

# REDUCING VEHICLE CRASH-RELATED EMS WORKER INJURIES THROUGH IMPROVEMENTS IN RESTRAINT SYSTEMS

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## 1.0 ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH), Division of Safety Research, collaborated with the U.S. Army Tank-Automotive and Armaments Command, the Canadian Forces Health Services Group Headquarters, the Ministry of Health & Long-Term Care, Ontario, Canada, and the U.S. Fire Administration on a research effort to increase the crash protection afforded emergency medical service (EMS) workers in ambulance patient compartments. The estimated fatality rate for EMS workers is 12.7 deaths per 100,000 workers, more than twice the national average of 5.0 for all U.S. workers. Transportation-related events, including ambulance crashes, are the most common cause of death among U.S. EMS workers. Ambulance crash investigations from the National Highway Traffic Safety Administration (NHTSA) and NIOSH were used to identify injury risk and circumstances. Results of these investigations show that regardless of occupant location, non-use of occupant restraints resulting in collisions between unrestrained occupants and compartment bulkheads and cabinets is the primary injury risk.

Seat belts currently provided in ambulances do not allow the mobility that EMS workers need to care for patients. As a result, EMS workers routinely work unrestrained in the patient compartment. Occupant restraints that provide mobility within the ambulance patient compartment, and are capable of mitigating crash-related injuries were evaluated using a mathematical model; a 29-run, laboratory-based, sled-testing program; and, a four-vehicle crash-test program. Each sled and crash test included four instrumented anthropomorphic test devices (ATDs) or crash test dummies. During these tests, the mobile restraints prevented the ATDs from secondary collisions in the patient compartment and were structurally sound at acceleration levels between 25 and 30gs. Use of mobile restraints has the potential to significantly reduce crash-related injuries to EMS workers in ambulance patient compartments. Recognizing seat belts have been viewed as an impediment to the ability of EMS workers to provide patient care, future NIOSH work with mobile restraints will focus on factors that affect user acceptance.

## 2.0 BACKGROUND

### 2.1 Injury Statistics and Risk

A 2002 study of Bureau of Labor Statistics data estimated that EMS personnel in the United States have an annual fatality rate from all causes of 12.7 per 100,000; more than twice the national average.<sup>1</sup> Although no national count

of ambulance crash-related injuries exists, the total number of fatal crashes involving ambulances can be ascertained using the NHTSA Fatality Analysis Reporting System (FARS). During the period 1991 – 2000, FARS data show ambulances were involved in 300 fatal crashes resulting in the deaths of 82 ambulance occupants and 275 occupants of other vehicles or pedestrians. EMS workers accounted for 27 of the fatalities. In 79% (273) of the crashes, the ambulance was impacted in the front quadrant (Figure 1). In addition to the 82 fatalities, 521 ambulance occupants suffered non-fatal injuries of varying severity, including 131 incapacitating, 222 non-incapacitating, and 168 identified as injured with severity unspecified. Riding in the patient compartment was associated with greater injury severity, when compared to riding in the front seat.<sup>2</sup> NIOSH and NHTSA investigations show that non-use of occupant restraints resulting in secondary collisions between unrestrained occupants and bulkheads, fixtures, and cabinets is the primary patient compartment injury risk.

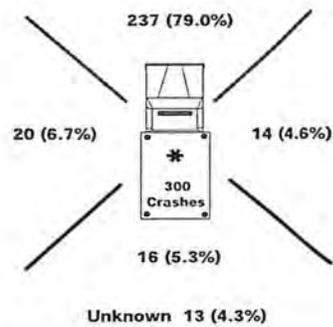


Figure 1: Impact attitude - fatal ambulance crashes, 1991 – 2000

## 2.2 Crash Protection in U.S. Ambulances

There are 3 types of ambulances in the U.S. A Type I ambulance mounts a patient compartment or box on a truck chassis. A Type II ambulance is a modified van with a narrow profile, and a Type III consists of a box mounted on a cutaway van chassis. EMS workers are likely to require greater mobility when working in Type I or IIIs than when working in Type IIs because of their larger patient compartments, thus the project focused on improving crash protection in the box-type patient compartment. The patient compartment seating locations, illustrated in Figure 2, include a rear facing attendant seat and a side facing squad bench with provision for 3 occupants. Many Type I and III ambulances also include a side facing CPR seat. Driver's compartment occupants are protected from crash-related injury by NHTSA required restraint systems installed by the chassis manufacturer. Patient compartment occupants are not afforded the same level of

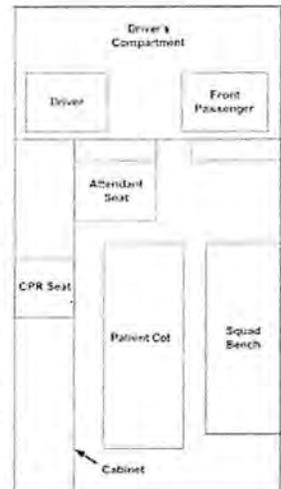


Figure 2: Top view - patient compartment.



Figure 3: Squad bench with seat belts

protection, with most limited to lap-belt only seat belts, and in many cases, dual-purpose seating systems. The crash protection commonly provided for the squad bench (Figure 3), as well as most other patient compartment seats, is a two-point lap belt (e.g., a seatbelt). Proper use of seat belts requires the occupant to be seated with his/her back against the seat back. This position prohibits moving to the edge of the seat to: access the patient; reach across the compartment to access supplies; or perform medical procedures which require standing or kneeling. Because of this, EMS workers routinely work unrestrained on the side-facing squad bench. A previous study confirms that less

than half of EMS workers use occupant restraints while in the patient compartment.<sup>3</sup> Thus, the aim of this project was to evaluate potential approaches to provide patient compartment occupants with the same level of protection afforded those in the driver's compartment, while still allowing them the mobility to care for patients.

### **3.0 METHODS**

#### **3.1 Design of Restraint System Evaluation Project**

The project team chose to attack the issue in a four step process: (1) identification of potential solutions; (2) evaluation of prospective solutions using digital human modeling (computer simulation); (3) testing of promising solutions under laboratory conditions on a dynamic horizontal accelerator (sled test); and, (4) vehicle crash testing in production ambulances.

#### **3.2 Identification of Potential Solutions**

The project team produced a nationwide call to the ambulance industry through an announcement in the Commerce Business Daily, now known as FEDBIZOPS. Nine interested parties, six of whom gave presentations and demonstrations of potential or suggested solutions, responded to the announcement. For the modeling phase, NIOSH selected four potential solutions that provided occupant restraint yet allowed mobility within the patient compartment. These mobile restraints were variations of similar concepts. The occupant wears a harness connected to the ambulance structure by tethers and retractor reels. The reels allow the tethers to payout when the occupant moves away from the attachment point and wind the tethers up when the occupant moves toward the attachment point. During a crash, the retractors automatically lock to prevent further movement of the occupant.

#### **3.3 Digital Human Modeling (Computer Simulation)**

A GESAC-Dynaman computer simulation program was used to analyze occupant motion during simulated crashes.<sup>4</sup> This program has been used extensively to evaluate vehicle occupant crash protection.<sup>5,6</sup> Using a simulated patient compartment, based on dimensions obtained from field measurements of ambulances, each mobile restraint was evaluated for its potential to prevent occupant impact with the patient compartment interior surfaces in front, rear, and side vehicle collisions. The simulations indicated that each of the mobile restraints offered nearly equal potential to prevent impact in the most extreme case: an occupant standing near the forward end of the squad bench.

#### **3.4 Sled Testing**

A sled test buck representing an ambulance patient compartment and matching the dimensions used for the computer simulations, was fabricated using a welded box frame similar to those found in many production ambulances. Additional stiffening was added to provide sufficient strength for repeated testing. The cabinet and countertop surfaces were simulated using sheet metal over the rigid frame structure. No surface padding was provided. Figures 4 and 5 provide interior views of the sled buck, with anthropomorphic test devices (ATD) prior to testing.



Figure 4: View of sled buck: street side from rear.



Figure 5: View of sled buck: curb side from rear.

The sled test program evaluated the mobile restraints in each of three crash attitudes (lateral, rear, and frontal). A total of 29 sled test runs were completed at a Defence R&D Canada (DRDC) research center in Toronto, Canada, from January – April 2003. The complete test matrix is provided in Table 1. In general, each test run included a 95<sup>th</sup> percentile Hybrid III ATD in the standing position, side-facing near the forward end of the bench, a 95<sup>th</sup> percentile ATD seated on the aft end of the squad bench, a 95<sup>th</sup> percentile ATD seated on the CPR seat, and a 50<sup>th</sup> percentile ATD seated in the attendant's seat. Each ATD contained instrumentation to measure head, thorax, and pelvis tri-axial accelerations, upper neck loads and moments, lumbar loads and moments, and belt loads. In all, 87 channels of data were collected during each test run. Additional channels were added to assess test buck response to each pulse (sled test run). To evaluate occupant kinematics, six high-speed video cameras recorded the ATD motion during each test.

Table 1: Sled test matrix.

Impact Direction	Number of Tests	Change in Vel. (kph)	Peak gs
Lateral	8	27	20
Rear	8	29	23
High Frontal	7	52	30
Low Frontal	6	40	25

### 3.5 Crash Testing

The crash tests used the same basic test plan and instrumentation package as the sled tests. Three frontal fixed barrier impact tests with targeted velocity changes (Delta-V) of 48 kph were conducted using three different Type III ambulances mounted on Ford E-350 chassis. A single side impact test, with a targeted ambulance Delta-V of 27 kph was conducted using a stationary Type I ambulance (Ford F-350 chassis) impacted by a truck traveling at 68 kph. Figure 6 and 7 show exterior views of each crash type. No rear impact crash testing was attempted.



Figure 6: Frontal Impact, 48 kph Delta-V



Figure 7: Side Impact, 27 kph Delta-V

### 3.6 Data Analysis and Industry Accepted Reference Values

Sled and crash test data collected from the ATDs was evaluated using injury assessment reference values (IARV) associated with the head injury criteria (HIC), neck loading (Nij), head and chest accelerations, and body kinematics.<sup>7,8,9</sup> An injury criteria value less than the IARV relates to a less than a 5% risk of significant injury to a human.<sup>10</sup> For analysis of these tests the IARVs matched those accepted by NHTSA and were set as follows:  $HIC_{36} = 1,000$ ;  $Nij = 1.0$ ; and chest acceleration = 60gs. Force and moment measurements from the ATDs are used to calculate  $HIC_{36}$  and  $Nij$ . The video data was examined by bio-mechanists to assess each restraint's ability to maintain body position and proper posture during the crash event.

## 4.0 RESULTS

### 4.1 Digital Human Modeling Simulations

Although a detailed validation of model results was not conducted retrospectively, a comparison of occupant kinematics between the Dynamman model, and the sled tested and crash tested ATD video data provides strong visual correlation. Figures 8, 9, and 10, represent the same test condition and mobile restraint system for the Dynamman model, sled test, and crash test, respectively. As shown in these views, the motion of the occupant in the model shows correlation to the ATD motion in the tests. While a formal validation process to include a refinement of the model would be helpful, the existing model provides a solid starting point for research in this environment.

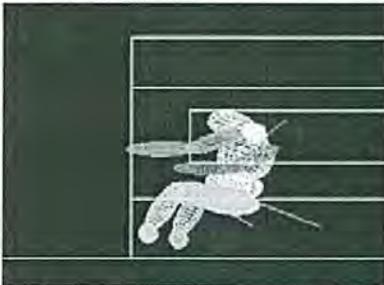


Figure 8: Simulation



Figure 9: Sled Test



Figure 10: Crash Test

### 4.2 Sled Testing

#### 4.2.1 Standing ATD:

All restraint systems tested attenuated the impact loads below the IARVs in side and rear crashes and prevented the standing occupant from contacting interior bulkhead surfaces. In the frontal crashes, all of the mobile restraints tested experienced some level of structural failure at the 52 kph Delta-V, 30g resultant impact acceleration. Failures included slipping retractor locking mechanisms, webbing tears, and failed stitching. With these failures, each system allowed the standing ATD to contact the forward bulkhead which produced  $HIC_{36}$ ,  $Nij$ , and chest accelerations in excess of the IARVs. However, after careful review and evaluation, all the failures appear to be correctable. Performance at a reduced Delta-V of 40 kph produced significantly improved results. Prior to the

reduced Delta-V testing, two of the four restraint manufacturers chose to make minor structural modifications to their systems. At this level, the two modified mobile restraints tested prevented forward bulkhead occupant strikes. A review of the data presented in Figure 11 shows the calculated HIC<sub>36</sub> values for two of the four systems fell well below the IARV for HIC<sub>36</sub> of 1,000. Plots for Nij and chest acceleration show comparable results. Based on these test results and the author's understanding of the unmodified systems, it is felt they, too, would have experienced a comparable level of improvement if modified.

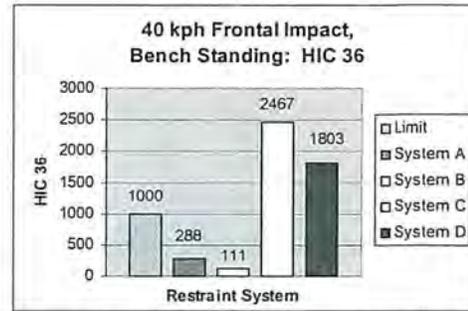


Figure 11: Sled test results – HIC<sub>36</sub> 40 kph ΔV

#### 4.2.2 Bench-Seated ATD:

Analytic results for the bench-seated ATD indicate that all the restraints, including the seat belts, provided adequate head, neck, and chest protection when used correctly. However, a review of the kinematic data for the seat belt shows excessive lower lumbar bending, especially in the forward crash condition. The four mobile restraint systems greatly reduced this motion without showing an increase in calculated head or neck injury parameters.

#### 4.2.3 Rear-Facing and CPR-Seated ATDs:

Results for the rear-facing attendant's seat show restraint performance for this location to be largely driven by seat design and adjacent cabinetry. Though a mid-level quality seat was chosen for this location, the seat back proved to be too short to protect the head and neck of a 50<sup>th</sup> percentile ATD in a frontal crash, with all restraints tested, including seat belts, exceeding the IARVs. Likewise, the CPR seat provided poor results regardless of restraint system used, including the seat belt (Figure 12). In the frontal



Figure 12: Lap belt at 40 kph ΔV

impacts, the ATD's head experienced what likely would have been a fatal impact with the overhead cabinet located immediately forward of the seating position, with HIC<sub>36</sub> values ranging from 2,354 to 6,367. Results from both seating locations indicate a need for redesign of the seats and cabinets to better protect the occupant head and neck.

### 4.3 Crash Testing - Correlation to Sled Testing

As discussed in section 3.5, the crash test phase of the program sought to match the sled test criteria of 48 kph Delta-V for frontal and 27kph Delta-V for side impacts. No rear impact crash testing was attempted. Analysis of the video and numeric data reveals a strong correlation between the sled and crash tests. However, of note were the resultant accelerations along the vehicle's longitudinal axis. The crash test impact velocities were chosen to reproduce the higher velocity sled tests, with the sled tests producing longitudinal accelerations of 30 gs. However, with the actual ambulance given the freedom to rotate in the z-axis, the resultant longitudinal accelerations of each of the three ambulances in the 48 kph frontal crash testing more closely matched the acceleration levels found in the

lower velocity 40 kph sled tests (25 g longitudinally). A 5 g vertical acceleration was achieved in the 48 kph frontal crash test (Figure 6 provides a visual illustration of this effect.) Figures 13 and 14 show comparisons of sled and crash test data for the standing ATD during the 40 kph Delta-V frontal sled test and the 48 kph Delta-V frontal crash test. In each of these tests, the mobile restraint systems prevented the ATD from contacting the forward bulkhead. Data analysis finds the HIC<sub>36</sub> and Nij to be well below the IARVs of 1,000 (HIC<sub>36</sub>) and 1.00 (Nij), respectively.

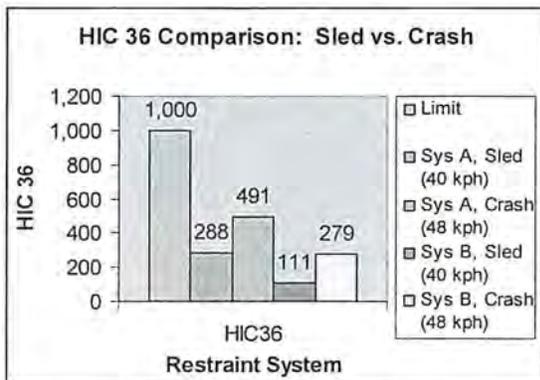


Figure 13: HIC<sub>36</sub> Comparison

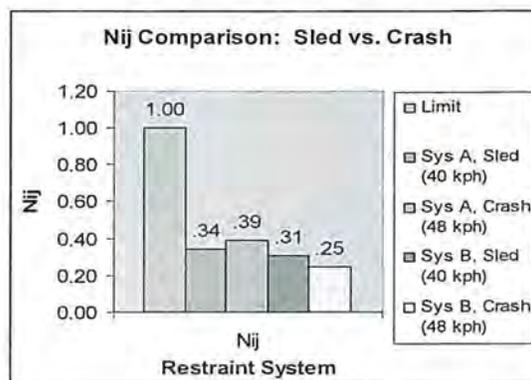


Figure 14: Nij Comparison

#### 4.4 Limitations of Testing

Generally speaking, most research related to head and neck injuries utilize the HIC and Nij to evaluate the injury potential from impact accelerations of the head. Both HIC and its predecessor, the Wayne State Tolerance Curve, are related to impact of the frontal portion of the non-helmeted head. In the case of the testing performed as part of this program, head contacts occurred to various regions of the head. Likewise, forces applied to the head affecting Nij came from a variety of angles. While HIC and Nij can still be calculated and are useful for comparative purposes, correlation to published injury criteria is not as clear as when the contacts and line of action are directed to the frontal region of the head. This test effort also purposely omitted equipment traditionally carried in the patient compartment by EMS workers (pulse oximeter, defibrillator, etc.). Previous testing has shown equipment of this size and type can create a real and substantial hazard to both the EMS worker and patient during an impact.<sup>11</sup>

#### 5.0 CONCLUSIONS

The use of mobile restraints in an ambulance patient compartment offers the potential to improve significantly the safety and health of EMS workers, especially when kneeling or standing near the bench seat. Use of these systems in the fully seated position provides opportunity for improvement over the existing seat belts. Overall seat design, cabinet geometry, as well as strategic placement of energy absorbing padding, are improvements worth considering prior to the purchase of a new or modified ambulance.

Sled testing, compared to vehicle crash testing, reduced test cost and time while providing repeatable test conditions. The disadvantage of this type of testing was the lack of recent test data on which to base the target crash pulses. In

addition, the crash pulses were uni-directional. Though it would have been possible to induce a pulse on a sloped or rotated test buck to simulate crash reactions in two planes (e.g., y-axis and z-axis), the size, mass and complexity of the buck limited this option.

## 6.0 ACKNOWLEDGEMENTS

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