

CRASH DATA RESEARCH CENTER

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CALSPAN ON-SITE CHILD RESTRAINT SYSTEM CRASH INVESTIGATION

SCI CASE NO.: CA09086

VEHICLE: 2009 TOYOTA HIGHLANDER

LOCATION: NORTH CAROLINA

CRASH DATE: DECEMBER 2009

Contract No. DTNH22-07-C-00043

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The crash investigation process is an inexact science which requires that physical evidence such as skid marks, vehicular damage measurements, and occupant contact points are coupled with the investigator's expert knowledge and experience of vehicle dynamics and occupant kinematics in order to determine the pre-crash, crash, and post-crash movements of involved vehicles and occupants.

Because each crash is a unique sequence of events, generalized conclusions cannot be made concerning the crashworthiness performance of the involved vehicle(s) or their safety systems.

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<p>16. Abstract This on-site investigation focused on a rear-facing infant Child Restraint System (CRS) installed in the rear center position of a 2009 Toyota Highlander that was involved in a severe frontal crash. The CRS was installed using the lower anchors of the Lower Anchors and Tethers for Children (LATCH) system. The Toyota was equipped with four-wheel anti-lock brakes, Electronic Stability Control (ESC), a Certified Advanced 208-Compliant (CAC) frontal air bag system, a knee air bag for the driver's position, front seat-mounted side impact air bags and side impact Inflatable Curtain (IC) air bags. The manufacturer of the Toyota has certified that the vehicle is compliant to the advanced air bag portion of Federal Motor Vehicle Safety Standard (FMVSS) No. 208. The CAC system consisted of dual-stage frontal air bags for the driver and front right passenger positions, seat track positioning sensors, safety belt buckle switch sensors, retractor pretensioners, and a front right occupant presence sensor. The Toyota Highlander was involved in a head-on crash with a 2006 Ford Mustang that was traveling in the opposite direction. The left rear corner of the Toyota was subsequently impacted by the front of a 2005 Ford E-450 van-based box truck. The Ford E-450 previously sideswiped a 1999 Toyota Camry. The Toyota Highlander's 26-year-old male driver, the 26-year-old female rear right passenger and the 11-month-old rear center passenger in the CRS were transported from the scene for medical treatment. The driver and rear center occupant of the Toyota expired at the hospital on the day of the crash. The driver and front right passenger of the Ford Mustang also sustained fatal injuries.</p>			
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**CALSPAN ON-SITE CHILD RESTRAINT SYSTEM CRASH INVESTIGATION
SCI CASE NO.: CA09086**

**VEHICLE: 2009 TOYOTA HIGHLANDER
LOCATION: NORTH CAROLINA
CRASH DATE: DECEMBER 2009**

BACKGROUND

This on-site investigation focused on a rear-facing infant Child Restraint System (CRS) installed in the rear center position of a 2009 Toyota Highlander that was involved in a severe frontal crash (**Figure 1**). The CRS was installed using the lower anchors of the Lower Anchors and Tethers for CHildren (LATCH) system. The Toyota was equipped with four-wheel anti-lock brakes, Electronic Stability Control (ESC), a Certified Advanced 208-Compliant (CAC) frontal air bag system, a knee air bag for the driver's position, front seat-mounted side impact air bags and side impact Inflatable Curtain (IC) air bags.



Figure 1: Front oblique view of the 2009 Toyota Highlander

The manufacturer of the Toyota had certified that the vehicle was compliant to the advanced air bag portion of Federal Motor Vehicle Safety Standard (FMVSS) No. 208. The CAC system consisted of dual-stage frontal air bags for the driver and front right passenger positions, seat track positioning sensors, safety belt buckle switch sensors, retractor pretensioners, and a front right occupant presence sensor. The Toyota Highlander was involved in a head-on crash with a 2006 Ford Mustang that was traveling in the opposite direction. The left rear corner of the Toyota was subsequently impacted by the front of a 2005 Ford E-450 van-based box truck. The Ford E-450 had previously sideswiped a 1999 Toyota Camry. The Toyota Highlander's 26-year-old male driver, the 26-year-old female second row right passenger and the 11-month-old second row center passenger in the CRS were transported from the scene for medical treatment. The driver and second row center occupant of the Toyota expired at the hospital on the day of the crash. The driver and front right passenger of the Ford Mustang also sustained fatal injuries.

The crash was identified through a news search on December 11, 2009. Based on the fatal injuries to the child in the CRS and the use of LATCH, this case was assigned for on-site investigation on December 22, 2009. The Toyota, the Ford Mustang, and the Ford truck were available for inspection and the on-site investigation was initiated on December 22, 2009. The investigation involved the inspection and documentation of the Toyota, the Ford Mustang and

the Ford E450, interviews with witnesses and medical personnel that responded to the scene of the crash, and the documentation of the crash site. The family of the second row right passenger of the Toyota refused to be interviewed.

SUMMARY

Vehicle Data

2009 Toyota Highlander

The 2009 Toyota Highlander was manufactured in March 2009 and was identified by the Vehicle Identification Number (VIN): JTEDS41A492 (production sequence deleted). The front-wheel drive Toyota was powered by a 3.5-liter, V-6 engine linked to a 5-speed automatic transmission. The braking system consisted of power-assisted front and rear disc brakes with four-wheel anti-lock and emergency brake assist. The Toyota was also equipped with a direct Tire Pressure Monitoring System (TPMS). All windows were closed at the time of the crash, evidenced by tempered glass fragments in the upper areas of the window gaskets of the disintegrated windows. The Toyota was equipped with Toyo Open Country A20 tires mounted on OEM six-spoke alloy wheels. The tire size matched the vehicle manufacturer recommendation of P245/65R17. The vehicle manufacturer recommended cold tire pressure was 207 kPa (30 PSI) for the front and rear. The specific tire data at the time of the SCI inspection was as follows:

Position	Measured Tire Pressure	Measured Tread Depth	Damage
Left Front	Tire flat	7mm (9/32 in)	Tire de-beaded, rim deformed, 4 cm (1.6 in) cut in sidewall
Left Rear	Tire flat	8 mm (10/32 in)	De-beaded
Right Rear	172 kPa (25 PSI)	8 mm (10/32 in)	None
Right Front	186 kPa (27 PSI)	7 mm (9/32 in)	None

The interior of the Toyota was configured with leather-surfaced seven-passenger seating. The front bucket seats were separated by a center console and were equipped with adjustable head restraints. Both head restraints had been removed at the time of the SCI inspection. The front right head restraint had been deformed by contact from the second row right occupant. The front seat tracks were both adjusted 9 cm (3.5 in) forward of the full-rear position. The driver seat had been deformed by the vertical intrusion of the floorpan and had displaced forward 12 cm (4.7 in) and left 6 cm (2.4 in). The driver seat back was at an angle 17 degrees aft of vertical. The front right seat back had been deformed forward by contact from the rear right occupant and was at an angle 3 degrees forward of vertical. The second row consisted of a split-bench with separate forward folding seat backs. The outboard seat backs were adjusted to an angle of 22 degrees aft of vertical. The third row consisted of a two-passenger bench seat with a folding back. This seat was stowed prior to the crash to allow for cargo that consisted of cardboard boxes of clothing with an estimated weight of 34 kg (75 lb).

The occupant safety systems consisted of 3-point lap and shoulder belt systems for the seven designated seating positions, front seat safety belt retractor pretensioners, dual stage CAC frontal air bags, seat-mounted side impact air bags, and IC air bags that provided protection for the six outboard seating positions.

2006 Ford Mustang

The 2006 Ford Mustang was manufactured in February 2006 and was identified by the VIN: 1ZVFT80N265 (production sequence deleted). The rear-wheel drive vehicle was powered by a 4.0-liter, V-6 engine, linked to a 5-speed manual transmission. The transmission gear selection lever was in fifth gear post-crash. The braking system consisted of power-assisted front and rear disc brakes with four-wheel anti-lock. All windows were closed prior to the crash. The Ford was equipped with Bridgestone Insignia SE tires. The tires were size P215/65R16, which matched the vehicle manufacturer recommended tire size. The tires were mounted on OEM multi-spoke alloy wheels. The vehicle manufacturer recommended cold tire pressure was 241 kPa (35 PSI). The specific tire data at the time of the SCI inspection was as follows:

Position	Measured Tire Pressure	Measured Tread Depth	Damage
Left Front	Tire flat	7 mm (9/32 in)	Tire de-beaded
Left Rear	Tire flat	7 mm (9/32 in)	Sidewall cut
Right Rear	Tire flat	7 mm (9/32 in)	Tire de-beaded
Right Front	186 kPa (27 PSI)	7 mm (9/32 in)	Tire de-beaded

The interior of the Ford was packed with the personal belongings of the driver, weighing an estimated 363 kg (800 lb). This included suitcases of clothing, boxes, and a flat-panel television positioned on the armrest between the two front seats. The rear seat backs of the Ford had been folded down to accommodate the cargo which filled the trunk and rear seat area.

2005 Ford E-450 Chassis Cab/Box Truck

The 2005 Ford E-450 chassis cab was manufactured in March 2005 and completed as a box truck in September 2005. The Ford was identified by the VIN: 1FDXE45S35H (production sequence deleted). The rear-wheel drive vehicle was powered by a 6.8-liter V-10 gasoline engine linked to a 5-speed automatic transmission. The braking system consisted of power-assisted hydraulic front and rear disc brakes with four-wheel anti-lock. The vehicle was configured with a wheelbase of 447 cm (176 in), a dual-rear wheel axle and was configured with a walk-through door from the rear of the cab into the box of the truck. The vehicle manufacturer recommended tire size was LT225/75R16 with a recommended tire pressure of 450 kPa (65 PSI) for the front and 550 kPa (80 PSI) for the rear. The vehicle was equipped with BCT Radial A/P tires on the left front and all four rear positions, and a Wildcat HT tire on the right front position. All tires

were size LT225/75R16 and were mounted on steel wheels. The tire data at the time of the SCI inspection was as follows:

Position	Measured Tire Pressure	Measured Tread Depth	Damage
Left Front	400 kPa (58 PSI)	6 mm (8/32 in)	None
Left Rear (Outer)	496 kPa (72 PSI)	7 mm (9/32 in)	None
Left Rear (Inner)	Unknown	7 mm (9/32 in)	None
Right Front	407 kPa (59 PSI)	10 mm (13/32 in)	None
Right Rear (Outer)	448 kPa (65 PSI)	7 mm (9/32 in)	None
Right Rear (Inner)	Unknown	7 mm (9/32 in)	None

1999 Toyota Camry

The 1999 Toyota Camry was identified by the VIN: 4T1BG22KXXU (production sequence deleted). The front-wheel drive Camry was powered by a 2.2-liter, four-cylinder engine linked to a 4-speed automatic transmission. The braking system consisted of power-assisted front disc and rear drum brakes with four-wheel anti-lock. The driver of the Camry refused to allow an inspection of the vehicle. Images of the vehicle were not available.

Crash Site

This crash occurred during the daylight hours of December 2009 on an asphalt surfaced 5-lane north/south roadway, inclusive of a center left turn lane. The conditions were clear and dry and at the time of the crash with an ambient temperature of 13 degrees C (55 degrees F). The outboard travel lanes were 4.2 m (13.8 ft) in width. The inboard travel lanes and the center left turn lane measured 3.6 m (11.8 ft) in width. The roadway was bordered on both sides by concrete curbs that were 15 cm (5.9 in) in height. Private driveways intersected the roadway. In the pre-crash area for the Toyota Highlander (**Figure 2**), the Ford E450 and the Toyota Camry, the roadway had a negative grade of 1.6 percent and included a shallow curve to the right that began 115m (377 ft) south of the area of impact. In the pre-crash area for the Ford Mustang, the roadway had a negative grade of 1 percent and was straight. A concrete sidewalk was immediately adjacent to the curb on the east roadside. Outboard of this sidewalk was a grass area that included interspersed trees and bushes. There was a driveway extending southeast from the main roadway near the area of



Figure 2: Pre-crash trajectory of the Toyota Highlander.

impact. The posted speed limit in the area of the crash was 72 km/h (45 mph). Schematics of the crash are included as **Figures 13** and **14** of this report.

Crash Sequence

Pre-Crash

The restrained 26-year-old male driver of the Toyota Highlander was operating the vehicle northbound on the inboard lane at a police estimated speed of 72 km/h (45 mph). The Toyota Highlander accelerated forward from a stopped position at an intersection that was located approximately 500 m (1640 ft) south of the crash site and was at the front of a group of vehicles traveling northbound. The Ford E450 box truck and the Toyota Camry were within the northbound group of vehicles traveling behind the Toyota Highlander. The Ford E450 was in the outboard lane and the Toyota Camry was in the inboard lane adjacent to Ford E450.

The restrained 26-year-old male driver of the Ford Mustang was operating the vehicle southbound on the same roadway at an estimated speed of 105 km/h (65 mph). **Figure 3** depicts the pre-crash trajectory of the Ford Mustang. Consistent witness statements describe the Ford Mustang as traveling at a speed significantly higher than the flow of traffic, with its driver executing multiple controlled lane changes between the inboard and outboard southbound lanes to pass other southbound vehicles. Prior to the area of impact, the Ford Mustang entered the center left turn lane. The vehicle traveled approximately 200 m (656 ft) in the center turn lane, operating at the same speed, significantly higher than the flow of traffic. As it approached the impending area of impact with the Toyota Highlander, the driver of the Ford Mustang initiated a sharp left steering input for an unknown reason. The Ford Mustang entered the inboard northbound lane in front of the Toyota Highlander.



Figure 3: Pre-crash trajectory of the Ford Mustang.

Crash

The front plane of the Ford Mustang impacted the front of the Toyota Highlander (Event 1). The direction of force for the initial impact was within the 12 o'clock sector for the Ford Mustang and within the 11 o'clock sector for the Toyota Highlander. The force of the impact actuated the driver's pretensioner and deployed the driver's frontal and knee air bags in the Toyota Highlander. The frontal air bags in the Ford Mustang also deployed. The momentum of the vehicles combined with the location and angle of the impact induced a counterclockwise (CCW) rotation to both vehicles subsequent to the impact. The Toyota Highlander reversed direction, rotated approximately 45 degrees CCW and traveled across the outboard lane, over the concrete curb and came to rest straddling the sidewalk on the east roadside 8.5 m (28 ft) southeast of the

initial point of impact facing northwest. The Ford Mustang rotated approximately 100 degrees CCW and came to rest in the center turn lane of the roadway 13.2 m (43.3 ft) from the initial point of impact, facing northeast. The Damage Algorithm of the WinSMASH program was used to calculate the severity of the crash (delta-V). The total delta-V of the Toyota Highlander was 71 km/h (44.1 mph). The longitudinal and lateral delta-V components were -67 km/h (-41.6 mph) and 24 km/h (14.9 mph). The total delta-V for the Ford Mustang was 75 km/h (46.6 mph) with a longitudinal and lateral delta-V of -75 km/h (-46.6 mph) and 0 km/h.

The driver of the Ford E450 witnessed the initial impact and initiated an avoidance maneuver by steering to the left. The left side of the Ford E450 impacted the right side of the Toyota Camry (Event 2). The driver of the Ford E450 then initiated an avoidance maneuver by braking and steering to the right. In the process the driver overcorrected and departed the roadway to the right over the east curb line.

The front of the Ford E450 impacted the left side of the Toyota Highlander (Event 3). The direction of force for this impact was within the 8 o'clock sector for the Toyota Highlander and within the 12 o'clock sector for the Ford E450. The Barrier Algorithm of the WinSMASH program was used to calculate a total delta-V of 7 km/h (4.4 mph) for the Toyota. The Toyota Highlander was displaced 3.4 m (11.2 ft) to the right and rotated 40 degrees CCW by the impact forces from the Ford E450. The Toyota Highlander came to rest straddling the east curb facing west. The Ford E450 came to rest facing north on the east roadside in a large bush immediately aft of the Toyota Highlander. After its interaction with the Ford E450, the Toyota Camry came to a controlled stopped north of the impact area in the outboard northbound lane.

Post-Crash

Police, emergency medical, and tow personnel responded to the crash site. A military medic was at a business across the street from the crash site and heard the impact. He retrieved a medical bag from his vehicle and ran approximately 80 m (260 ft) to the Toyota Highlander. The driver of the Toyota Highlander was conscious when the medic arrived. He evaluated the driver and proceeded to the passenger side of the vehicle. The medic opened the right rear door and assessed the infant in the second row center seat. The infant appeared to be unconscious upon his arrival. The medic had prior knowledge of the CRS and LATCH systems. He loosened the LATCH lower anchor strap and unhooked the LATCH clips from the lower seat anchors of the Toyota Highlander. As he removed the CRS and base from the vehicle, a volunteer firefighter arrived at the vehicle. Together the medic and the firefighter removed the CRS shell and the base as a unit and placed it on the ground to assess the infant. A nurse arrived on-scene and attempted to remove the infant from the CRS. The infant was still restrained by the 5-point harness of the CRS. The firefighter and the medic unbuckled the chest clip and the lower buckle of the 5-point harness and removed the infant from the CRS and placed her on the ground. As

they were assessing the infant, professional fire and medical personnel began to arrive on-scene and the infant's treatment was taken over by these personnel.

The driver's door of the Toyota Highlander was jammed closed. The door was pried open by emergency personnel and the driver was removed from the vehicle. The second row right occupant had traveled into the front right seat and floorpan area and was found with her head in the right floor pan area forward of the front right seating position. The right front door was opened and the rear right occupant was removed while unconscious.

Both doors of the Ford Mustang were jammed closed post-crash. The right door was pried open and the left door was opened with extrication equipment. The driver and front right passenger were removed from the vehicle.

The driver and passenger of the Ford E450 and the driver of the Toyota Camry exited their vehicles under their own power. They were not injured and not medically transported from the scene.

The drivers of the Toyota Highlander and the Ford Mustang were transported by air ambulance to a regional trauma center where they expired on the day of the crash. The infant passenger and the second row right passenger in the Toyota Highlander, and the front right passenger of the Ford Mustang were transported by ground ambulance to a local trauma center. Due to a need for services not available at the local trauma center, the infant passenger of the Toyota Highlander was transported by air ambulance to the same regional trauma center as the driver for treatment of a severe brain injury. She expired at the trauma center approximately six-hours post-crash. The second row rear right passenger of the Toyota Highlander was hospitalized for a four day treatment of head lacerations, facial fractures and closed head injuries. The front right passenger of the Ford Mustang expired three days post-crash from blunt force injuries.

The Toyota Highlander, the Ford Mustang and the Ford E450 were towed from the scene due to disabling damage. These vehicles were inspected at the local tow yards. The Toyota Camry was driven from the scene and was not inspected.

2009 Toyota Highlander

Exterior Damage

The Toyota Highlander sustained severe frontal damage as a result of the impact sequence with the Ford Mustang (**Figure 4**). The direct contact damage extended across the entire end-width of the vehicle. The bumper fascia, bumper beam, grille, hood and the left front fender separated during the crash event. The maximum crush was located at the left frame rail end and measured 101 cm (39.8 in). The right frame rail crush measured 29 cm (11.4 in). The center point of the right shock tower was displaced 22 cm (8.7 in) rearward. The left shock tower was displaced 61

cm (24 in) rearward. The front wheels were displaced rearward and the left wheelbase was shortened by 65 cm (25.6 in); the right wheelbase reduced 8 cm (3.1 in). The Collision Deformation Classification (CDC) assigned for this impact was 11FDEW5.

The rear aspect of the left side of the Toyota sustained minor severity damage from the impact with the Ford truck (Event 3). **Figure 5** is a view of the left side damage to the Toyota. The direct damage began at the left rear corner and extended 129 cm (50.8 in) forward. The damage at locations C3-C6 was overlapped by the deformation of the left rear door as a result of the initial event and the extrication efforts during the removal of the driver. A residual crush profile was obtained at the mid door level and was as follows: C1 = 10 cm (3.9 in), C2 = 5 cm (2 in), C3 = 0, C4 = 0, C5 = 0, C6 = 0. The maximum crush measured 10 cm (3.9 in) and was located at the left rear bumper corner. The damage height measured 50-89 cm (19.7-35 in), consistent with the 51 cm (20.1 in) front bumper height of the Ford truck. The CDC assigned for this impact was 08LZEW1. The left side doors were jammed closed post-crash. The right side doors were closed and operational post-crash.



Figure 4: Frontal damage sustained by the Toyota.



Figure 5: Left rear damage sustained in Event 3 impact.

The windshield was completely fractured with a 40 cm (15.7 in) laminate tear that began near the right A-pillar, 15 cm (5.9 in) below the windshield header, and extended left and downward to the center of the base of the windshield. The left front, left rear door quarter glazing, and the left rear window adjacent to the cargo area were disintegrated from the impact forces. The left rear door glazing, backlight and all right side glazing were not damaged in this crash.

Interior Damage

The Toyota sustained severe interior damage that was attributed to passenger compartment intrusion, occupant contact and air bag deployment. The driver loaded the steering wheel rim through the air bag resulting in 4 cm (1.6 in) of deformation to the lower half of the steering wheel rim. The driver loading resulted in the complete separation of the steering column's shear capsules. The upper section of the steering column separated at the point where it passes through

the firewall. There was an area of deformation that was 15 cm (5.9 in) in width to the steel backer panel behind the left knee bolster located 0-15 cm (0-6 in) left of the steering assembly junction. The bolster deformation was attributed to the driver's left knee. There was body fluid on the window sill and interior of the left door attributed to lacerations to the driver's left arm and forehead.

The center console was displaced to the left 29 cm (11.4 in) and there was a scuff mark 31 cm (12.2 in) in height on the right side of the console beginning 6 cm (2.4 in) forward of the aft edge of the center console and extending forward 14 cm (5.5 in). The upper aspect of this center console scuff mark also included blue fabric transfers. This contact was attributed to the anterior aspect of the second row right passenger's left knee and lower leg. The front right seat back was displaced forward 21 cm (8.3 in) as a result of loading from the second row right occupant. There was a depression in the rear aspect of the seat back located 3-18 cm (1.2-7.1 in) outboard of the left edge of the seat back and 17-45 cm (6.7-17.7 in) below the upper edge of the seat back. There was a scuff mark measuring 6 cm (2.4 in) in width and 7 cm (2.8 in) in height located at the upper left rear corner of the front right seat back, attributed to the rear right passenger's abdomen. The rearview mirror separated from the windshield and the mirror glass had disintegrated. The plastic housing for the rearview mirror contained long black hair and body fluid attributed to the second row right passenger's head. There was a scuff mark with impressions from a cloth pattern on the vent housing of the center instrument panel. The scuff mark began at the left edge of the clock bezel and the lower edge of the vent housing extending left 25 cm (9.8 in) and upward 17 cm (6.7 in). This cloth pattern transfer was attributed to the second row right passenger's chest. There was body fluid and long black hair on the radio located 4-20 cm (1.6-7.9 in) inboard of the right edge of the center instrument panel and 4-14 cm (1.4-5.5 in) above the lower edge of the panel attributed to the rear right passenger's head. There was a slight scuff mark and body fluid on the right instrument panel 56 cm (22 in) in width and decreasing in height from 17-12 cm (6.7-4.7 in) from left to right, also attributed to the second row right passenger's head.

The intrusion to the Toyota is listed on the following table:

Position	Component	Direction	Magnitude
Row 1 Left	A-pillar	Longitudinal	28 cm (11 in)
Row 1 Left	Toe pan	Longitudinal	22 cm (8.7 in)
Row 1 Left	Instrument panel	Longitudinal	36 cm (14.2 in)
Row 1 Left	Front seat back	Longitudinal	12 cm (4.7 in)
Row 1 Left	Seat back	Lateral	6 cm (2.4 in)
Row 1 Left	Floorpan	Vertical	10 cm (3.9 in)
Row 1 Center	Instrument panel	Longitudinal	17 cm (6.7 in)
Row 1 Center	Floorpan	Vertical	12 cm (4.7 in)
Row 1 Right	Toe pan	Longitudinal	14 cm (5.5 in)

Position	Component	Direction	Magnitude
Row 1 Right	Front seat back	Longitudinal	21 cm (8.3 in)
Row 2 Left	Floorpan	Vertical	10 cm (3.9 in)
Row 2 Center	Floorpan	Vertical	10 cm (3.9 in)

As a result of the vertical intrusion of the floorpan, the driver's seat was displaced forward and laterally to the left. The seat was in contact with the left B-pillar.

Manual Restraint Systems

The Toyota was equipped with 3-point manual lap and shoulder belt systems for the seven designated seating positions. The second row center lap and shoulder belt was integrated into the seat back. All belt systems utilized continuous loop webbing. The driver's belt system utilized a sliding latch plate, and a retractor-mounted pretensioner, which actuated during the crash. The driver D-ring was height adjustable and was located in the mid position, 7 cm (3 in) above the full-down position. The driver's safety belt retracted onto an Emergency Locking Retractor (ELR) that had Energy Management features. The driver was using the safety belt at the time of the crash, which was supported by loading evidence on the belt webbing. The evidence consisted of a frictional abrasion on the belt webbing near the latch plate and an abrasion on the inside aspect of the latch plate (side against driver). This latch plate abrasion extended across the full width of the latch plate. The frictional abrasion on the belt webbing was 10 cm (3.9 in) in width and was located 95-105 cm (37.4-41.3 in) above the floor anchor. The driver's belt webbing had been cut in two locations by medical personnel to free the driver from the vehicle. The belt was cut 24 cm (9.4 in) above the floor anchor and 15 cm (5.9 in) below the upper D-ring. Additionally, the actuated retractor pretensioner locked the safety belt in the used position. The total length of extended and locked webbing measured 202 cm (79.5 in).

The front right, second and third row safety belt systems utilized a switchable ELR/Automatic Locking Retractor (ALR) with sliding latch plates. In addition, the front right belt system (unoccupied position) utilized a retractor pretensioner, which did not actuate during the crash, and a height adjustable D- ring that was in the full-up position.

The second row right passenger did not utilize the safety belt during the crash, evidenced by the condition of the belt and contact points within the vehicle. The CRS in the second row center seat was installed using the LATCH lower anchors. The second row center belt was not in use at the time of the crash.

Frontal Air Bag System

The Toyota was equipped with a CAC frontal air bag system. The driver's air bag was concealed within the center hub of the four-spoke steering wheel by two cover flaps. The upper flap measured 15 cm (5.9 in) in width and 8 cm (3.1 in) in height. The lower flap measured 15 cm (5.9 in) in width at the horizontal tear seam, 7 cm (2.8 in) in width at the lower aspect and 11 cm (4.3 in) in height. The driver's air bag (**Figure 6**) measured 54 cm (21.3 in) in diameter in its deflated state. The air bag was tethered by two tethers at the 12 and 6 o'clock positions. The air bag was vented by two vent ports located at the 11 and 1 o'clock positions of the rear aspect of the air bag. There was no damage to the driver's frontal air bag. The left half of the air bag was covered by a dried film of a clear-type liquid.



Figure 6: Driver's frontal air bag in the Toyota.

The driver's knee air bag deployed from the lower aspect of the left instrument panel. The knee air bag was concealed by two rectangular cover flaps. These flaps were 26 cm in width at the horizontal tear seam. The upper flap was 2 cm in height; the lower flap was 5 cm in height. The air bag was 50 cm (19.7 in) in width and 28 cm (11 in) in height. It did not contain vent ports and was not tethered. There was no damage or contact evidence on the knee air bag.

The front right air bag was mounted within the upper aspect of the right instrument panel. The front right seat was not occupied during the crash; therefore the CAC system suppressed the deployment of this air bag.

Side Impact Air Bag System

The Toyota was equipped with front seat-mounted side impact air bags and roof side rail-mounted IC air bags. The seat back mounted side air bags and the IC air bags did not deploy in this crash.

Child Restraint System

The Child Restraint System (CRS) installed in the second row center seating position of the Toyota Highlander was a Graco Snug Ride rear-facing infant seat. The CRS was designed to be used with or without a detachable base (**Figure 7**). The CRS manufacturer recommended height of a child to use this seat was 73 cm (29 in) or less and the recommended weight range was 2.3-10 kg (5-22 lb). The reported height and weight of the child (79 cm/13kg) was beyond the recommended limits of the CRS. The model number obtained from the placard on the rear of the

seat was 7E02DNY3. The seat and the base were both manufactured on July 8, 2008 and also shared the same model number. The serial number on the CRS and the base also matched. The CRS and base were placed on the second row center seat and secured to the vehicle using the lower anchor strap and LATCH bars. The lower anchor strap was routed through the rear-facing belt path of the CRS base and was attached to the bars. The vehicle manufacturer indicated that only the outboard positions of the second row were suitable for the LATCH installation. The use of the “borrowing” the inboard anchors to install a CRS in the center position was not an approved installation technique. The top tether was not used for this rear-facing installation.



Figure 7: Rear center CRS.

The infant passenger was restrained in the CRS by the 5-point harness system. The chest retainer clip was used. The volunteer firefighter who assisted in the removal of the CRS from the vehicle and the removal of the infant from the child seat stated that the chest clip was in the center of the infant’s chest, at approximately armpit level, and that the infant was not wearing any excessively bulky clothing under the harness. The harness straps were in the top slots at the time of the SCI inspection. The CRS was equipped with an adjustable carry handle to transport the CRS when not installed in a vehicle. The carry handle was in the stowed (forward) position at the time of the SCI inspection.

The CRS had been removed from the Toyota post-crash. There was an imprint on the LATCH webbing from the length adjustment buckle. The imprint was located 23 cm (9.1 in) above the end of the left LATCH hook. When the adjustment buckle was returned to this position, the LATCH webbing length measured 82 cm (32.3 in) from the tip of the left hook to the tip of the right. When the base and CRS were returned to the Toyota, this length of webbing would be of a length to tightly install the base in the vehicle. There was an angle adjustment foot on the lower rear of the base. This foot was in the upper position of three available settings. When the base and CRS were replaced in the vehicle, the angle of the CRS was shown to be within the required limits by the operational blue and yellow angle indicator. **Figure 8** depicts the CRS and base reinstalled in the second row



Figure 8: CRS and base on rear center seat of the Toyota.

center position of the Toyota. The CRS was in close proximity to the rear aspect of the center console.

The shell of the CRS was not damaged in the crash. The shell, fabric cover, and 5-point restraint were unremarkable for damage and/or contact evidence. Located under the fabric cover behind the occupant's back was a 3 cm (1 in) thick section of foam padding. A formed white Styrofoam backer was located behind the foam padding in the area of the head and back of the infant. There was no damage evident to the upholstery foam or Styrofoam backer.

The base sustained minor damage from the crash. A crack and color loss due to stress loading were present at the rear left of the base, between the second and third cutouts for securing the angle adjustment foot. There were frictional abrasions present on both ends of the belt path at the location where the belt webbing angled down to attach to the lower anchors. There was a 3 cm (1.2 in) by 8 cm (3.1 in) impression in the plastic of the belt path with a diamond/straight line pattern consistent with the pattern noted on the belt webbing, located at the right end of the belt path. The hooks at the ends of the webbing were not deformed; however, there was an area of black paint missing from the inside of each hook where the hook engaged the vehicle's anchor. There was no deformation to the inboard LATCH anchor bars in the seat bights of the Toyota's second row seat. There were scratches present on the lower anchor bars.

2006 Ford Mustang

Exterior Damage

The front plane of the Ford sustained severe damage from the impact with the Toyota (**Figure 9**). The direct damage extended from the front left bumper corner to the front right bumper corner. The maximum crush was located 18 cm (7.1 in) inboard of the right frame rail end and measured 77 cm (30.3 in). The left frame rail end was displaced rearward 40 cm (15.7 in); the right frame rail end crushed 59 cm (23.2 in). Both front wheels were displaced rearward resulting in wheelbase reductions of 55 cm (21.7 in) on the left and 24 cm (9.4 in) on the right. The CDC assigned for this impact was 12FDEW3.



Figure 9: Frontal damage sustained by the Ford Mustang.

2005 Ford E-450 Medium/Heavy Truck

Exterior Damage

The frontal structure of the Ford truck sustained minor-severity damage in the impact event with the Toyota Highlander (Event 3). This damage is depicted in **Figure 10**. The direct contact damage began 40 cm (15.7 in) right of the vehicle's centerline and extended 179 cm (70.5 in) left. The maximum crush was located at a level above the bumper, 9 cm (3.5 in) left of the centerline. The damage to the bumper was limited to surface abrasions on the top aspect of the bumper. The bumper was displaced downward 3 cm (1.2 in). As a result, crush profiles were documented at the heights of the bumper and the lower radiator support. The residual crush at the bumper level was zero. The above bumper crush profile was: C1 = 0, C2 = 2 cm (0.8 in), C3 = 5 cm (2 in), C4 = 10 cm (3.9 in), C5 = 10 cm (3.9 in), C6 = 0 cm. Maximum crush measured 11 cm (4.3 in) and was located 9 cm (3.5 in) left of the vehicle centerline. The truck's wheelbase dimensions were unchanged. The CDC assigned for this impact was 12FDEW1.



Figure 10: Frontal damage to the Ford truck.

The initial impact sequence to the Ford truck (Event 2) resulted in surface abrasions to the aluminum rub strip at the left lower aspect of the truck's box. However, the abrasions attributed to this crash overlapped previous abrasions that were present on this strip. It was impossible to isolate the damage that resulted from this event.

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2009 Toyota Highlander Occupant Demographics

Driver

Age/Sex:	26-year-old/Male
Height:	170 cm (67 in.)
Weight:	99 kg (218 lb)
Eyewear:	None
Seat Track Position:	Mid track, 9 cm (3.5 in) forward of full-rear
Manual Safety Belt Use:	Lap and shoulder belt
Usage Source:	Vehicle Inspection
Egress from Vehicle:	Extricated by EMS
Mode of Transport from Scene:	Air ambulance to a regional trauma center
Type of Medical Treatment:	Expired five hours post crash

Driver Injuries

Injury	Injury Severity (AIS 90/Update 98)	Injury Source
Small bowel avulsion from mesentery (approx. 61 cm)	Severe (541426.4,8)	Steering wheel rim
Avulsion of the sigmoid colon with complete transection	Severe (540826.4,8)	Steering wheel rim
Multiple mesentery complex lacerations	Severe (542026.4,8)	Steering wheel rim
Liver lacerations (multiple small)	Moderate (541822.2,1)	Steering wheel rim
Left arm fracture NFS	Moderate (751800.2,2)	Left door panel
Avulsion of the rectus muscles NFS	Minor (590800.1,9)	Steering wheel rim
3 cm (1.2 in) laceration to forehead	Minor (290602.1,7)	Left A-pillar trim
Left eyelid laceration	Minor (297602.1,2)	Left A-pillar trim
Left side chin abrasion (2 x 1 cm)	Minor (290202.1,8)	Driver's frontal air bag
Lower left side of neck contusion	Minor (390402.1,2)	Safety belt
Left shoulder abrasion (3 x 3 cm)	Minor (790202.1,2)	Safety belt
Left forearm abrasion (8 x 5 cm)	Minor (790202.1,2)	Left door panel
Left forearm laceration (7 x 3 cm) and left elbow area (2 x 1 cm) laceration with protruding bone	Minor (790602.1,2)	Left door panel
Right shoulder contusion (12 x 4 cm) and right upper arm contusion (10 x 5 cm)	Minor (790402.1,1)	Steering wheel rim
Right hand contusions (2 x 1 cm each) on dorsal aspect	Minor (790402.1,1)	Center instrument panel
Chest abrasion	Minor (490202.1,9)	Safety belt
Left shoulder contusion	Minor (790402.1,2)	Safety belt

Injury	Injury Severity (AIS 90/Update 98)	Injury Source
Contusion to right side of abdomen	Minor (590402.1,1)	Center console
Contusion across lower abdomen	Minor (590402.1,8)	Safety belt
Right hip contusion (9 x 4 cm)	Minor (890402.1,1)	Safety belt

Source – External autopsy and ER records

Driver Kinematics

The 26-year-old male driver was seated in a mid-track position 9 cm (3.5 in) forward of full-rear. He was restrained by the manual 3-point lap and shoulder belt system. The initial impact with the Ford actuated the driver’s retractor pretensioner and deployed the driver’s frontal and knee air bags. In response to the frontal impact forces, the driver initiated a forward and left trajectory within the front left seating position. He loaded the belt system, resulting in the contusions to his chest and abdomen. The steering assembly and left instrument panel began to intrude into the vehicle towards the driver. The driver’s abdomen, chest and left face/cheek loaded the deployed frontal air bag. The driver’s abdomen loaded through the air bag and engaged the steering wheel rim, deforming the rim and resulting in the laceration of the left abdominal wall muscles, the liver lacerations and small bowel avulsion from the mesentery. The driver’s left knee loaded the knee bolster, deforming the bolster. The driver’s face contacted the intruded A-pillar trim resulting in the forehead and left eyelid laceration.

After the initial impact, the Toyota came to rest on the east roadside, straddling the curb. The impact to the aspect of the left plane by the Ford truck induced a CCW rotation to the Toyota. The driver responded with a left trajectory and loaded the left door panel. This kinematic pattern resulted in the fracture and soft tissue injuries to his left arm. The driver then rebounded into the center console with the right side of his abdomen, resulting in a contusion. His lower body was held in place by the safety belt and his upper body extended beyond his right hip.

The driver was unable to exit the vehicle due to his injuries and the jammed driver’s door. He was conscious at the time emergency personnel arrived and reported being unable to feel his legs. Emergency personnel pried the left front door open, cut the driver’s safety belt and removed the driver from the vehicle. Total extrication time was 25 minutes. The driver was transported by air ambulance to a state trauma center where he expired 5 hours post-crash.

Second Row Right Passenger

Age/Sex: 26-year-old/Female
 Height: 160 cm (63.in)
 Weight: 56 kg (123 lb)
 Eyewear: None
 Seat Track Position: Not adjustable
 Manual Safety Belt Use: None
 Usage Source: Vehicle Inspection
 Egress from Vehicle: Extricated by EMS while unconscious
 Mode of Transport from Scene: Ground ambulance to local trauma center
 Type of Medical Treatment: Admitted to a local trauma center for 4 days.

Second Row Right Passenger Injuries

Injury	Injury Severity (AIS 90/Update 98)	Injury Source
Concussion (with loss of consciousness)	Moderate (160406.2,0)	Center instrument panel
Left temporal artery laceration with associated 3 cm irregular left temporal laceration	Minor (220202.1,2)	Center instrument panel
4 cm forehead laceration	Minor (290602.1,7)	Center instrument panel
Periorbital abrasion	Minor (297202.1,9)	Center instrument panel
Periorbital contusion	Minor (297402.1,9)	Center instrument panel
Bilateral forearm abrasions	Minor (790202.1,3)	Center instrument panel
Left lower leg abrasions	Minor (890202.1,2)	Center console
Left lower leg contusions	Minor (890402.1,2)	Center console
Right lower leg abrasions	Minor (890202.1,1)	Front right seat back
Right lower leg contusions	Minor (890402.1,1)	Front right seat back
Left axilla abrasion	Minor (790202.1,2)	CRS shell
Right heel laceration (small)	Minor (890602.1,1)	Unknown

Source - Hospital records.

Second Row Right Passenger Kinematics

The 26-year-old female rear right occupant was seated in the second row right seat of the vehicle in order to attend to the 11-month-old infant in the center position. She was not restrained. In response to the initial impact force, the rear right occupant initiated a forward and left trajectory within the rear right seating position. The occupant traveled forward until her knees impacted the center console and the rear of the front right seat back (**Figure 11**). The occupant's left knee and lower leg loaded the right side of the center console. Her right knee and lower leg engaged the rear of the front right seat back displacing it forward. As her lower body was slowed by the center console and front seat back, the occupant's torso continued forward and engaged the upper left corner of the front right seat back, depositing a scuff mark as she passed over the seat back. Her left axilla (armpit) contacted the CRS shell and was abraded. The occupant's left elbow impacted the rear center child's head which resulted in the child's left head injury. The adult occupant's interaction with the child compressed the child into the CRS. The adult occupant was then in a forward trajectory between the front seats leading with her head. She impacted the windshield and rearview mirror with her arms detaching the rearview mirror and resulting in the soft tissue forearm injuries. Her head impacted the center instrument and radio resulting in the concussion and head lacerations (**Figure 12**). She came to rest in the center of the front row of the Toyota between the front seat backs.



Figure 11: Right interior view of the passenger's contacts to the seat back and center console.



Figure 12: Right interior view depicting the passenger contacts to the center instrument panel.

The passenger was unconscious when medical personnel removed her from the vehicle through the operable front right door. She was transported by ground ambulance to a local trauma center where she was admitted for 4 days.

Second Row Center Passenger

Age/Sex: 11-month-old/Female
 Height: 79 cm (31 in)
 Weight: 13 kg (28 lb)
 Eyewear: None
 Seat Track Position: Not adjustable
 Manual Safety Belt Use: 5-point harness of a CRS secured with LATCH system
 Usage Source: Vehicle Inspection
 Egress from Vehicle: Extricated by bystanders while unconscious
 Mode of Transport from Scene: Ground ambulance to local trauma center, transferred by air ambulance to a regional trauma center
 Type of Medical Treatment: Expired five hours post crash.

Second Row Center Passenger Injuries

Injury	Injury Severity (AIS 90/Update 98)	Injury Source
Bilateral subdural hematoma (left greater than right)	Critical (140654.5,3)	Second row right occupant
Bilateral pulmonary contusions with hemo/pneumothorax (posterior left, right unspecified)	Severe (441410.4,3)	Shell of the CRS
Basal cistern effacement and cerebral swelling with loss of gray white matter differentiation	Severe (140664.4,9)	Shell of the CRS
Complex right temporal skull fracture	Severe (150406.4,1)	Shell of the CRS
Cerebral hemorrhage NFS	Severe (140629.4,9)	Shell of the CRS
Midline occipital skull fracture	Serious (150202.3,8)	Shell of the CRS
Pneumocephalus (left)	Serious (140682.3,2)	Second row right occupant
Pneumocephalus (right)	Serious (140682.3,1)	Shell of the CRS
Left parietal skull fracture NFS	Moderate (150400.2,2)	Second row right occupant
Large left mid scalp hematoma	Minor (190402.1,2)	Second row right occupant
Bilateral hip and thigh contusions; right thigh 10x3 cm, left thigh 7 x 2.5cm	Minor (890402.1,3)	Internal harness of CRS
Bilateral thigh abrasions	Minor (890202.1,3)	Internal harness of CRS

Source – External Autopsy/ Hospital records

Second Row Center Passenger Kinematics

The 11-month-old female passenger was restrained in a rear-facing infant CRS installed with the lower LATCH anchors in the second row center seat position of the Toyota. She was restrained within the CRS by the 5-point harness system. The height and weight of the infant exceeded the CRS manufacturers recommended limits for the CRS by 5 cm (2 in) in height and 3 kg (6 lb) in weight. As a result, the infant's head was probably located at the upper aspect of the CRS shell.

The infant responded to the frontal impact by initiating a forward trajectory with respect to the vehicle, within the CRS. The posterior aspect of the infant's head and back areas loaded, and ramped up the shell. Her thighs and shoulders loaded the 5-point harness. In turn, the combined mass of the infant and the CRS loaded the LATCH belt and anchors. The upper aspect of the CRS was probably displaced downward as the base of the unit compressed into the seat cushion.

Coincident to this kinematic pattern, the unrestrained second row right passenger initiated a forward and slightly left trajectory. The left axilla of the unrestrained passenger engaged the right side (with respect to the vehicle) of the CRS shell. This contact resulted in a contusion to the passenger's axilla area. Immediately prior to this contact or subsequent to this contact, the left elbow or shoulder of the unrestrained passenger impacted the left side of the infant's scalp. The direct occupant-to-occupant interaction resulted in a large left scalp hematoma to the infant passenger, bilateral subdural hematoma, a left parietal skull fracture, and left side pneumocephalus.

The occupant-to-occupant interaction further compressed the head of the infant passenger into the upper aspect of the CRS, compressing the foam padding against the Styofom backer and shell of the CRS. As a result of the infant's response to the frontal impact forces and the subsequent contact and compression by the unrestrained front right passenger, the infant sustained a complex right temporal skull fracture, a midline occipital skull fracture, cerebral hemorrhage, basal cistern effacement and cerebral swelling, and right pneumocephalus.

The child's back loaded the shell of the CRS resulting in bilateral pulmonary contusions with hemo/pnuemothorax. As the child ramped up the CRS during her response to the crash forces, her hips and upper thighs loaded the integral harness system resulting in bilateral contusion and abrasions.

The infant came to rest secured in the CRS. The CRS remained secure to the based that was restrained by the LATCH belts. Post-crash, bystanders, some with medical experience, removed the infant and the CRS from the Toyota. She was noted to be unconscious. She was then removed from the 5-point restraint by the bystanders and placed on the ground, where she was assessed by the bystanders and the first arriving emergency medical personnel. The only evidence of injury at this time was a small amount of blood released from her tear ducts.

The infant was transported by ground ambulance to a local hospital with trauma certification. She was assessed in the emergency department and due to the need for pediatric services not available at this facility; she was prepared for helicopter transferred to a regional trauma center. The infant arrived at the regional trauma center approximately two hours post-crash. She expired as a result of her injuries five hours post-crash.

It should be noted that the shell of the CRS and the Styrofoam backing in the area of the infant's head was not damaged by her loading or by the subsequent compression of her head into the CRS by the unrestrained passenger.

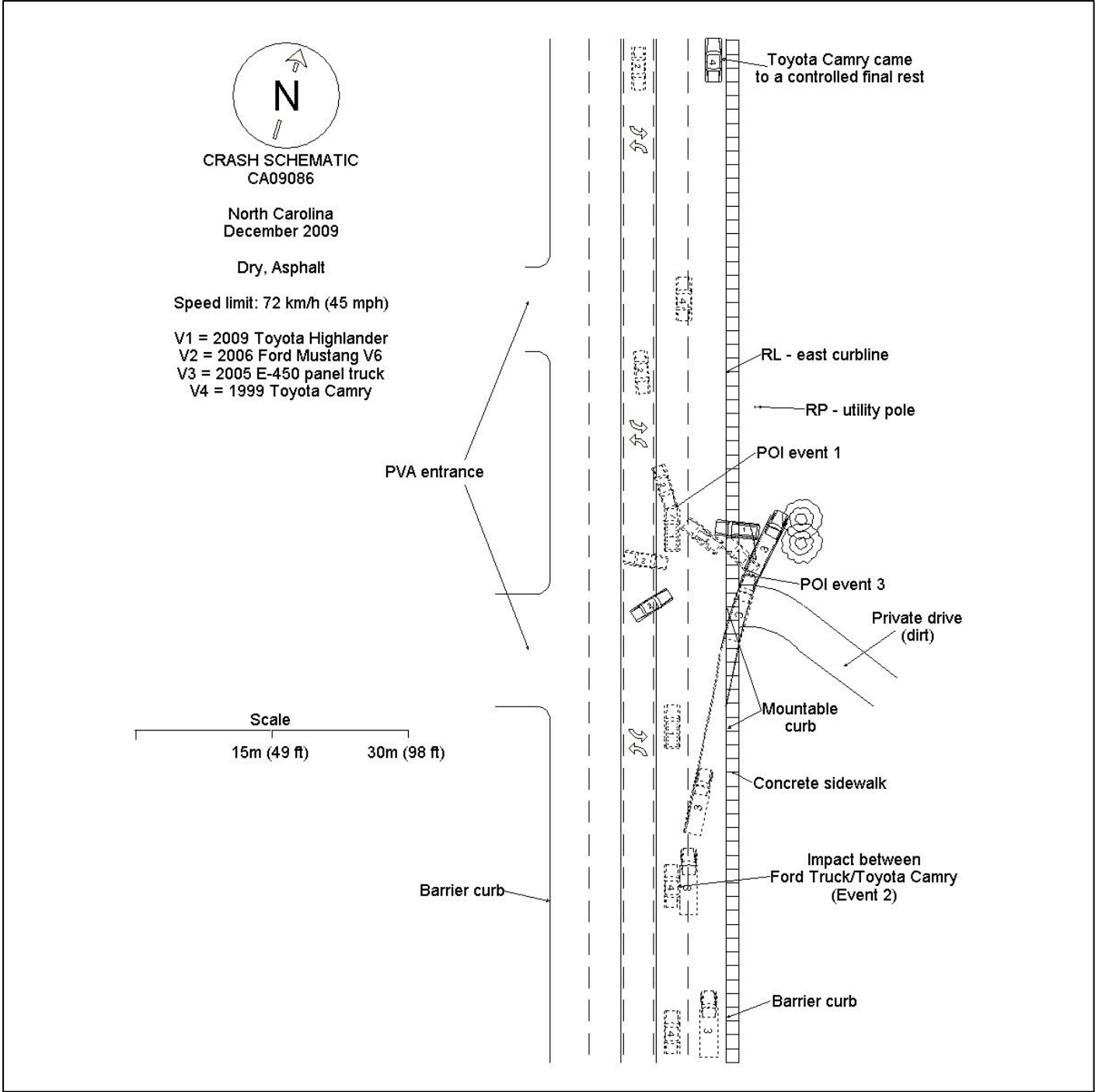


Figure 13: Crash Schematic

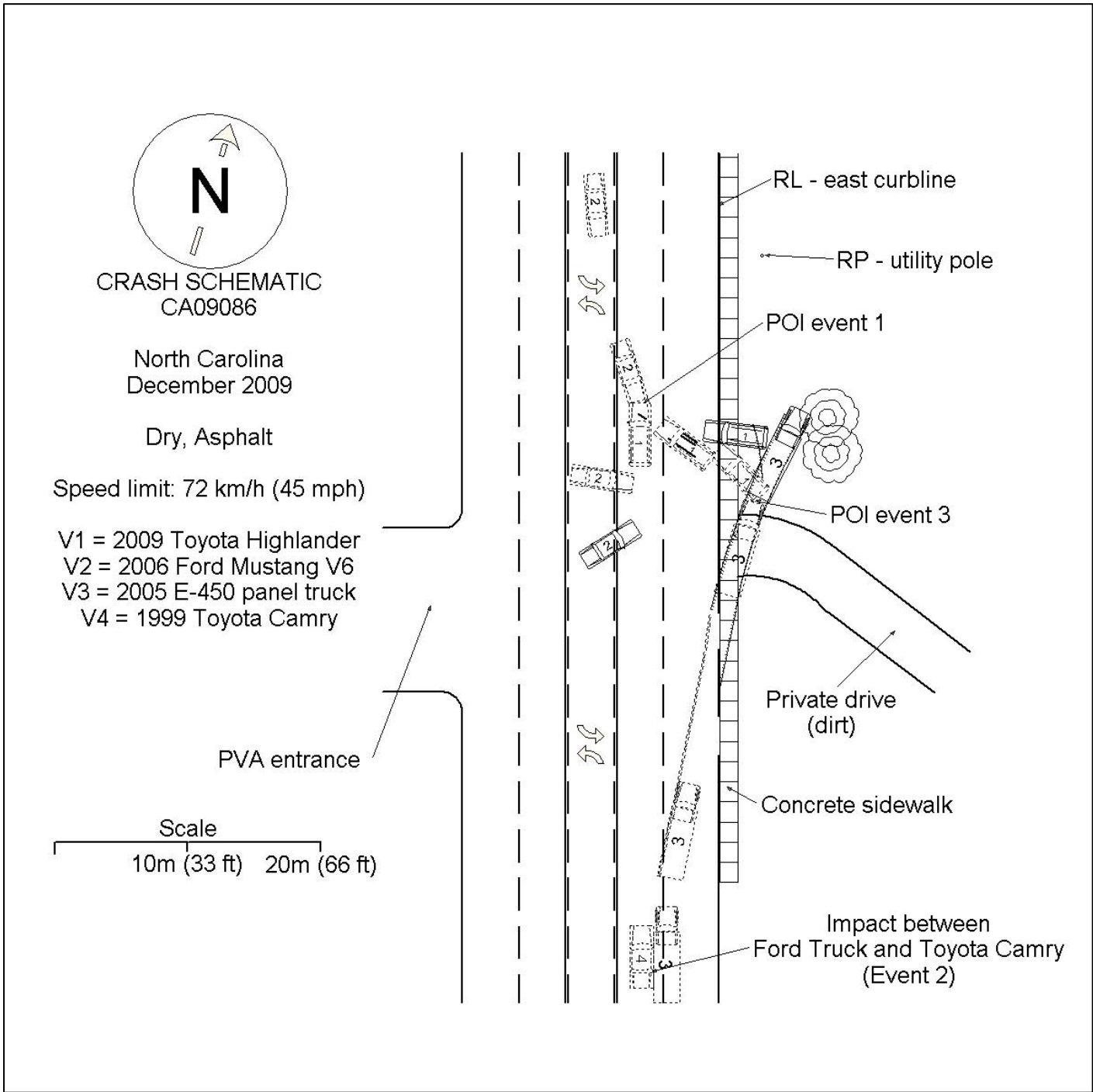


Figure 14: Enlarged area at impact locations