Creating a Safe Work Environment for Emergency Medical Service Workers

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Abstract

Seat belts are required in U.S. ambulances, as with other motor vehicles manufactured in accordance with the current Federal Motor Vehicle Safety Standards (FMVSS), as regulated by the National Highway Traffic Safety Administration (NHTSA). These regulations are also cited in the Specification for the Star of Life Ambulance, KKK-A-1822F, as issued by the General Services Administration (GSA), which is widely adopted as the defacto industry specification for ambulances. The required occupant restraints do not allow emergency medical service (EMS) workers the mobility required to care for patients.[1] As a result, EMS workers routinely work unrestrained in the patient compartment, daily risking their safety and health in the care of others.[2] In an effort to solve this problem for existing and new ambulances alike, the National Institute for Occupational Safety and Health tested four different retrofittable restraint systems, each of which provide improved crash protection for the worker while allowing the mobility needed to provide patient care. In parallel, the City of Winter Park (Florida) Fire and Rescue

Department (WPFD), in collaboration with Medtec Ambulance Corporation, has designed and fielded a new ambulance patient compartment that significantly reduces the need for the EMS worker to move from a seated position to care for the patient. Together, these two work environment changes represent unique opportunities to substantially improve worker safety without compromising patient care.

The objective of this research study was to utilize digital human modeling tools to evaluate reach envelopes for three different human body sizes (5^{th} percentile female, as well as, the 50^{th} and 95^{th} percentile male: by stature and weight), when positioned in two different commercially available ambulance patient compartments. The evaluation was expanded to test each body size, in each environment, using two different restraint systems: one fixed and one allowing mobility, if needed, to assess the ability of a worker to care for the patient and reach equipment while remaining restrained. The underlying premise is that it is better to be restrained than unrestrained, and further, it is better to be restrained and seated than restrained and out of the seat.

Results from this study illustrate the strengths and limitations of the patient compartment configuration in an ambulance built and fielded in accordance with the current FMVSS and the Federal Specification for the Star of Life Ambulance, KKK-A-1822E, as issued by the General Services Administration (GSA). This study also discusses potential improvements to the safety and health of EMS workers, if NIOSH tested mobile restraint systems, which increase reach envelope while allowing EMS workers to remain restrained, were adopted. The approach taken by the WPFD to redesign the work environment by substantially reducing the need for mobility, thus allowing EMS workers to remain seated and restrained for the majority of their work tasks, offers a real opportunity to improve the safety of ambulances to be fielded in the future if this design were to be adopted. Finally, the WPFD design when coupled with a mobile restraint offers the best of both designs: the ability to stay seated and restrained for most work tasks while still allowing for restrained mobility when needed.

Background

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 three times the national fatal occupational injury rate of 4.0/100,000 workers.[3] Although no national count of ambulance crash-related injuries exists, the total number of fatal crashes involving ambulances can be ascertained using the National Highway Traffic Safety Administration (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. 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.[4] NIOSH and NHTSA crash 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.[5-12]

Ambulance Patient Compartment Evolution

NIOSH began its EMS worker safety research program in 2001. At its inception, the ambulance project team recognized substantial gaps existed in the design of the ambulance patient compartment. First, and foremost, the primary mission in the rear compartment of the ambulance is to provide patient care for a supine patient with an ever increasing array of medical care equipment. Secondly, it is a moving work environment with a need to protect the occupants, both patients and workers, should a crash or near-crash event occur. Unfortunately, as is frequently the case, the primary mission has largely superseded the requirements of the secondary mission, thus the effectiveness of the required occupant protection systems found in the patient compartment of the ambulance is limited by non-use, occupant orientation, and the surrounding environment when compared to those found in the front seat.

An Historical Look at Patient Compartment Design in the U.S.

Beginning in 1965, the need for EMS was given national attention through a report entitled, "Accidental Death & Disability: The Neglected Disease of Modern Society" published by the Division of Medical Sciences, National Academy of Sciences/National Research Council (NAS/NRC).[12] This publication explicitly outlined the severity of the emergency medical care situation in this country as follows:

- There was a lack of uniform and adequate Federal, State and Local laws and standards concerning EMS (only six states had written standards).
- Both the ambulance and on-board equipment (if any at all) were of poor quality and design. The vehicle offered little room for patient, attendant or equipment.
- Radio communications between emergency services and hospitals were seriously lacking. Only 5% of the nation's ambulances had radio contact with a hospital.
- Personnel were sadly lacking in training for emergency care of patients. Only about 50% of the nation's EMS personnel had even American Red Cross certificates and many had no training at all.
- Hospitals themselves were staffing emergency rooms with part-time physicians, who may or may not have had training or experience in emergency care or trauma.

In 1966, national law addressing development of EMS systems, Public Law 89-563, the "National Traffic and Motor Vehicle Safety Act of 1966" was the first national effort to focus on improving deficiencies in EMS systems.[14] This Act mandated the following:

- Federal Department of Transportation (DOT) promulgates minimum standards for provision of care for accident victims.
- States can be penalized up to 10% of their Federal Highway funds if they do not comply with this law.

What remained as an open issue was the basic design criteria that needed to be applied to the vehicle itself, as the primary emphasis of this Act was on the care and treatment provided to victims of highway traffic accidents.

It was not until 1969 that medical equipment and vehicles were targeted for significant improvement as The Committee on Ambulance Design Criteria published a report entitled, "Medical Requirements for Ambulance Design and Equipment." This report, submitted to and published by, the Department of Transportation's National Highway Traffic Safety Administration (DOT-NHTSA), called for sweeping changes in both the design of vehicles and medical equipment carried aboard.[15]

Safe and Effective Workstation Design

Hazards Associated With Interior Layout and Design

When designing a new work environment, an ergonomist has many tools at his/her disposal. Using these tools, the ergonomist may model work tasks and the work environment to streamline individual job tasks and optimize the work environment. Combined, these changes are expected to increase productivity while minimizing the safety risks imposed on a worker. However, when assessing an existing work environment for safety improvement, one must look for opportunities to control existing hazards to minimize the risk of injury, or at the very least, reduce the magnitude of injury without impacting productivity should an adverse event occur.

In the work environment studied in this paper, the patient compartment of an existing Type I or III ambulance, the research team was placed in the latter category and was constrained by the present work environment as it is estimated that over 300,000 ambulances are on the road today. All are built with roughly the same layout: a gurney located at or near the centerline of the patient compartment; a bench seat on the curb side; a rear facing attendant's seat at the head or forward end of the gurney; and a CPR seat on the street side of the patient compartment, located parallel to the chest of the patient when supine on the gurney. Through earlier work, the NIOSH team realized it was constrained by many operational truths inherent in the industry today.

- An ambulance, and by extension the patient compartment, is expected to be a mobile patient care environment.
- The ambulance patient compartment contains a wide array of equipment and supplies which are expected to be easily accessible to the worker during patient care.
- The worker is expected to be able to access, and is trained to utilize, all of the available equipment while the ambulance is enroute to a patient care facility. Many pieces of equipment are loose, located on countertop-like surfaces or adjacent seating.
- The ambulance, as configured today and as illustrated in Exhibits 1 – 4, requires the worker to move about the patient compartment, most often unrestrained, to access equipment and the patient.
- Side-facing seating positions (i.e. curbside bench seating and streetside CPR seats) in ambulances are only required to be equipped with lap belts. Where present or required, combination lap/shoulder belts (Type 2) rely on, a worker to be seated with his/her back against the seatback, to be used effectively. In this position the worker is generally unable to reach the patient or needed equipment, thus he often works unrestrained.
- And finally, everything that is unrestrained will move toward the location of the impact at the velocity it was traveling prior to impact. This includes the unrestrained worker.

Exhibit 2. View from the rear looking forward to the left or street side where loose equipment and numerous head impact risks from cabinets are present.

Exhibit 1. View from the rear looking forward to the right or curb side where a loose oxygen bottle sits on the bench and head impact risks from cabinets are present.

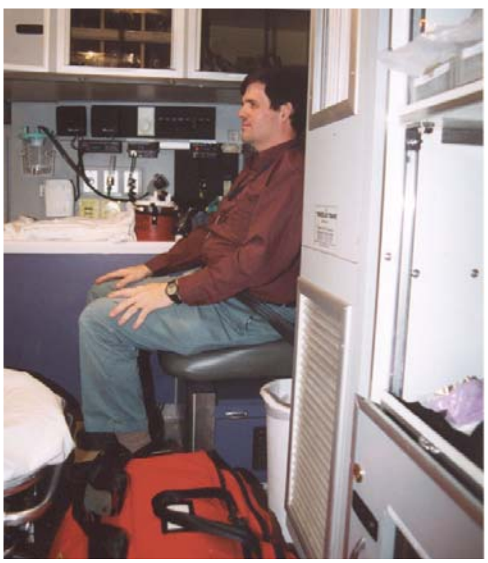

Exhibit 3. An additional hazard; loose equipment on an open work surface adjacent to worker.

Exhibit 4. Illustrates a common risk to each EMS worker: the need to leave the seat to attend to the patient.

Improving the Work Environment from a Worker Safety Perspective

When reviewing the Hierarchy of Controls from the most effective (elimination or substitution) to the least effective (personal protective equipment) several truths were evident.[16] Workers are at risk not because the equipment around them is unrestrained in the patient compartment, but because the worker and equipment are both unrestrained in a *moving patient compartment* that might stop or change direction (turn) abruptly without an effective warning system. However, through a review of the key elements in the Hierarchy of Safety & Health Controls, we are better positioned to take advantage of opportunities for improvement.

- Elimination or substitution: While all can agree the ambulance patient compartment is much safer for the worker occupant when not moving, the reality is the ambulance must move to complete its mission. Thus we are unable to eliminate the primary hazard: the moving work environment. However, some of the risk associated with the need to stand as demonstrated in the Exhibits above, can be reduced or eliminated through a redesign of the patient compartment by moving the patient and equipment closer to the worker. This can be done in a new design, but would likely prove to be too costly for the retrofit of an existing ambulance.

- Engineering Controls: Some of the hazards observed included poorly padded surfaces, lack of crashworthy mounting for equipment, and poor cabinet design when considering worker head height while seated. As a result of work by NIOSH and others in the industry, some of these issues have now begun to be addressed through changes to design specifications such as those promulgated by the General Services Administration and the Ambulance Manufacturer's Division of the National Truck Equipment Association. However, none of the proposed or enacted changes have affected the primary issues related to worker movement: work environment size, equipment location, or limited worker mobility when wearing the required occupant restraint.

- Warning: Alarms or lights to warn of an impending turn are currently being installed in some ambulances and may prove to be helpful at slow speeds or during mild turning events. However, a worker's reaction time and strength will limit the effectiveness of these tools during a crash or an aggressive braking or turning event, thus these warnings would be most helpful when the risk of injury is the lowest.

- Training and Administrative Controls: Many procedures, tools, and training methods have been tried and in some cases proven to be somewhat successful in their intent to improve driver training and reactions. These controls include installation of driver monitoring systems, changes in shifts to reduce time on duty, and driver training to increase hazard awareness recognition. However, none can completely eliminate all hazardous events as the ambulance driver controls only his own driving. He is also faced with thousands of other motorists, all with varying levels of skill and attentiveness, and all with the potential to directly impact the ambulance work environment.

- Personal Protective Equipment: The personal protective equipment provided to a worker today is often limited to a lap belt on a dual purpose bench seat. (The bench is intended to act as a secondary supine patient carriage position.) This could change if motor vehicle industry regulations were amended to allow special forms of occupant restraints. For example, the air ambulance community offers seating and restraint systems built specifically to allow the worker to move to the edge or completely off the seat to attend to the patient or reach equipment are now being introduced. Starting in 2003, NIOSH researchers have tested a variety of restraint types and demonstrated that each has the ability to restrain a 6'2", 220 lb manikin while in a standing position, as illustrated in Exhibit 4 above, without impacting the forward bulkhead in a 30 mph hour crash. NIOSH has also demonstrated that these systems can be retrofitted to the interior of an existing patient compartment.

Methods

The objective of this effort was to assess the ability of an EMS worker to reach both the patient and several key pieces of medical equipment when stationed in the primary seating location utilized for patient care: the squad bench on the curb side of the vehicle. Four different occupant seating and restraint configurations were modeled in the JACK™ digital human modeling package based on measurements taken from two different operational vehicles. Both vehicles met the basic requirements set forth in the purchase specification promulgated by the GSA at the time of its purchase and manufacture for a box type (Type I or III) patient compartment.[17]

One of the two vehicles is a traditionally built ambulance with a full, fixed bench on the curb side of the patient compartment. This vehicle was equipped with two types of restraints: (1) a lap belt which severely limits mobility and forces the worker to remain seated with his hips adjacent to the seat back; and, (2) a mobile restraint system similar to those tested previously by NIOSH that allows the worker to move to the edge of the bench or stand while still remaining tethered to the wall of the vehicle. The second vehicle was redesigned by the co-authors and employees of the City of Winter Park (Florida) Fire and Rescue Department (WPFD). The design replaces the more common curb side bench seat with an integrated, sliding seat equipped with a fixed, 5-point harness or restraint. This design also includes other changes to equipment location and mounting to reduce the need to move from the seated position. For comparison purposes, the fourth case modeled was the WPFD ambulance equipped with the mobile restraint system.

Modeling Package

The software package Jack™ version 5.1 from UGS, was used to conduct the ergonomic analysis for this project. Jack™ is a widely used ergonomic tool that simulates virtual humans in virtual environments. Jack™ was used to conduct the reach analysis on both the GSA ambulance and the Winter Park ambulance. Rhinocerous™ version 3.0 SR2 from McNeel was used to create the 3D models of the ambulance interiors. Rhinocerous™ is widely used by 3D modelers to create models for industrial design, marine design, and various product prototypes. The GSA ambulance was modeled by taking direct measurements and using a FARO™ digitizing arm from FARO Technologies Inc. The Winter Park ambulance was modeled directly from blueprints of the ambulance interior.

Human Body Sizes Utilized

For this study, the Jack™ 95th male, 50th male, and 5th female were used. Jack™ uses the Army Natick Survey User Requirements (ANSUR) 1988 anthropometric database. The scaling function in Jack™ was used to generate the 95th male and 5th female manikin using regression equations from the ANSUR database.[18] (Gordon et al. 1989). The percentiles used for each manikin combined both stature and weight. The use of these manikins provided meaningful results in a short amount of time. While using a larger family of manikins might have made this work more comprehensive, it is understood that when components have large adjustment ranges the position of parts of the body rarely account for more than half of the variance.[19] Table 1 lists the anthropometric reference values for each of three Jack™ manikins used.

Manikin Type	Stature (mm)	Stature (in)	Weight (kg)	Weight (lbs)
5th – Percentile Female	1524	60	49	109
50th – Percentile Male	1753	69	78	171
95th – Percentile Male	1854	73	98	216

Table 1. Provides a listing of the key anthropometric measures for each of the Jack™ human models evaluated in this paper.

Three restraint systems were examined in this project: the standard lap belt; the 5-point harness (fixed lap belt, movable shoulder); and, the mobile restraint. However, recognizing the fixed, 5-point harness works exactly like the lap belt during normal work task execution (restraining the worker at the hips while allowing the full range of motion for the shoulders and upper torso), it was modeled as if only a lap belt were present. When the lap belt was used the manikin was initially positioned using the Jack™ seated straight posture. When a restraint system allowing full mobility was modeled, the manikin was positioned using the Jack™ human control tool. Exhibit 5 shows an example of the lap belt configured manikin in a seated position while Exhibit 6 shows the manikin off the seat reaching for an equipment control while using a mobile restraint.

Exhibit 5. This image depicts a seated manikin, restrained at the hips as would be observed when using a required lap belt on the bench seat of a typical ambulance built to the GSA, KKK-1822 Star of Life (SOL) ambulance specification.

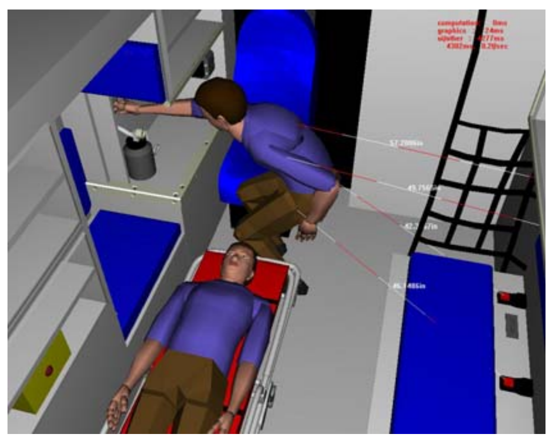

Exhibit 6. This image depicts a standing manikin, restrained at the hips and shoulders, but free to move as needed as would be observed when using a mobile restraint on the bench seat of a retrofitted, SOL specified, ambulance.

The mobile restraint is a harness system with shoulder and hip straps. The shoulder straps are fed through grommets located on the wall (standard retrofit design) or imbedded in the seatback (WPFD design). The hip restraints are tethered back to traditional lap belt locations and connectors. To simulate this in Jack™ the Ruler function was used. This worked well as our goal for the mobile restraint was to determine the length of webbing needed to reach various points within each ambulance. Sites were created within Jack™ for the shoulder grommet and lap belt locations. The rulers were connected from the shoulder (e.g., human.right_clavical.lateral) to the shoulder grommet sites and from the hip (e.g., human.lower_torso.right_side) to the lap belt sites. Though the authors acknowledge variability in harness fit would affect the overall reach envelope on actual human subjects, for the purposes of this evaluation, the restraint itself was assumed to fit snuggly and appropriately on the body.

Environment Comparisons

Each interior work environment, hereafter identified as either "standard SOL" (fixed bench seat) or "WPFD" (new design with sliding curb side seat) was analyzed using the delivered restraint system, as well as a modified restraint system that allowed mobility. Five common reach points were identified and located in each ambulance based on their known positions. These reach locations or targets will later be identified as points: (A) the patient's left wrist; (B) the patient's mouth; (C) the primary radio controls; (D) the suction device; and (E) the defibrillator unit.

Description of the Standard Star of Life (SOL) Ambulance: GSA KKK-1822

The interior of the standard SOL ambulance utilized for this effort measures 119 inches long, by 87 inches wide, by 68 inches high. It includes a full uniform bench seat measuring 80.5 inches long, by 22.25 inches deep, by 19 inches high. It is equipped with a gurney with a centerline 8.5 inches to the street side of the center line of the ambulance. It also includes a cabinet over the bench seat that measures 78 inches long, by 9 inches deep, by 14 inches high measured from the ceiling down. Exhibits 7 and 8 provide isometric views of the curb and floor side layout, with equipment and patient reach points, as well as, restraint anchor locations labeled.

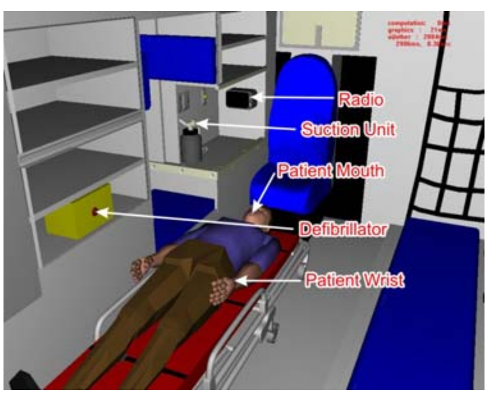

Exhibit 7. Street side view of the SOL ambulance with reach targets.

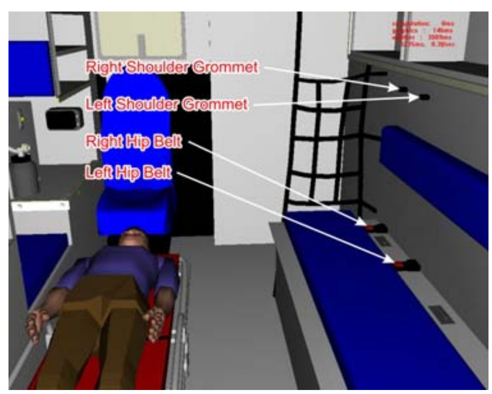

Exhibit 8. Curb side view of the SOL ambulance with restraint targets.

The location of each of the five reach points is measured in three dimensions beginning from the lower aft corner of the interior of the patient compartment. Likewise, the reference attachment points for each of four belt locations (left and right hip and left and right shoulder) are specified and referenced to the lower aft corner of the interior of the patient compartment. Specific measurements for each reach point for the standard SOL configuration are provided in Table 2. The coordinate system is oriented such that the X-axis is the fore and aft axis with respect to the gurney, the Y-axis is the vertical axis from floor to ceiling, and the Z-axis runs laterally from the curb side to the street side of the ambulance. All are zero at the aft, curb side corner of the floor.

Reference Point	Reference Point Definition	X – location (in)	Y – location (in)	Z – location (in)
Point A	Patient Arm (left wrist)	40.00	23.90	-43.90
Point B	Patient Mouth	68.00	22.00	-52.00
Point C	Radio Controls	106.90	38.30	-69.00
Point D	Suction Unit	83.90	35.80	-74.00
Point E	Defibrillator Unit (centerline)	34.70	33.10	-66.70
Belt Attachment	Right Shoulder Grommet	70.71	48.58	-1.01
Belt Attachment	Left Shoulder Grommet	60.63	48.58	-1.01
Belt Attachment	Right Hip Belt	74.02	20.11	-3.67
Belt Attachment	Left Hip Belt	56.58	20.11	-3.67

Table 2. Specific locations for each of five reach points for the standard SOL configuration as measured in three dimensions beginning from the lower aft corner of the interior of the patient compartment.

Description of the Winter Park Fire and Rescue Department (WPFD) Ambulance

The interior of the WPFD patient compartment utilized for this effort measures 170 inches long, by 88 inches wide, by 72 inches high. It includes a modified bench seat measuring 49.5 inches long, by 23 inches deep, by 16 inches high with an integrated sliding seat installed immediately forward of the bench. The sliding seat has as range of 8.25 inches measured from the full back to full forward position. It is equipped with a gurney with a centerline 4 inches to the street side of the center line of the ambulance. It also includes angled cabinets fore and aft of the sliding seat with the aft cabinet measuring 31.5 inches long, by 9.5 inches deep, by 14 inches high measured from the ceiling down. It is significant to note there is no cabinet directly above the sliding seat position. A clearance requirement, though implemented in 2005 by the WPFD and Medtec Ambulance, has now been added to the August 2007 revision of the GSA KKK-A-1822F specification and adopted as a performance requirement promulgated by the Ambulance Manufacturers Division of the National Truck Equipment Association. Exhibits 9 and 10 provide isometric views of the curb and floor side layout, with equipment and patient reach points, as well as, restraint anchor locations labeled.

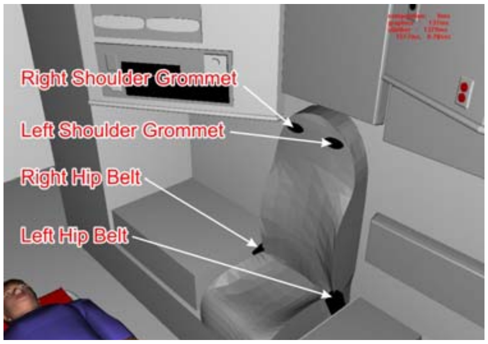

Exhibit 9. Curb side view of the WPFD ambulance with restraint targets.

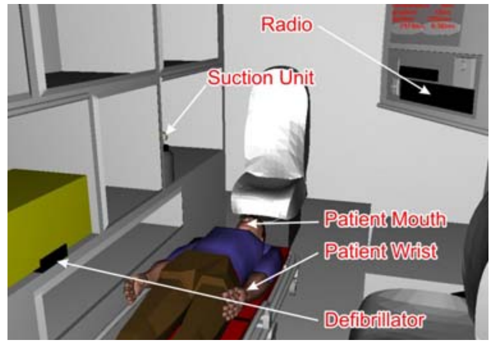

Exhibit 10. Street side view of the WPFD ambulance with reach targets.

The location of each of the five reach points is measure in three dimensions beginning from the lower aft corner of the interior of the patient compartment. Likewise, the reference attachment points for each of four belt locations (left and right hip and left and right shoulder) are specified and referenced to the lower aft corner of the interior of the patient compartment. Specific locations for each of five reach points for the WPFD configuration are provided in Table 3. As with the SOL model, the coordinate system for the WPFD ambulance is oriented such that the X axis is the fore and aft axis with respect to the gurney, the Y axis is the vertical axis from floor to ceiling and the Z axis runs laterally from the curb side to the street side of the ambulance. All axes are zero at the aft, curb side corner of the floor.

Reference Point	Reference Point Definition	X – location (in)	Y – location (in)	Z – location (in)
Point A	Patient Arm (left wrist)	57.40	22.52	-39.32
Point B	Patient Mouth	87.24	21.20	48.02
Point C	Radio Controls	88.25	48.50	-13.05
Point D	Suction Unit	90.37	37.11	-67.79
Point E	Defibrillator Unit (centerline)	55.13	28.88	-65.11
Belt Attachment	Right Shoulder Grommet	67.17	46.00	-4.81
Belt Attachment	Left Shoulder Grommet	58.62	46.00	-4.81
Belt Attachment	Right Hip Belt	72.52	18.74	-6.31
Belt Attachment	Left Hip Belt	53.51	18.74	-6.31

Table 3. Specific locations for each of five reach points for the WPFD configuration as measure in three dimensions beginning from the lower aft corner of the interior of the patient compartment with sliding seat in the full back position.

The WPFD design incorporated numerous design changes to enhance productivity all with the safety of the EMS worker in mind. The primary changes include:

- Designating the bench seat, or integrated sliding seat, as the primary worker location.
- Redesigning the bench seat area with the worker in mind, including a seat that slides toward the patient to move the worker closer to the patient without the need to unbuckle restraint.
- Installing a fixed, 5 point harness in lieu of standard seat belt to better ensure the worker remains coupled with the seat in the event of an accident.
- Adding covered storage areas next to primary work seat designed to match the portable supply case and sharps container thus moving readily used supplies to more accessible, safe, and secure locations.
- Relocating communication, lighting and climate control to an angled, overhead cabinet near the primary work location to improve accessibility and reduce likelihood of head strike.
- Removing a section of the cabinet directly above bench seat.
- Hard mounting EKG unit on an adjustable bracket to remove projectile risk associated with loose equipment.

Most of these design changes are illustrated in Exhibits 11 – 12, respectively.

Exhibit 11. The angled communication cabinet, sliding seat with 5 pt harness, and removed overhead curb side cabinet are illustrated.

Exhibit 12. Hard mounted EKG unit to adjustable, sliding bracket installed in compartment to remove projectile risk associated with loose equipment while providing easy access for most workers.

Limitation and Constraints of Modeling - Seating/Positioning Assumptions

- Modeler placement and posing of manikin: A single modeler was used to complete the work for this paper. This was done to increase consistency when it came to manikin positioning.

However, it should be understood that manikin positioning remains highly subjective and will affect final measurements.

- Pinch grasp: The pinch grasp was used for all measurements in lieu of reach-to-touch measurements commonly associated with extended fingers. This hand posture was chosen to more accurately reflect the hand position required to actually complete a task.
- Pelvic fore and aft bend angles: The pelvic fore/aft bend angles used were the maximum values provided in Jack™ . The limits were set at +85 degrees (bending at waist forward toward the knees) and -52 degrees bending backward into the seat back.
- Axial rotation: The axial rotation angles or body twist angles used were the maximum values provided in Jack™ . The limits were set at +/- 43 degrees (rotation with spine as centerline).
- Lateral bending: The lateral bending angles utilized in this modeling effort matched the maximum values provided in Jack™ . The limits were set at +/- 40 degrees.
- The use of the term "standard SOL ambulance" is a misnomer as there is no "standard" per se. Ambulances purchased to the GSA spec vary in height, width, and length. Those changes will affect equipment placement and by consequence reach measurements.

Results

The results of this work will be presented individually for each of the four cases modeled: (1) standard SOL ambulance with lap belt only; (2) WPFD ambulance with a fixed, 5 point harness; (3) standard SOL ambulance with a mobility restraint system; and, (4) WPFD ambulance with a mobility restraint system. Data for cases (1) and (2) are presented with the understanding the proper use of the production systems is to remain restrained and seated. Thus, data will show whether or not manikins representing the 5th female, 50th male and 95th male can reach each of five identified work task locations. If the manikin cannot reach the identified work location, the distance measured from the hand positioned in the pinch grasp mode to the target work task location will be provided. The analysis covering cases (3) and (4) will compute the amount of mobile harness webbing needed on each retractor reel to allow a worker to reach each of the five identified work task locations in both of the work environments. Data is provided representing the 5th female, 50th male, and 95th male manikins by stature and weight combined. Exhibits 13 and 14 provide interior views of the GSA and WPFD ambulance models for comparison.

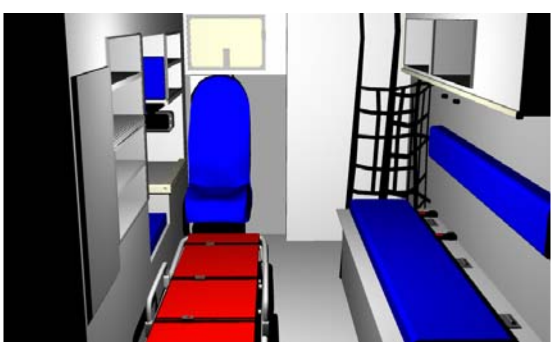

Exhibit 13. Interior view of the GSA ambulance model.

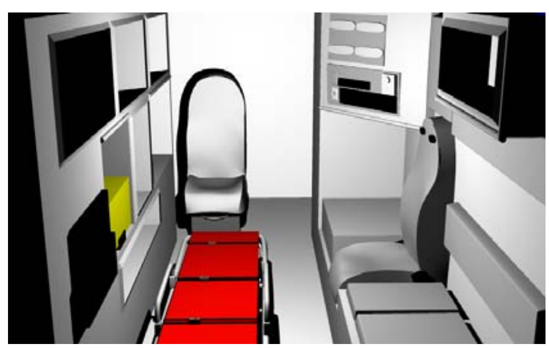

Exhibit 14. Interior view of the WPFD ambulance model.

Case (1): Worker Reach Limitations Using a Lap Belt in a Standard SOL Ambulance

Most ambulances purchased today are based on the standard SOL layout. Each has a bench seat on the curbside, a rear facing attendant's seat at the head of the gurney, and often a CPR seat on the street side of the ambulance with the primary patient care seating location being the forward end of the bench seat. As a result of the Jack™ modeling performed herein, it is confirmed that few if any EMS workers can reach the patient or needed equipment while wearing the only restraint provided; a lap belt. A review of the data by manikin size, as provided in Table 4 below, reveals the 5th percentile female and 50th percentile male manikins were unable to reach a single target location. The 95th percentile manikin, with the largest reach envelope, was able to reach both targets on the patient (Exhibits 15 and 16) but unable to reach any of the identified equipment. The manikin hand nearest the target location was used for each reach measurement.

Body Size	PT A, Lft Hand (in)	Pt B, Rt Hand (in)	Pt C, Rt Hand (in)	Pt D, Rt Hand (in)	Pt E, Lft Hand (in)
5th Female	9.7	8.9	39.0	32.3	28.2
50th male	5.0	3.4	33.0	26.2	22.2
95th Male	0.0	0.0	30.4	23.5	19.6

Table 4. Reach distance from worker hand using pinch grasp while wearing a fixed lap belt while properly seated on the bench of the standard SOL ambulance.

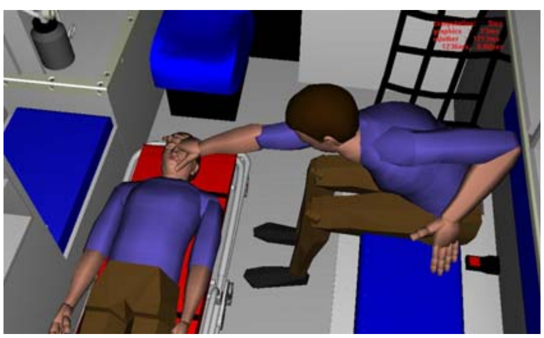

Exhibit 15. The 95th manikin is reaching toward the patient's mouth.

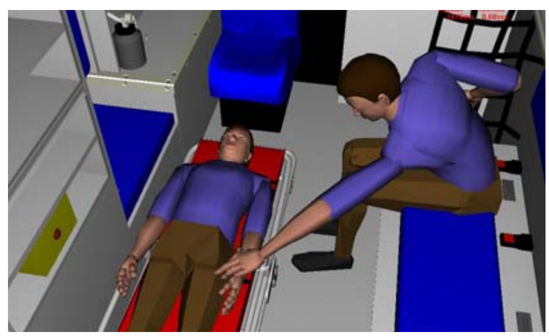

Exhibit 16. The 95th percentile manikin is reaching toward the patient's left wrist.

Case (2): Worker Reach Limitations Using a Fixed, 5 Pt. Harness in the WPFD Ambulance

The analysis of the WPFD environment and existing restraint, a fixed, five point harness, followed the same methodology as that used for the standard SOL ambulance and lap belt configuration described above. Again, the hand nearest the target was used to determine if each could be reached by the 5th female, 50th male, and 95th male, respectively. The only difference in this analysis and that performed earlier, is that the WPFD seat was analyzed in two different positions: seat in the full forward position (closest to the patient); and seat in the full back position (seat pushed back away from patient). This was done to look at the maximum seat ranges available. The analysis as summarized in Tables 5 and 6, respectively, shows significant differences when compared to the standard SOL layout. For example, regardless of seat position, all manikin sizes were able to reach the patient's mouth and the relocated radio controls while remaining fully restrained, a substantial improvement when compared to the standard SOL ambulance bench seat and restraint configuration. Exhibits 17 and 18 provide illustrations of the 5th percentile female reaching the mouth and radio controls while seated and fully restrained.

Body Size	PT A, Lft Hand (in)	Pt B, Rt Hand (in)	Pt C, Rt Hand (in)	Pt D, Rt Hand (in)	Pt E, Lft Hand (in)
5th Female	0.0	3.2	0.0	22.7	12.2
50th male	0.0	0.0	0.0	16.7	6.3
95th Male	0.0	0.0	0.0	13.7	3.7

Table 5. Reach distance from worker hand using pinch grasp while wearing a fixed, 5 point harness with the sliding seat in the full forward position.

Body Size	PT A, Lft Hand (in)	Pt B, Rt Hand (in)	Pt C, Rt Hand (in)	Pt D, Rt Hand (in)	Pt E, Lft Hand (in)
5th Female	0.0	10.2	0.0	29.6	19.8
50th male	0.0	4.0	0.0	23.7	13.6
95th Male	0.0	1.7	0.0	20.7	10.9

Table 6. Reach distance from worker hand using pinch grasp while wearing a fixed, 5 point harness with the sliding seat in the full back position.

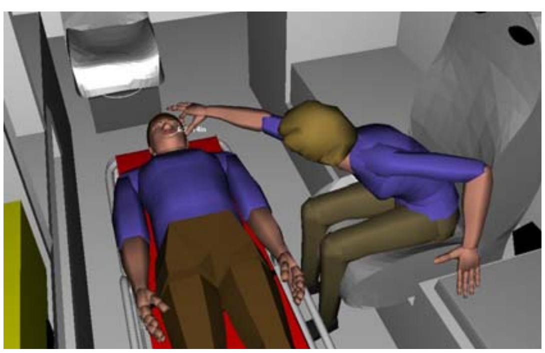

Exhibit 17. A 5th percentile female reaching the patient's mouth with seat full forward.

Exhibit 18. A 5th percentile female reaching the radio controls with the seat full forward.

Case (3): Mobile Restraint Webbing Needed To Reach All Five Work Task Points In Standard SOL Ambulance

Tables 7, 8 and 9 provide an analysis of the webbing that would be needed if the standard SOL ambulance were to be modified to include a restraint that allows mobility while keeping the worker tethered to the wall nearest the primary work location; the forward end of the bench seat. Exhibits 19 and 20 provide illustrations of this case in the real and modeled worlds. Based on this analysis, a minimum of 58.1 inches of webbing on the retractor reel would be required to allow the shoulders of the 5th percentile female enough tether to reach the radio controls. The amount of webbing required decreases as the size of the worker increases. Therefore, for the same condition the 50th percentile male is estimated to require only 53.7 inches of webbing while the 95th percentile male is estimated to require only 51.0 inches of webbing.

In a similar fashion, the amount of webbing required to allow the hips the ability to move from the seated position to a standing position as necessitated by the location of the radio and suction units varies by worker size. At a minimum, and to accommodate workers ranging from the 5th percentile female to the 95th percentile male, by stature and weight, designers should anticipate a need to place a minimum of 51.5 inches of webbing on each retractor reel.

Exhibit 19. 50th male demonstrating mobile restraint in the standard SOL ambulance while reaching for suction unit.

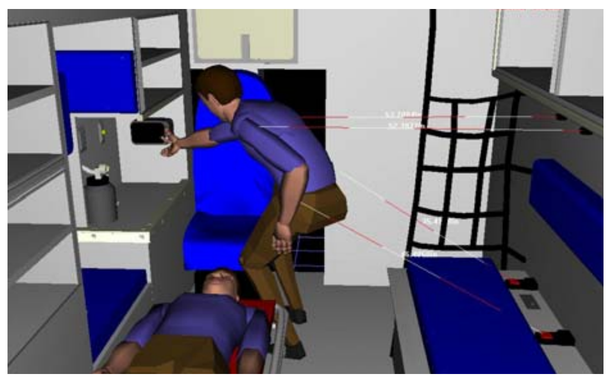

Exhibit 20. A view of the 50th percentile male manikin positioned as if wearing a mobile restraint in the standard SOL ambulance.

Body Reference Pt.	Point A Webbing (in)	Point B Webbing (in)	Point C Webbing (in)	Point D Webbing (in)	Point E Webbing (in)
Left Hip	17.4	17.4	51.5	46.0	37.3
Right Hip	24.2	18.0	40.0	43.0	42.7
Left Shoulder	32.8	27.4	57.1	47.4	45.6
Right Shoulder	30.3	36.1	58.1	57.0	55.3

Table 7. Mobile restraint webbing needed for a 5th percentile female to reach each of the five work task points in standard SOL ambulance.

Body Reference Pt.	Point A Webbing (in)	Point B Webbing (in)	Point C Webbing (in)	Point D Webbing (in)	Point E Webbing (in)
Left Hip	13.9	12.4	46.5	42.3	35
Right Hip	20.1	13.0	35.4	39.1	41.2
Left Shoulder	29.6	22.2	52.4	43.9	42.0
Right Shoulder	27.6	31.2	53.7	53.2	52.9

Table 8. Mobile restraint webbing needed for a 50th percentile male to reach each of the five work task points in standard SOL ambulance.

Body Reference Pt.	Point A Webbing (in)	Point B Webbing (in)	Point C Webbing (in)	Point D Webbing (in)	Point E Webbing (in)
Left Hip	13.3	11.5	45.3	39.7	33.1
Right Hip	19.3	12.0	34.3	36.1	39.2
Left Shoulder	28.5	20.6	49.1	41.0	39.4
Right Shoulder	26.7	29.2	51.0	50.2	50.4

Table 9. Mobile restraint webbing needed for a 95th percentile male to reach each of the five work task points in standard SOL ambulance.

Case (4): Mobile Restraint Webbing Needed To Reach All Five Work Task Points In WPFD Ambulance

Recognizing the WPFD layout significantly improved but did not solve all worker reach issues, the team chose to test one further case. The team combined the WPFD interior with a mobile restraint. All reach measurements assumed the EMS worker had already moved the sliding seat to the forward position. In those cases where the worker could not reach a particular piece of equipment, the use of the mobile restraint feature was employed. Thus, measurements presented in Tables 10 - 12, provide the amount of webbing needed to allow an EMS worker to reach his target, be that a supine patient or piece of equipment.

In the case of the WPFD ambulance, the most difficult item to reach was the suction unit, located on the street side wall slightly forward of the patient's head. In order for the 5th percentile female to reach this unit (identified as Point D in Tables 10 – 12), a minimum of 31.5 inches of webbing is required on the hip reels and a minimum of 36.3 inches of webbing would be required on the shoulder reels. The amount of webbing required decreases as the size of the worker increases. Therefore, for the same condition the 50th percentile male is estimated to need only 29.4 inches of webbing for the hip reels and 34.5 inches of webbing for the shoulder reels while the 95th percentile male is estimated to need only 28.7 inches of webbing for the hip reels and 34.1 inches of webbing for the shoulder reels, respectively.

Body Reference Pt.	Point A Webbing (in)	Point B Webbing (in)	Point C Webbing (in)	Point D Webbing (in)	Point E Webbing (in)
Left Hip	0.0	10.3	0.0	31.5	23.2
Right Hip	0.0	7.2	0.0	26.4	25.0
Left Shoulder	0.0	20.0	0.0	27.2	34.2
Right Shoulder	0.0	27.0	0.0	36.3	29.2

Table 10. Mobile restraint webbing needed for a 5th percentile female to reach each of the five work task points in the modified WPFD ambulance.

Body Reference Pt.	Point A Webbing (in)	Point B Webbing (in)	Point C Webbing (in)	Point D Webbing (in)	Point E Webbing (in)
Left Hip	0.0	0.0	0.0	29.5	24.4
Right Hip	0.0	0.0	0.0	24.0	26.1
Left Shoulder	0.0	0.0	0.0	27.5	32.8
Right Shoulder	0.0	0.0	0.0	34.9	29.1

Table 11. Mobile restraint webbing needed for a 50th percentile male to reach each of the five work task points in the modified WPFD ambulance.

Body Reference Pt.	Point A Webbing (in)	Point B Webbing (in)	Point C Webbing (in)	Point D Webbing (in)	Point E Webbing (in)
Left Hip	0.0	0.0	0.0	28.7	23.0
Right Hip	0.0	0.0	0.0	23.3	24.9
Left Shoulder	0.0	0.0	0.0	26.9	29.5
Right Shoulder	0.0	0.0	0.0	34.1	26.8

Table 12. Mobile restraint webbing needed for a 50th percentile male to reach each of the five work task points in the modified WPFD ambulance.

Conclusions

Using commercially available digital human modeling tools, this research demonstrated that incremental improvements in worker safety can be achieved by modifying the environment through thoughtful positioning of equipment and worker in conjunction with improvements to personal protective equipment. In the simplest of terms, modeling confirmed that a 50th percentile male worker was unable to reach the patient's left or near wrist while seated on the bench wearing the required lap belt provided with the vehicle: he was 5 inches short of reaching this target when using the pinch grasp common when taking a pulse. By modifying the environment, as was done in the WPFD ambulance, to include a lower, sliding seat, not only could the left wrist be reached by the 50th percentile male, but it could also be reached by the 5th percentile female: an improvement of at least 9.7 inches. This target was the closest located to the worker in either environment.

Likewise, the newly designed WPFD ambulance interior showed clear advantages when compared to the standard SOL layout as it allowed the worker to remain coupled to the primary seating position while reaching the patient's mouth (except the 5th percentile female) and key communication and climate control systems. Additionally, modeling and analysis can also be used to further refine the ambulance interior presented by WPFD, should other ambulance services wish to build on this concept. At a minimum, the next generation vehicle might consider identifying alternate locations for the suction unit to reduce the need for a worker to leave his seat to access this piece of equipment.

It must be noted the authors do not advocate a worker stand, nor do they suggest a worker will be fully protected when wearing a mobile restraint and standing 50+ inches from the seat in a moving ambulance. However, the authors are suggesting it is better to be restrained all of the time rather than none of the time as is often the case today.[2] Moreover, use of mobile restraints in conjunction with a WPFD redesigned interior (Case 4) offers greater opportunities for protection. By comparing the worst case out-of-seat positions for both interior configurations, it was determined the WPFD design would require 38% less webbing on each retractor for the shoulders and 39% less webbing on each retractor for the hips, to complete the same patient care tasks. Thus, the redesigned interior allows a worker to remain restrained in his seat or at least restrained closer to the seat, during each patient care task.

Finally, though the authors strongly advocate the use of digital human modeling as a tool to refine the compartment interior and examine seating and restraint options, any final decision regarding the selection of seating and restraints should be supported by full scale testing to ensure each design meets or exceeds existing FMVSS.

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