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Directed Studies:
A Focused Approach to Collision Investigation

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EXECUTIVE SUMMARY

For over twenty years the Road Safety and Motor Vehicle Regulation Directorate of Transport Canada has maintained a national network of university-based teams. These teams conduct investigations of real-world collisions in support of the Directorate's safety programmes. Recently, the work required of these teams has been redefined to create a programme of directed studies which are focused on specific safety issues. Currently, three directed studies are in progress: collisions involving air bag deployments, moderately-severe side impacts, and heavy truck crashes. The conduct of these studies is discussed in the light of Transport Canada's policies, and potential changes to the motor vehicle safety standards.

SOMMAIRE

Depuis plus de 20 ans, la Direction générale de la sécurité routière et de la réglementation automobile de Transports Canada maintient un réseau d'équipes d'enquête sur les collisions routières dans des universités canadiennes. Les enquêtes effectuées par ces équipes sont à l'appui des programmes de sécurité de la Direction générale. Récemment, la tâche de ces équipes a été redéfinie afin de mettre sur pied un programme d'enquêtes dirigées qui sont axées sur des questions précises de sécurité. À l'heure actuelle, trois de ces études sont en cours: les collisions mettant en cause le déploiement de coussins gonflables, les collisions latérales modérément graves, et les collisions mettant en cause les camions lourds. Ces études font l'objet de discussions en tenant compte des politiques de Transports Canada et des modifications éventuelles qui seront apportées aux normes de sécurité des véhicules automobiles.

INTRODUCTION

In the early seventies Transport Canada set up a network of research teams based at ten universities across Canada. Initially, these teams conducted in-depth investigations of a relatively small number (120-150) of motor vehicle collisions on an annual basis. The teams adopted a multi-disciplinary approach where the expertise of a broad range of road safety professionals was brought to bear on the individual crashes. All aspects of the collisions under study were researched in detail, and were categorized as human, vehicle, and environmental factors in the pre-crash, crash, and post-crash phases of the collision event. Thus, the Canadian Multi-Disciplinary Accident Investigation programme (MDAI) was born.

Over the years, the collision investigation programmes undertaken by the university teams have been modified to meet the changing demands of road and motor vehicle safety in Canada. In the early eighties, the initial in-depth MDAI study was changed to obtain a sample of fatal, personal injury, and property damage collisions involving light duty trucks. Approximately 1000 individual crashes were captured annually for inclusion in the database for the Light Truck and Van Study (LTV). The sampling system adopted was such that this database could be used to derive national estimates for specific data elements. Later, a similar sampling system was used for the Passenger Car Study (PCS) which focused on collisions in which at least one passenger car was involved, and which resulted in either injury or fatality to some road user.

Recently, in response to budgetary constraints, the number of teams has been reduced to eight. This downsizing of the network resulted in an inability for the remaining teams to collect sufficient data from which to derive reliable national estimates. This has, therefore, required a further realignment of the tasks to be undertaken by the teams. The outcome has been a new programme where in-depth information is obtained on narrowly-focused motor vehicle safety issues. Because of the precisely defined areas of interest in the collisions under study, the overall case load for the teams is now in the order of 350 cases per annum.

This research programme, the individual elements of which are known collectively as directed studies, has now been underway for eighteen months. Three studies are currently in progress, each of which addresses safety issues of specific interest to Transport Canada's Road Safety and Motor Vehicle Regulation Directorate. In particular, the current studies are all aimed at safety issues which are likely to involve regulatory action in the near future.

METHODOLOGY

Each directed study is intended to be conducted over a relatively short time frame, and has specific goals established at the onset. Current studies have durations of the order of one to two years, and this is likely to prove to be the norm. For each study, a client for the collision data to be obtained is identified, in order to ensure that there is a specific end user, with defined needs, for the final product.

Once the programme is fully operational, it is intended that each directed study will be conducted in a closed loop system. Each study will encompass an initial design phase, and will be subject to a pilot study in order to debug and refine the proposed data collection system. With this process completed, the main data collection effort will be undertaken by the university teams. At the end of the data collection phase, an exhaustive and detailed review of these data will be conducted, and a final report compiled.

The initial development of a new study will be conducted by Directorate personnel. A study design team, consisting of standards engineers, researchers, collision investigators, and data analysts, will work in conjunction with the client to develop an appropriate methodology. The initial study design will then be pilot tested to debug and refine the data collection and recording systems. To this end, the Directorate's collision investigation division will undertake a study of a limited number of real world crashes meeting the study's criteria. The experience so gathered will assist in identifying appropriate collision investigation, reconstruction, and documentation techniques, and allow for the development of any special tools which may be required. The data collection forms, coding protocols, and data entry system can all be tested, debugged, and enhanced as necessary. The pilot study will also provide a limited dataset which can be analyzed to ensure that appropriate data elements are being captured to answer the questions posed by the study's client.

Once an appropriate methodology has been determined, a "turn-key" operation can be handed over to the university teams who will proceed with the identification and documentation of crashes meeting the study criteria. Local variations in police reporting systems, vehicle disposition, and medical care, will require some customizing of the case identification mechanisms, and of the sequencing of individual collision investigations. For each study, a basic set of required data elements will have been prescribed in order to ensure that all of the necessary data is captured. Similarly, a general report format will have been defined to ensure that the results are presented in a standardized format. However, the teams will be afforded the flexibility to provide details of specific items of interest which may arise in the cases under study. This provides a mechanism to alert the Directorate to collision events and consequences which, although not directly related to the specific safety issue under study, nevertheless may still be of concern. Completed cases submitted to the Directorate will be subject to quality assurance reviews, the results of which will be fed back to the teams. This latter process will aid in resolving any specific problem areas, and provide a means to disseminate innovative research techniques. On-going analysis of the accumulating data by Directorate personnel may further refine data needs and coding protocols.

The precise data requirements and mode of operation will be tailored for each specific study. Perhaps, the best way to consider this is by example, so we will discuss the methodology being adopted for the current Air Cushion Restraint Study (ACRS). The focus of this study is on collisions involving air bag deployments. In particular, the interest is in the severity of such crashes and the mechanisms of injury to the occupants of the case vehicles. The intention has been to acquire a convenience sample of such collisions with no intentional biases, and to focus the investigative effort on the collision performance on the case vehicles.

Consequently, for this study, teams are working within a well defined area of operation and are attempting to obtain information on all air bag crashes which occur over the period of the study. While local conditions dictate how this process is actually achieved, typically the investigating team is notified of the occurrence of an air bag deployment by police officers or towing company personnel.

Where appropriate the team may respond to the collision scene whilst emergency services are still present. Otherwise the scene is visited at a later date, following the removal of the involved vehicles. In either case, physical evidence such as tire marks, gouges, fluid spills, and debris, relevant to the collision under study is identified and recorded. Such details are used to reconstruct the pre-crash and post-crash dynamics of the involved vehicles, the location of the point of impact, the collision configuration, and the vehicles' final resting positions.

The primary vehicle inspection is conducted at the point of deposition. The non-case vehicle is considered merely as an object struck, and the inspection of this vehicle is limited to recording details of the external damage. The vehicle is documented photographically, and measurements of the location and extent of the damage crush profile are made. A Collision Deformation Classification (CDC) [1] is assigned to the observed damage pattern. These same procedures are also carried out on the case vehicle. The crush data so obtained are used in the reconstruction of the collision event. An evaluation of the pattern of damage on each vehicle, the direction and extent of the deformation observed, and the correlation of specific mutual contacts, allows the experienced investigator to determine the orientation of the two vehicles at the point of impact, and the directions of the principal forces acting. Analysis of the damage using a computer-based reconstruction program [2] allows for the estimation of the collision severity measures equivalent barrier speed (EBS) and change in velocity (Delta-V) for each vehicle.

For the case vehicle, in addition to examining the external damage, a detailed inspection is carried out on the interior of the occupant compartment. Specific items of interest, include the position and adjustment of occupied seats and their associated head restraints. An H-point template is used to define the seating geometry, and to quantify seat position, in a standardized manner. The type of occupant restraint system, including seat belts, child restraints, and air bags, available to each vehicle occupant is determined and the details of the restraint recorded. Particular attention is paid to the identification of any witness marks which may indicate occupant loading. Visible occupant contacts with portions of the vehicle interior are identified and recorded. Attention is also paid to safety devices which promote the crashworthiness of the vehicle. Specific items of interest include any rearward displacement of the steering column which may have occurred as a result of the crash; deformation of the steering wheel or compression of the column due to occupant loading; the collision performance of the door locks, hinges, and latching systems; retention of the windshield; the occurrence and extent of any intrusion into the occupant space; and the integrity of the vehicle's fuel system.

Where possible, all of the occupants of the case vehicle are contacted and are subjected to a detailed interview process. Data such as the age, gender, height and weight of each occupant are obtained. Particular attention is paid to the adjusted position of the occupant's seat, their pre-impact posture, and the use, and manner of such use, of the seat belt system. The incidence of any pre-existing medical conditions which might have influenced the injury outcome of the collision are explored, as is the usage prior to the crash of any medication, non-prescription drugs, and alcohol. Specific descriptions of any injuries sustained are sought and, whenever possible, confirmation of these injuries are obtained by consulting official medical records. The details of any such injuries are coded using AIS 90 [3].

Once all of the field data has been collected, the investigating team analyzes these data and reconstructs the crash in as much detail as possible. This may entail a determination of the dynamics of the involved vehicles during the collision events, computation of appropriate measures of the crash severity, consideration of the occupant kinematics, and a determination of occupant injury mechanisms. The results of the collision investigation and reconstruction of each crash are documented in the form of a technical report with many of the data elements being coded to form part of an associated electronic database.

In order to ensure that the necessary resources are available to close the loop of the study process, a dedicated data analyst on the Directorate's staff has been assigned to the directed studies' programme. This analyst, working in close cooperation with the study client, will conduct an exhaustive review of the final database for each study. A final report, including specific conclusions and recommendations, will be produced and made available to Directorate personnel for review and appropriate action. Copies of such reports will also be provided to the investigating teams. Final reports will be disseminated to agencies which participated in the data collection process in order to ensure that these agencies are informed of the study's outcome. It is also envisaged that various aspects of the study's findings will be published in the international scientific literature in order to widely disseminate the results to interested parties.

Whereas the initial series of studies which are currently underway have not precisely followed the model outlined above, many of the listed features have been implemented. The project within Transport Canada is now fully staffed, and future studies are being developed according to the model. It should be evident that the combination of in-house and university personnel working on different phases of each study provides for an efficient cycle for the research programme. While one study is underway, data from the previous study will be being analyzed, and future studies will be under development. Such a process will be necessary if a series of short-term projects is to be maintained.

Air Cushion Restraint Study (ACRS)

The primary collision investigation programme currently being undertaken by the teams is a study of motor vehicle crashes involving deployments of air bag systems. For seven of the eight teams this study forms the majority of their annual case load. One team is conducting a pilot study on heavy truck crashes and performs only a limited number of air bag investigations. The details of the study have been provided above. The important points to note are that the cases selected constitute a convenience sample which is believed to be free of intentional bias, and that the criterion for inclusion of a collision in the study is that an air bag system deployed, regardless of injury outcome to the vehicle occupants.

Transport Canada has suggested changes to Canadian Motor Vehicle Safety Standard 208 (CMVSS 208 - Occupant Protection) relating to the injury criteria used in compliance testing [4]. In particular, a maximum acceleration of 80g is proposed for the dummy's head in the 48 km/h frontal barrier test. Previously, the head injury criterion (HIC) has been used as a compliance measure, with a HIC of 1000 defining the acceptable upper limit; however, the scientific validity for HIC has recently been shown to be questionable [5]. Furthermore, it has been determined that a maximum head acceleration of 80g effectively discriminates between non-contact events, and those in which a "hard" contact is made between the dummy's head and the steering assembly.

An additional requirement of the compliance test, is that the chest deflection measured in the dummy must not exceed 50 mm. The femur load limit of 10 kN remains unaltered. In addition to these dynamic test requirements, the geometry of the available seat belt system would be subject to a static test using the Belt-deployment Test Device [6]. These measures have been selected to reduce the potential for injurious head contacts with the vehicle interior, to preclude serious thoracic and abdominal injuries, and to maintain some control on the occurrence of lower extremity injuries.

Crash testing has suggested that compliance with those criteria relating to the head, and to some extent the chest, can be achieved through the introduction of air bag systems. Specifically hard contacts with the steering assembly in the rather severe frontal crash test, are replaced by contacts with the air bag "cushion". This is likely to be the course of action taken by manufacturers for vehicles sold in Canada, especially since the United States Congress has issued requirements for the introduction of air bags into light duty vehicles by 1997-98. Nevertheless, one issue of concern is the disparate seat belt usage rates between our two countries, and a perceived need to have air bag systems offer some protection to unrestrained occupants. The current air bag study was intended to address this and other issues, and to compile some real-world data on the collision performance of air bags in the Canadian collision-involved population.

On-going analyses of the study data have provided some interesting insights into the performance of air bags as supplemental restraint systems, albeit that these results are necessarily of a preliminary nature. A review of the initial series of almost 100 cases [7] showed that most crashes were of low severity and that there was a high rate of seat belt use amongst involved occupants. A limited number of high severity collisions provided some indications that the deploying air bag did afford some supplemental protection to fully-restrained occupants, and certainly benefited the unrestrained. The limited data available also suggested that there was potentially some downsides to the deployment of air bags, particularly for occupants who might be in close proximity to the deploying bag.

Following one year of data collection, a further review of the cases submitted supported many of the earlier findings [8]. Since the vast majority of collisions in which air bags deploy are of relatively minor severity, these systems offer little if any additional benefit to fully restrained occupants over that which might be expected from the use of seat belts alone. The benefits of passenger side air bags which deploy in crashes are also questionable because of relatively low occupancy in this seating position.

The findings to date strongly suggest that the collision performance of the combination of seat belts and air bag systems should be optimized if a largely restrained population is to derive benefits from air bag deployments. It should be noted that industry is currently developing "smart" air bag systems which will identify the presence of an occupant, the proximity of the occupant to the air bag module, and the occupant's restraint use. Future air bag systems will no doubt use such information to determine deployment characteristics.

Moderately-Severe Side Impacts (SIDE)

Considerable international research has been conducted on the problems associated with side impact crashes. Even for fully restrained occupants, moderate severity near-side collisions pose significant potential for serious injury. The current safety standard, CMVSS 214 -Side Impact Protection, uses a quasi-static testing procedure which does not necessarily relate well to many real-world collision events.

Proposals from both the United States and Europe would require future compliance testing in the form of a staged collision between a moving deformable barrier and a stationary test vehicle, with instrumented dummies in the near-side seating positions being used to assess the crashworthiness of the test vehicle. The American [9] and European [10] test procedures are significantly different due to the use of dissimilar moving barriers, collision configurations, and side-impact dummies. Canadian research has assisted in quantifying the inherent differences in the methodologies [11].

The final form of the revised side impact protection rule has yet to be determined, and Transport Canada is currently soliciting public input into the decision making process [12]. Nevertheless, manufacturers are currently designing vehicle side structures to meet the requirements of the proposed American compliance test, and a number of vehicles are currently being marketed as complying with the proposed US standard. With such vehicles being present in the fleet, a directed study is planned to investigate the crashworthiness of late model vehicles in side impact crashes which resemble the conditions of the proposed compliance test. This study is currently in the design and pilot testing phase, with most of this work being conducted by Directorate staff.

Criteria vehicles for this study will be passenger cars, light trucks, and vans which are less than five years old. The collision damage to the side of the case vehicle must include a portion of the occupant compartment, and there must have been an occupant seated adjacent to the damaged area. In order to further replicate the crash test conditions, the principal direction of force to the case vehicle must be within 45 degrees of the normal to the struck side. The requirement for moderately severe side impacts is intended to screen out both minor crashes, which are unlikely to result in any significant injuries, and also collisions where the impact is so great, and the resulting damage so extensive, such that these would be effectively unsurvivable. To approximate these conditions, the maximum crush into the occupant compartment will normally extend inside the roof side rail but not reach further than halfway across the seat.

It is anticipated that with these collision criteria a variety of injury types and severities will be observed in the real-world crashes studied. The emphasis in this research programme is on collision severity and injury mechanisms, particularly as these apply to the near side occupants in the case vehicle. To this end, extensive measurements of the crush profile will be recorded, and detailed descriptions of the individual injuries will be sought. Crush measurements will be taken at 15 cm intervals along the entire side damage profile. These data will be recorded at a minimum of four vertical levels, these being at the heights of the sill, mid-door, belt line, and roof side rail. Detailed information concerning the location, type, and extent of individual injuries sustained by the vehicle occupants adjacent to the struck side will be obtained from official medical sources. By combining these data, specific load paths may be identified, and particular injury mechanisms determined.

Heavy Freight Vehicle Pilot Study

The involvement of heavy trucks, and especially tractor-trailer combinations, in collisions is of concern to many road users. The large size of such units often provides the dominant mass in multi-vehicle collisions, and the usual geometry of heavy trucks can also lead to substantial hazards in certain crash types. The associated problems of night-time vehicle conspicuity and truck underride provide prime examples of these concerns. Vehicle size, as it pertains to heavy trucks, also plays a major role in the related issues of rollover stability and load retention. All of these issues are of current concern to the Directorate as new and revised safety standards are being considered as potential countermeasures.

CMVSS 108 - Lighting Equipment currently requires a combination of marker lamps and reflex reflectors to be installed on heavy trucks. Despite such aids to night-time identification, other drivers continue to engage heavy trucks in rear-end or side impacts. Considerable research has been conducted on this phenomenon and there are a number of possible scenarios which may explain such incidents. Drivers may simply not see the truck; they may see it but not perceive the hazard correctly; or they may perceive the presence of the truck too late to take effective avoiding action. The availability of retro-reflective tape has provided a means to make significant improvements to the conspicuity of heavy trucks in a very cost effective manner. Such treatment is required for new trailers by current US regulations. CMVSS 108 will be modified, as an interim measure, to allow the use of retro-reflective tape treatments meeting the US standard; however, issues such as target patterns and tape colour are presently being considered further.

The usual height of a truck's cargo deck provides a major hazard for a light duty vehicle which comes into collision with the truck since the most likely contact to the smaller vehicle will be to the greenhouse area of the occupant compartment. Rear-end crashes often involve a high closing speed and, in the absence of an adequate rear guard, the back of the truck may intrude considerably into the occupant space of the bullet vehicle. Often in side-impact crashes the bullet vehicle, travelling down an unlit highway, encounters a tractor-trailer making a turning manoeuvre such that the tractor occupies the on-coming lane and the trailer straddles the bullet vehicle's travel lane. The tractor's headlights often mask the presence of the trailer for the on-coming driver. If the travel speed of the bullet vehicle is high, and contact is made in a gap between the truck's axles, the consequences can be disastrous. In such situations even an underride guard would be unlikely to mitigate the crash severity to any great extent. There is however another side-impact situation, the overtaking manoeuvre, which may well be amenable to an underride guard treatment. Without such a guard, it is easy for the nose of a passenger car for example to ride under the side deck of a tractor-trailer and become jammed against the wheels of the trailer. Not only can this be extremely hazardous for the occupants of the passenger vehicle, but it may also result in upsetting the truck. It can be noted that such incidents often involve shallow approach angles and low relative velocities. Consequently, an appropriately designed guard system could well provide adequate protection against such occurrences.

The height of the cargo deck, and the relatively large mass of cargo carried, also results in a low rollover threshold for heavy trucks. This is compounded by the limited dynamic performance of large trucks, especially tractor-trailer combinations, in manoeuvres such as rapid lane changes, and by their interaction with environmental features such as drainage ditches should these vehicles egress from the travelled portion of the roadway. When a heavy vehicle rolls over, there is potential for loss of the cargo which, in itself, may present a hazard to other road users. This has certainly been found to be the case for heavy, and very dense objects, such as coils of sheet metal and rolls of paper [13].

These hazards have been recognized for some time and Transport Canada has made a commitment to a load security task force of the Canadian Council of Motor Transport Administrators (CCMTA) to study areas of federal jurisdiction which would improve load security in Canada. As part of a joint federal-provincial initiative, federal load security standards would complement revisions to provincial regulations. In particular, CMVSS 905 - Trailer Cargo Anchor Points, is being developed to address the issue of the strength of the connection between the trailer and the tie-down system. Features of the tie-down systems themselves, such as the number of securement devices, their placement, load limits, and inspection requirements are specified by provincial regulations.

The proposed CMVSS 905 will require that anchorage locations in sufficient numbers, and of adequate strength, will be available on heavy duty trailers with a GVWR of 10,000 kg or greater which are used in hauling heavy, high-density loads. The minimum strength of each anchor point will be 88,960 N (20,000 lb) which corresponds to the ultimate tensile strength of commonly used securement devices such as chains and straps. The minimum number of anchor points will be based on the rated cargo mass of the trailer according to a prescribed formula. Consideration is also being given to including van-type trailers and straight trucks, and trailers designed for additional cargo types such as pulp-wood.

Some early work on the above-noted issues was carried out as a special project of the Collision Investigation Division of Transport Canada's Road Safety and Motor Vehicle Regulation Directorate. This work has been extended by one of the university teams which is presently carrying out a pilot study of heavy truck crashes, and enhancing the data collection and reporting methodology. To date a limited number of cases have been completed. A preliminary review of the captured data is presently underway.

Conclusions

Although our initial directed study on air bag systems has not yet been completed, the initial results are extremely encouraging. The method lends itself exceptionally well to obtaining a reasonable quantity of data on a specific safety issue within an acceptable time frame. The verification and feedback systems which are in place are ensuring that the captured data is of high quality. On-going analysis of the accumulating database is providing preliminary results which give clear indications of some of the likely outcomes of the study, and is enabling early consideration of potential recommendations. The dedicated analytical capability which has been implemented also provides an efficient mechanism for interrogation of the database with respect to specific areas of interest and provides a means of rapidly researching topical concerns.

It is also believed that the cyclical approach to new studies will further enhance the ultimate utility of this research programme. The project has only recently been fully staffed but considerable progress is now being made on a number of fronts. As a result, future studies will be subject to more intensive design, development and pilot programmes. This process, together with input from the participating university teams, and the in-house data analysis capability, will ensure a successful closing of the research loop and the provision of a valuable end-product.

Notwithstanding the above comments, all of the directed studies which are conducted in the future may not necessarily be constrained to this pattern. The original concept for the programme included the notion of considerable flexibility in its operation. As we have seen, all of the teams need not be working on the same project at the same time. Consequently, there remains the possibility of conducting one major project, several small projects, or any combination, in a given time frame. Similarly, the study topic may not always be prescribed by the Directorate. As the programme matures, there may well be scope for joint research projects with other agencies to address issues of mutual concern. This may well give rise, for example, to federal-provincial studies of specific road and motor vehicle traffic safety issues.

The Multi-Disciplinary Accident Investigation programme has evolved over the years, from its beginning as an in-depth study of a small number of crashes, through a statistically-based national sampling system, to our current effort which to some extent reflects the middle ground between these two extremes. With the challenges posed by new technologies and present economic realities, this programme of tightly focused directed studies is likely to serve Canadians well in addressing critical safety issues.

Acknowledgments

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