year-old male. He was wearing a green camouflage hunting jacket and blue jeans. According to his daughter, his mobility was restricted by problems with a hip. At the scene, the pedestrian was discovered lying prone on the pavement. Cardiopulmonary resuscitation was attempted. The pedestrian was transported to hospital where he was pronounced dead on arrival.

Traces of ethanol were noted in post-mortem blood and urine samples, consistent with his family's statement that he had a glass of wine with dinner.

The pedestrian's injuries included a hyper-extension fracture-dislocation of the atlanto-occipital joint, avulsion of the brain stem, a basal subarachnoid haemorrhage, multiple bilateral rib fractures and pulmonary contusions, fractures to the mid-sternum, lacerations to the aorto-iliac junction, transections of the ileum and sigmoid colon, diastatis fracture of the pubic symphysis, compound bilateral fractures of the mid- tibias and fibulas, and a closed fracture of the mid-shaft of the left radius.

CFCP-9606

A 2000 Toyota Camry four-door sedan was travelling northbound on a two-lane, urban collector during the hours of darkness. There was artificial illumination from a street lamp on the west side of the road; however, according to on-scene personnel, the area was still extremely dark. It was raining and the roads were wet. The road had a posted speed limit of 50 km/h.

The case vehicle's driver, a 50-year-old female, was accompanied by her 16-year-old son in the right-front seat and his 16-year-old girlfriend in the right-rear seat. All of the vehicle occupants were fully restrained.

A 74-year-old, male pedestrian, who was using a cane for assistance, was attempting to cross the northbound lane. The pedestrian was wearing dark clothing. According to both the vehicle's driver and right-front passenger, the pedestrian suddenly

became visible to them in the middle of the road. He was not looking in the direction of the vehicle. The driver braked hard and swerved to the right in an attempt to avoid the collision; however, the front of the Camry struck the pedestrian.

There was damage to the vehicle's front grille, and depressions at both the leading edge and rear portion of the hood. There was a starburst fracture in the middle of the right side of the windshield, as well as damage to the base of the windshield, directly below this starburst. Human hair was identified in the latter area. There was also a large depression in the rear portion of the roof. The vehicle damage was indicative of the pedestrian undergoing a roof-vault trajectory subsequent to the initial impact. A mark on the front bumper, adjacent to the right headlight, was matched to the damage profile of the pedestrian's cane.

The pedestrian was transported to hospital where he was admitted to the intensive care unit. He was taken to the operating room for decompression of a right subdural haematoma. Post-operatively, his neurological status deteriorated, despite therapeutic attempts. A subsequent CT scan showed a massive infarction of the right hemisphere with a significant shift and intraventricular haemorrhage. Two days after admission, clinical examination indicated that he met the criteria for brain death. Three days after the crash, life support was terminated and he was pronounced dead.

At autopsy, the pedestrian's injuries were found to include a thin residual subdural haematoma at the base of the right side of the brain and over the right convexity, multiple acute contusions, cortical and subcortical of the right side of the brain, with focal lacerations, including lacerations and contusions of the corpus callosum and secondary acute intraventricular haemorrhage, diffuse cerebral edema with herniation and secondary Duret haemorrhages of the brain stem.

CFCP-9607

A 2003 GMC Sierra 4x4 pickup truck was eastbound on a four-lane, urban arterial roadway. The 51-year-old, male driver brought the truck to a halt prior to turning left onto a one-way street. He let several oncoming cars pass and then commenced his turn. At this point he noticed a pedestrian directly in front of his truck. He braked hard, but the pedestrian was struck and thrown to the ground where his head hit the pavement.

The vehicle had two small scrape marks near the centre of the hood and the licence plate was dented inwards slightly. In addition, the grille was broken; however, the driver indicated that this damage had occurred some months earlier. The nature of the collision damage, and the observed short pre-impact skid marks, were indicative that the truck's speed was relatively low, and consistent with the left turn manoeuvre from a stopped position.

The pedestrian was an 85-yr-old male. He was transported to hospital and underwent a CT scan. The scan showed a subdural haematoma with a large midline shift. In the view of the attending neurosurgical consultants, the problem was not amenable to surgery . Accordingly, he was placed in palliative care. He died eight hours after the crash. No autopsy was ordered since the subdural haematoma diagnosed by the CT scan was attributed as the cause of death.

CFCP-9608

A 1995 Ford Contour four-door sedan was observed by a police officer to be travelling at high speed. The officer followed the vehicle, observed that the license tag was expired and attempted a traffic stop. The Contour's driver disregarded the cruiser's flashing red lights and turned onto a two-lane, undivided, urban collector. The Contour drove through a stop sign, at which point the police pursuit was terminated.

Approximately 1.2 km further down the road the Contour entered a sharp curve to the left. The driver lost control and the vehicle ran off the right side of the roadway whilst rotating clockwise. The left side of the vehicle struck a chain link fence and a wooden utility pole adjacent to the edge of the roadway.

There was direct damage over the Contour's left-rear door, with a maximum crush of 96 cm, and considerable intrusion into the left-rear occupant compartment.

The driver was an unrestrained 20-year-old male. His blood alcohol level was found to be 32 mg% and, therefore, below the level for legal impairment. However, the toxicological screen also indicated the presence of cocaine, crack cocaine, meth-amphetamine, morphine, and cannabis. The driver sustained a fractured pelvis, with associated internal haemorrhaging, and a fractured finger.

The right-front passenger was a fully-restrained 20-year-old male At the collision scene, he exhibited a large amount of blood coming from a head wound, was having breathing difficulties, and was in-and-out of consciousness. He was transported to hospital in a state of advanced coma. Severe brain edema developed and he expired on the following day. At autopsy, his injuries were found to include a basal skull fracture with diffuse cerebral edema, a subarachnoid haemorrhage, small mid-brain haemorrhages, and intraventricular haemorrhages, fractures of the C6-T1 spinal processes, bilateral pneumothoraces and haemothoraces, and a fracture of the left scapular.

CFCP-9609

A 2004 Hyundai Accent four-door sedan was northbound on a two-lane undivided rural collector. It was daylight, and the weather was cloudy with freezing rain. The roadway was icy. The posted speed limit was 80 km/h. The 23-year-old, female driver lost directional control due to the icy road conditions. The Accent crossed the roadway centerline, directly in front of a southbound 2001 Peterbilt Truck Tractor hauling a 2003 Advance tank trailer containing 51,000 litres of fuel. The front of the truck tractor struck the right side of the Hyundai.

The Accent sustained direct damage to the right side, extending from the right A-pillar to the right rear bumper. There was extensive intrusion into the occupant compartment.

At the collision scene a weak pulse was detected in the driver of the Accent. Extrication from the vehicle proved to be difficult. An attempt at endotracheal intubation was unsuccessful. Despite 30 minutes of cardiopulmonary resuscitation, she was pronounced dead on arrival at hospital.

The driver's injuries included a patchy mild subarachnoid haemorrhage, bilateral cerebral and brain stem contusions, fractures of multiple bilateral posterior ribs, bilateral contusions and lacerations of the lower pulmonary lobes with moderate right haemothorax, subendocardial haemorrhages of the left ventricle, lacerations of the right hepatic lobe, and of the spleen, with moderate haemoperitoneum, and a displaced closed fracture of the proximal right femur.

CFCP-9610

A 1993 Mazda MX-6 two-door sedan, was eastbound on a two-lane, undivided, rural arterial. The asphalt-paved road was in good condition, and on a slight down-grade for eastbound traffic. On each side of the road was a gravel shoulder abutted by a drainage ditch. It was dark with no artificial illumination on the roadway. The weather was clear. There was some drifting snow and patches of ice on the road surface.

The vehicle was travelling well in excess of the speed limit. The driver stated that the right-front passenger kept urging him to go faster and that he had complied with these requests. The vehicle rounded a shallow curve to the right and entered a

straight section of road where the driver observed an on-coming vehicle. A witness in the latter vehicle noted that the case vehicle rounded the curve straddling the centerline and in a clockwise yaw.

The driver of the case vehicle attempted to steer his vehicle back into the eastbound lane but, instead, he lost directional control. The vehicle ran onto the gravel shoulder on the south side of the road in a counterclockwise yaw. The right side of the vehicle collided with a wooden utility pole located at the southern edge of the shoulder. The vehicle spun out of this impact, rolled over, running along the ditch, and came to rest on its wheels.

The driver was a fully-restrained, 22-year-old male. His blood alcohol level was measured as 30 mg%. He sustained only minimal injuries as a result of the collision.

The right-front passenger was a 23-year-old, fully-restrained male. This occupant was pronounced dead at the scene. An autopsy was not performed, the Coroner indicating that the passenger had sustained obvious fatal head and neck injuries .

CFCP-9611

A 2000 Chevrolet Malibu four-door sedan was travelling northbound along a two lane, undivided, provincial highway. It was dark in the early morning. The weather was clear and the asphalt-paved roadway was dry and in good condition. The posted speed limit was 80 km/h.

The Malibu crossed the roadway centerline directly into the path of a southbound 1996 Saturn SL1 four-door sedan. The vehicles collided head-on with about two-thirds overlap of their front ends. Both vehicles were extensively damaged. Maximum crush was 87 cm to the left-front corner of the Malibu and 120 cm to the left-front corner of the Saturn.

The driver of the Malibu was a 54-year-old female seated in the forward of middle position. She was restrained by the lap/torso seat belt. The load-limiting retractor did not activate, but there was loading evidence on the D-ring. The driver's front air bag deployed in the crash. There was steering wheel rim deformation and a spoke on the rim was fractured. Damage to the knee bolster indicated occupant contact. The driver sustained major injuries.

The Saturn's driver was a 33-year-old male, 180 cm in height with a mass of 141 kg. He was seated in the fully rearward position. Loading marks on the D-ring indicated the driver was restrained by the lap/torso seat belt. The driver's front airbag deployed in the crash. The driver deformed the steering wheel rim and there was full steering column shear capsule separation. The knee bolster was also deformed from occupant contact.

It took approximately one and a half hours to extricate this driver. At the scene he was noted to be hypotensive, and was taken to the hospital with resuscitation in progress. He received intravenous fluids and blood transfusions at the hospital, and had a left chest drain inserted for a left pneumo-thorax. He was taken to the operating room, and was found to be bleeding from a branch of the superior mesenteric artery. This was controlled surgically. He was taken to the operating room a second time, with attention being focused on the orthopaedic problems. However, he went into cardiac arrest, and died despite aggressive resuscitation.

At autopsy the injuries to the Saturn's driver were found to include bilateral rib fractures, bilateral contusions to the lungs and a left pneumothorax, a laceration to the superior mesenteric artery, bilateral contusions to the diaphragm, fractures of upper lumbar vertebrae, contusion of the left lobe of the liver, haematoma to the retroperitoneum, extensive bilateral fractures of the pelvis, fracture of the mid-third of the left femur, and a fracture to the right patella.

CFCP-9612

A 2001 Chevrolet Astro minivan, initially westbound, was stopped at a red traffic light on a two-lane, undivided, urban collector. When the light turned green, the driver entered the intersection, intending to turn left onto a four-lane, undivided, urban arterial. The vehicle's driver waited for one vehicle to clear the intersection and then proceeded to make the turn. The driver failed to observe a female pedestrian who was crossing the intersecting road from west to east. The pedestrian was looking to her right as she crossed in front of the van. The left-front corner of the van struck the pedestrian and knocked her to the ground.

The Astro had a 2-3 cm depression in the upper-rear portion of the left-front fender. The vehicle failed a post-collision safety inspection as the left and right idler arms were worn out, and both the right high-beam headlight and the transmission shift-indicator were not functional. These defects were not causal factors in the case collision.

The Astro's driver was a fully-restrained, 24-year-old male. He was uninjured in the collision.

The pedestrian was a 30-year-old female. She was coming from an appointment at the time of the crash. She was wearing a bright red, three-quarter length coat and black pants with red and white stripes.

At the scene, the pedestrian was found to be stuporous and quickly lapsed into a deep coma. She had an initial Glasgow Coma Scale (GSC) rating of 10 and, upon arrival at hospital, had deteriorated to GSC 3. A CT scan was performed. Subsequently, because of her hopeless neurological prognosis, and by consent of her next-of-kin, only comfort therapeutic measures were undertaken. Death was pronounced 34 hours after her admission to the hospital.

The pedestrian's injuries included a linear, longitudinal fracture extending from the left occipital calvarium, along the parasagittal left base of the skull, to the midline of the right anterior cranial fossae, bilateral fronto-temporal cerebral lacerations and contusions with edema and brain stem herniation, and a mild diffuse clotted subdural haemorrhage.

Discussion

The initial crashes in the present series are comprised of ten single-vehicle and two vehicle-vehicle collisions. Of the single-vehicle collisions five were impacts with pedestrians, four with crashes into poles, and one incident involved a run-off road situation resulting in vehicle rollover. The two vehicle-vehicle incidents both involved head-on crashes.

The first crash in the current series was a single-vehicle, run-off-road incident, giving rise to an impact with the embankment of a median ditch and a subsequent vehicle rollover. Detailed analysis of the collision identified a number of human, vehicular and environmental factors that contributed to the collision causation and its consequences. It is, therefore, instructive to consider the issues raised, and some of the potential countermeasures that they suggest, in some detail.

The driver was found to have recently used cannabis and, while the blood serum level was not high, recent research indicates that it was likely sufficient to produce impairment of the driver's psychomotor function. Moreover, cannabis has been shown to have a greater affect on highly automated behaviors, such as road tracking and speed control, than for more complex driving tasks requiring conscious control.[4] Thus, given the nature of the vehicle's pre-crash dynamics, the use of this drug must be considered a contributing factor in this case.

It was evident that the driver allowed the left side wheels of the vehicle to egress from the asphalt-paved roadway surface onto the gravel shoulder. At

this point, he applied inappropriate steering action in an attempt to regain the paved surface and, in the process, placed the vehicle in yaw. A subsequent over-steer condition resulted in complete loss of control, the front-end impact in the ditch, and the ensuing rollover.

The vehicle was travelling in excess of the posted speed of the roadway. Nevertheless, while the speed of the vehicle was a contributing factor in terms of the severity of the initial impact, and the subsequent consequences of the collision, it was not considered to be the cause of the initial loss of control. The asphalt pavement was dry, the vehicle tires more than adequate to maintain traction, and the radius of the curve sufficient for a critical speed well in excess of the vehicle's travel speed.

An appropriate action on the part of the driver in this case would have been to maintain a relatively straight course along the shoulder while reducing the vehicle's speed, by taking his foot off the accelerator and gently applying the brakes, to the point where moderate steering input could safely be applied to turn the vehicle fully back onto the asphalt pavement. While such recovery techniques are taught in some driver education courses, there is no standard curriculum for such courses, nor any requirement for licensed drivers to have taken such courses. Brief mention is made of appropriate recovery techniques in the provincial driver's handbook, but the general public are largely unaware of the availability of this information. Since such over-steer conditions, following vehicle drop off onto soft gravel shoulders, is a relatively common cause of single-vehicle crashes, some effort should be expended to apprise the public of the necessary information.

If the driver was fatigued, or distracted from some source, a median rumble strip may well have been effective in providing an early warning of the errant path of his vehicle and providing an opportunity for him to take appropriate corrective action. Rumble strips are known to be effective in such situations [5], and are frequently implemented when applicable road sections are reconstructed or repaved.

The subject roadway was a relatively old design and, due to restrictions imposed on its construction had a less than desirable cross section. As a result, the median was narrow and featured a deep central ditch. In consequence, the road was unforgiving for errant vehicles and this proved to be precisely the case in the subject incident. The hard impact with the back slope of the ditch resulted in the deformation of the driver's seatback from occupant loading, the rollover of the vehicle, and the ejection of the occupant. Comprehensive amelioration of the roadway would require extensive reconstruction, perhaps by filling in the median, installing barrier systems, paving the shoulders, and adding rumble strips.

New vehicle technologies can be seen to have potential for avoiding these types of collisions in the future. Lane-departure warning systems, using on-board video-cameras and image processing systems may well provide earlier warning of the vehicle potentially going to egress from its intended travel lane than could be afforded by rumble strips at the roadside. [6] Fatigue detection systems, such as eye-movement detectors, could also be used to notify the driver to the fact that he was not fully alert. [7] And, electronic stability control systems, using a combination of reducing engine power to slow the vehicle, and selective brake application at one or more wheels to provide a counter moment to correct a vehicle yaw condition, have been shown to reduce the incidence of single-vehicle incidents. [8]

The crashworthiness of the case vehicle in the subject incident was compromised by the excessive yielding of the driver's seatback, and the inability of the lap belt to prevent the occupant from ramping up the deformed seatback and slipping out of the restraint. While the case collision involved a severe rear end impact, failure of seat backs in less severe crashes has frequently been noted.

Safety engineers must strike a balance in the stiffness of the seat back structure between making it so stiff as to provide the potential for increased whiplash to vehicle occupants, and insufficient strength resulting in yielding or complete system failure. New seat and head restraint designs accommodate the desire to reduce the frequency of and mitigate the severity of whiplash injuries, while some seat belt systems are integrated into the seat and require modified structural designs.

Canadian Motor Vehicle Safety Standard 207 – Anchorage of Seats [9] requires the "..application of a force that… produces a moment of 3,300 pound-inches about the seating reference point…" during which the seat must not change its adjusted position. Effectively, this specifies a force in the order of 1500 N (330 lb) acting at the centre of the seatback, or 750 N (165 lb) acting at the top of the seat back. While such loading is unlikely to be achieved in static conditions, considerably greater loading regimes are quite possible in even moderate collision situations. Consequently, given the evident limitations in the current standard, and technological advances in seat performance, it would be prudent to review the requirements of the present regulations.

The provision of a sliding tongue in the vehicle's seat belt may well have been a contributing factor to the system's inability to retain the occupant once the seatback yielded. Possible countermeasures here might be a requirement for locking tongues, as provided in many passenger seating positions to accommodate the installation of child restraints, or the provision of seat belt pretensioners that would deploy in rear-end impacts. However, it should be noted that preventing excessive deformation of the seatback would obviate the need for any such changes to the restraint system.

While similar detailed analyses were conducted on individual crashes in the present series, for the purposes of this paper, the findings from the remaining incidents will be grouped into convenient categories.

Pedestrian Impacts

The pedestrian crashes fell into three broad groups – impacts at night, with pedestrians crossing the road from the drivers' left; collisions with pedestrians where the vehicle was making a left turn at an intersection; and one crash where the pedestrian undertook a mid-block dash directly in front of an oncoming vehicle.

Both collisions in the first of the above-noted groups were characterized by elderly pedestrians, wearing dark clothing, attempting to cross the road in darkness, and approaching from the driver's left.

Under such conditions, the pedestrian's outer clothing would have produced little conspicuity. In addition, with the vehicle's headlights on low beam and the headlight beam pattern skewed to the right side of the road, the fact that the pedestrian was crossing the road from the driver's left would have resulted in further difficulty for the driver to observe the individual. [10] It is noteworthy that, in each of the two cases in the present series, the vehicle occupants did not see the pedestrian until immediately before the impact.

Clearly, it is not practical to illuminate every roadway to try to avoid all pedestrian impacts. In addition, considerations for potential glare to oncoming vehicles impose constraints on the beam patterns that can be used for headlights. Consequently, much of the responsibility for avoiding vehicle-pedestrian collisions, under similar circumstances to those encountered in these cases, rests with pedestrians.

Unfortunately, research indicates that pedestrians dramatically underestimate their visibility to vehicle drivers, mistakenly believing that drivers can see pedestrians just as well as pedestrians are able to see well-lit, oncoming vehicles. [11]

Some northern countries, notably Finland, have enacted regulations whereby pedestrians and cyclists must wear reflectors on their outer clothing

during hours of darkness. [12] Such measures have been shown to have positive results in the reduction of crashes with these target groups.

Night-vision systems, typically using infra-red detectors, provide the potential for drivers to identify hazards, such as pedestrians, under conditions of darkness. [13] Current systems are limited to use in high-end vehicles, and the effectiveness of these devices under real-world conditions, especially in reasonably-well lighted urban settings, has yet to be determined.

While enhanced pedestrian conspicuity is a worthy goal, sometimes pedestrians take unexpected actions that would negate the effect of such countermeasures. The alcohol-impaired pedestrian in CFCP-9604 is a case in point where his dash into the roadway gave the vehicle driver no possibility of avoiding the impact.

When such crashes are unavoidable, modifications to vehicle structures to provide pedestrian impact protection have been proposed [14], and some such systems are currently in production in various parts of the world. However, pre-impact vehicle speeds in the case collisions were found to be approximately 10-15 km/h above the posted speed limit. Even in an urban environment, striking a pedestrian at such speeds may well limit the effectiveness of vehicle structural modifications.

Where pre-impact braking is a viable option for the vehicle driver, brake assist systems, which provide maximum braking effort early in a panic-braking situation, have been shown to be likely to afford an opportunity to mitigate the severity of pedestrian impacts if not avoid collisions entirely. [15]

The other grouping of pedestrian fatalities was where impact occurred with vehicles undertaking left turns at intersections. In each of the two subject cases, the vehicle driver was turning left after having stopped. Consequently, in these cases, the vehicle's speed at impact was low. However, the provision of a pedestrian-friendly vehicle front end would be unlikely to have affected the outcome in either case, since the injury mechanism was that of knocking the pedestrian to the ground, with a subsequent head strike against the hard roadway surface.

It is clear that, in each of our subject cases, the vehicle driver failed to observe the pedestrian crossing the intersecting roadway prior to making the turn. It is likely that the driver was totally focused on the on-coming traffic, finding a gap, and making his turn. Unfortunately, such driving practice is commonplace in busy urban environments. While drivers generally know that they have to give way to pedestrians in such situations, in their haste to make a turn, they often fail to look for pedestrians crossing the roadway. Previous studies have shown left-turn manoeuvres to result in more pedestrian impacts than when drivers are undertaking right turns [16], and that both drivers and pedestrians fail to adequately scan for each other. [17] Many jurisdictions have adopted pedestrian safety campaigns on this theme, encouraging both drivers and pedestrians to watch out for each other.

In one of the above-noted collisions, a line of vehicles was parked along the street and adjacent to the side of the intersection where the pedestrian was initially located. In particular the vehicle closest to the intersection was within a 9 m zone adjacent to the intersecting roadway, prescribed by regulation as a no-parking area. While the presence of parked vehicles may have restricted the driver's view of pedestrians on the sidewalk, there seemed to be sufficient clear zone such that the driver should have been able to see the subject pedestrian prior to commencing his turn.

Nevertheless, this requirement of the provincial highway traffic act is intended as a specific pedestrian safety countermeasure. However, the existence of the regulation is not generally known and drivers usually rely on specific signage at the roadside. While enforcement of parking regulations may help to reduce the incidence of such

infractions, an associated public education campaign would be useful in raising awareness of both the potential problem, and pedestrian safety in general.

In the location of the subject collision, there was signage relating to vehicle parking zones. However, the specific sign was situated 18 m from the intersection, and indicated that parking was allowed on both sides of the sign. Without knowledge of the provincial regulation noted above, drivers might well assume that parking was thus permitted all the way to the intersection. Thus, attention also needs to be paid to detailed signage requirements in such circumstances.

Pole Impacts

With regard to single-vehicle to pole impacts, the common factors in the present series of crashes were elevated vehicle speed and driver loss of directional control.

Alcohol was a factor in three out of the four subject cases, with alcohol impairment and alcohol mixed with illegal drugs being major issues in two incidents. The latter incident was compounded by the driver refusing to stop on the command of a police officer. Where one driver was below the level of legal impairment, his judgment was obviously clouded since he acquiesced to his passenger's urging to travel at excessive speed and subsequently was unable to maintain directional control of the vehicle. Tragically, in the one case where the driver was acting as a designated driver for a group of friends, he choose to travel at high speed along a gravel-covered road surface and then deliberately swerved the vehicle from side to side, to the point where he lost directional control.

As noted earlier, electronic stability control (ESC) systems are designed to assist drivers in maintaining directional control, by actively controlling braking and engine power, in situations where the vehicle is on the point of yaw. Such systems may well assist drivers to avoid some run-off-road situations and subsequent collisions. However, their effectiveness when a vehicle is travelling at high speed and being operated by an alcohol-impaired individual remains in question. Vehicle dynamics are subject to the laws of physics and even automated systems may be overdriven by determined individuals.

However, as noted earlier, collision studies have shown the potential for collision reduction through the use of ESC. Nor, is the effect of such systems necessarily limited to singe-vehicle crashes. For example, the first of the two head-on collisions in the present series (CFCP-9609) involved a loss of control on an icy road surface that resulted in the vehicle crossing the centerline and impacting a tractor-trailer. It appears the subject driver was in a hurry to arrive for a previously-arranged appointment but that her travel speed was not excessive. In this case, the availability of ESC on her vehicle may well have been sufficient to prevent the initial loss of control and hence avoid the head-on crash.

The incidence of fatal collisions involving vehicles running off the travelled portion of the roadway suggests that greater attention should be paid to the concept of the forgiving roadside.[18] Ideally, one would wish to see an area free of obstacles that could cause serious injuries to occupants of an errant vehicle, and a relatively flat recovery area affording the driver with an opportunity to return to the road without incident. When these conditions cannot be provided, hazardous features in the recovery area should be made breakaway, or shielded with an appropriate barrier, to reduce the severity of any collision.

Many of the side impact crashes in the present series involved extensive intrusion into the occupant compartment and, as a result, the opportunity to provide adequate occupant protection was somewhat limited. Nevertheless, some of these collisions involved fatalities to far-side occupants and/or situations where the presence of side air bags, and particularly side head curtains may well have been able to mitigate the injuries sustained.

Such air bag technologies are rapidly becoming standard equipment in the new vehicle fleet and future benefits to collision-involved vehicle occupants are likely to accrue. [19]

Event Data Recorders

The causes of the second head-on collision in the current series were not identifiable. The driver of the vehicle that crossed the roadway centerline had no recollection of the pre-crash events. Both case vehicles were equipped with event data recorders (EDR's). The information that these units captured demonstrated the severe nature of the frontal impact to each vehicle. The data were also useful, although not definitive, in considering possible driver actions.

The pre-crash data retrieved from the EDR on the bullet vehicle were not consistent with the driver intending to overtake. The vehicle's throttle application, engine rpm, and travel speed were all relatively constant for several seconds prior to algorithm enable (AE). In the last second before AE, the driver evidently was in the process of taking her foot off the accelerator and, presumably, going to brake. It appears, therefore, that the vehicle drifted over the centerline and into the path of the on-coming vehicle.

Once the bullet vehicle crossed the roadway centerline, the driver of the target vehicle had no opportunity to take avoiding action. Both vehicles were equipped with three-point seat belts and front air bags; however, the severity of the crash was at the limits of human biomechanical tolerances.

Consequently, vehicle-based technologies, such as lane-departure warning systems and fatigue detection systems, using on-board video-cameras and image processing systems, may be the only means of avoiding such collisions and their tragic consequences in the foreseeable future. Similarly, sophisticated in-vehicle crash recorders may be the only means by which the detailed circumstances of such collisions can be identified.

Conclusions

The findings from this preliminary series of in-depth collision investigations indicate that, very often, valuable information can be gathered on collision causation, and that such data can be used to readily identify a range of potential counter-measures. While the present work is being conducted primarily in an urban environment, a companion paper considers the results from a similar study conducted in a more rural setting. Clearly a mix of collisions from a variety of regions across the country would be required to adequately identify and address safety issues that affect all Canadian road users.

Despite the extremely limited nature of the present sample of cases, some characteristic safety issues and likely countermeasures have been identified. In particular, with respect to vehicle-pedestrian collisions, it is evident that vehicle drivers need to pay more attention to the presence of pedestrians, especially when turning at intersections and, conversely, pedestrians need to be more aware of their lack of conspicuity to vehicle drivers at night. While some jurisdictions have enacted education campaigns to address some of the related issues, it is clear that relevant safety information needs to be more widely disseminated. Similarly, risky driving behaviour, particularly speeding while under the influence of alcohol and/or drugs, can readily lead to inappropriate steering actions and catastrophic crash situations. Public education on this issue is well advanced, yet a small group of road users persist in such behaviour. In the short term, on-road enforcement programs, targeted at such drivers, are probably the main method by which the problem can be controlled. Technological solutions, such as passive alcohol sensors, may be a further tool to address the issue. [20]

Vehicle technologies, including collision avoidance systems such as electronic stability control, lane-departure warning, and driver fatigue detection, may well have a beneficial impact on the frequency of future collisions. Other technologies such as

brake assist, pedestrian-friendly vehicle structures, advanced occupant protection systems such as side air bags and head curtains, may mitigate injuries when crashes do occur.

One driving manoeuvre that is not well understood, and certainly not well performed by many drivers, is recovery after the vehicle runs of the paved roadway onto a soft shoulder. While this specific situation occurred in only one case in the current series, similar inappropriate steering action was the cause of a number of the subject collisions. While some consideration has been given to educating drivers to the correct driving technique to maintain directional control, a concerted effort is required to make this information more widespread. A possible technique to achieve this would be a media campaign using video footage illustrating the potential for loss of control and of the ability of drivers to regain control in such situations. A high-profile personality such as a Canadian race car driver could be used to act as a credible spokes-person on the issue. At the other extreme, a web site could be developed to illustrate the "Lessons to be learned…" from fatal crashes, with one segment being devoted to a graphical illustration of the loss of control that can result from over-steering after running onto a gravel shoulder, and an explanation of the appropriate corrective action.

The lack of hard data on the reasons for the occurrence of one of the head-on collisions in the current series of cases, and the unavailability of an account of the collision events from the surviving driver, reinforce the desirability of having on-board crash recorders in motor vehicles. While the data obtained from the EDR's in the case collision were rather limited, they did provide extremely useful information as to the actions of one driver and the crash severity. The utility of EDR's in such situations has been previously noted.[21] The most recent versions of these devices are considerably more sophisticated , and subsequent generations are likely to provide even more data. Consequently, the installation and use of advanced EDR's in future vehicles should be encouraged.

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