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CALSPAN ON-SITE SIDE IMPACT INFLATABLE OCCUPANT PROTECTION SYSTEM CRASH INVESTIGATION
SCI CASE NO.: CA09067

VEHICLE: 2007 BMW 525i SEDAN

LOCATION: NORTH CAROLINA

CRASH DATE: SEPTEMBER 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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16. Abstract This on-site investigation focused on the side impact inflatable occupant protection system in a 2007 BMW 525i sedan that was involved in a side impact crash. The vehicle was equipped with four-wheel antilock brakes, a Certified Advanced 208-Compliant (CAC) frontal air bag system, front door-mounted side impact air bags and side impact Inflatable Curtain (IC) air bags. The manufacturer of the BMW 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 includes dual-stage frontal air bags for the driver and front right passenger positions, seat track positioning sensors, retractor and buckle pretensioners, safety belt buckle switches, and a front right occupant presence sensor. The BMW was impacted on the left plane by a 1996 Toyota Avalon. The BMW was deflected to the right and departed the road impacting a highway warning sign and an embankment prior to coming to final rest. The driver's frontal air bag, the left side impact air bag and the left IC in the BMW deployed during the crash sequence. The restrained 39-year-old male driver of the BMW sustained minor severity soft tissue injuries in this crash. He refused medical treatment at the scene and did not seek follow-up treatment.			
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TABLE OF CONTENTS

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BACKGROUND

This on-site investigation focused on the side impact inflatable occupant protection system in a 2007 BMW 525i sedan **(Figure 1)** that was involved in a side impact crash. The vehicle was equipped with four-wheel antilock brakes, a Certified Advanced 208-Compliant (CAC) frontal air bag system, front door-mounted side impact air bags and side impact Inflatable Curtain (IC) air bags. The manufacturer of the BMW 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 includes dual-stage frontal air bags for the driver and front right passenger positions, seat track positioning sensors, retractor and buckle pretensioners, safety belt buckle switches, and a front right occupant presence sensor. The BMW was impacted on the left plane by a 1996 Toyota Avalon. The BMW was deflected to the right and departed the road impacting a highway warning sign and an embankment prior to coming to final rest. The driver's frontal air bag, the left side impact air bag and the left IC in the BMW deployed during the crash sequence. The restrained 39-year-old male driver of the BMW sustained minor severity soft tissue injuries in this crash. He refused medical treatment at the scene and did not seek follow-up treatment.

Figure 1: Left front oblique view of the 2007 BMW 525i.

The crash was identified by NHTSA's Crash Investigation Division through the weekly survey of the General Estimates System (GES) police reports searching for cases of interest to the Agency. The police report was forwarded to the Calspan Special Crash Investigations (SCI) team on October 6, 2009 and assigned for an on-site investigation. The on-site investigation was initiated on October 9, 2009 and involved the inspections of the BMW and the Toyota, a detailed interview with the driver of the BMW, and documentation of the crash scene.

SUMMARY

Vehicle Data

2007 BMW 525i

The 2007 BMW 525i sedan was identified by the Vehicle Identification Number (VIN): WBANE53517C (production number deleted). The odometer reading was 45,327 km (28,171 mi) at the time of the crash. The rear-wheel drive BMW was powered by an inline 3.0-liter, 6-cylinder engine linked to a 6-speed automatic transmission with a manual shift feature. The brake system consisted of power-assisted front and rear disc brakes with four-wheel antilock, brake assist and electronic brake force distribution. In addition, the BMW was equipped with Electronic Stability Control (ESC), traction control and a direct Tire Pressure Monitoring System (TPMS). The driver noted that the TPMS warning light was not on prior to the crash. All windows were closed at the time of the crash. The BMW was equipped with Continental ContiTouring Contact tires, size P225/50R17 mounted on OEM five-spoke alloy wheels. The tire size matched the vehicle manufacturer recommendation for this vehicle. The vehicle manufacturer recommended cold tire pressure was 221 kPa (32 PSI) for the front and 228 kPa (33 PSI) for the 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	186 kPa (27 PSI)	4 mm (5/32 in)	None
Left Rear	214 kPa (31 PSI)	7 mm (9/32 in)	None
Right Front	200 kPa (29 PSI)	6 mm (8/32 in)	None
Right Rear	207 kPa (30 PSI)	7 mm (9/32 in)	None

The interior of the BMW was configured with leather-surfaced five-passenger seating. The front bucket seats were separated by a center console and were equipped with adjustable head restraints. The driver's head restraint was adjusted 6 cm (2.4 in) above the full-down position at the time of the SCI inspection. The front right head restraint was in the full-down position. The driver's seat track was adjusted 2 cm (0.8 in) forward of the full-rear position. The front right seat track was in the full-rear position. The driver's seat back was adjusted to an angle of 24 degrees aft of vertical. The unoccupied front right seat back was set at 26 degrees aft of vertical. The second row consisted of a bench with split folding backs. The rear outboard seats were equipped with adjustable head restraints that were in the full-down positions. The rear center seat was equipped with an integrated head restraint.

The interior occupant safety systems consisted of 3-point lap and shoulder belt systems for the five designated seating positions, front seat safety belt retractor and buckle pretensioners, dual stage CAC frontal air bags, and door-mounted side impact air bags. The BMW also contained IC air bags that consisted of tubular air bags contained in slings that provided protection for the four outboard seating positions.

1996 Toyota Avalon

The 1996 Toyota Avalon XLS was identified by the VIN: 4T1BF12B7TU (production sequence deleted). The front-wheel drive Toyota was powered by a 3.0-liter, V6 engine linked to a 4-speed automatic transmission. The brake system consisted of power-assisted front and rear disc brakes with four-wheel antilock. The front door windows were open prior to the crash; the rear door windows were closed. The Toyota was equipped with four BF Goodrich Touring T/A tires, size P205/65R15. The tires matched the manufacturer recommended size. The manufacturer recommended cold tire pressure was 221 kPa (32 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	165 kPa (24 PSI)	4 mm (5/32 in)	None
Left Rear	152 kPa (22 PSI)	2 mm (3/32 in)	None
Right Front	172 kPa (25 PSI)	3 mm (4/32 in)	None
Right Rear	165 kPa (24 PSI)	1 mm (1/32 in)	None

Crash Site

This crash occurred during daylight hours on a two-lane north/south rural roadway. The conditions were clear and dry at the time of the crash. The roadway consisted of two asphalt travel lanes. The northbound traffic lane measured 3 m (9.8 ft) in width, and the southbound traffic lane measured 3.5 m (11.5 ft). There was a right curve for northbound traffic that transitioned into a straight section in the area of the impact. The northbound road grade was level. The pre-crash area of the BMW (southbound) had a negative grade of 1.6 percent **(Figure 2)**. Adjacent to the east road edge was a depression that was 40 cm (15.7 in) wide, 15 cm (5.9 in) deep and 17.7 m (58.1 ft) in length. The roadway was bordered by grass roadsides and embankments that sloped away from the roadway. The embankment on the east roadside began 2.4 m (7.9 ft) east of the east road edge and had a negative grade of 88 percent. The embankment on the west roadside began at the west road edge and had a negative grade of 16 percent. This transitioned to a steeper negative grade of 81 percent 2.8 m (9.2 ft) west of the west road edge. A highway warning sign was located on this section of embankment and was struck by the BMW. At the bottom of the west embankment was a ditch with a centerline located 6.7 m (22 ft) west of the west road edge. Beyond this ditch was an embankment with a positive 13 percent grade. The ditch embankment

Figure 2: Southbound trajectory view of the crash site.

was the area of impact for the third event in this crash sequence and the BMW's final rest location. The posted speed limit in the area of this crash was 72 km/h (45 mph). The Crash Schematic is included as **Figure 11** of this report.

Crash Sequence

Pre-crash

The restrained 39-year-old driver of the BMW was operating the vehicle southbound on the two-lane roadway at a driver estimated speed of 72 km/h (45 mph). The restrained 40-year-old driver of the Toyota was operating the vehicle northbound, negotiating a right curve on the same roadway. The driver of the Toyota allowed the vehicle to drift to the right. The right tires of the Toyota departed the roadway and entered the depression located along the edge of the pavement. The driver of the Toyota applied a rapid steering input to the left in an attempt to regain his travel lane and crossed the centerline of the roadway. The driver of the BMW initiated a reported avoidance action by steering to the right and braking.

Crash

The front plane of the Toyota impacted the left front side area of the BMW (Event 1). The direction of force was within the 11 o'clock sector for the BMW and the 1 o'clock sector for the Toyota. The force of the impact actuated the BMW driver's safety belt pretensioners and deployed the driver's frontal air bag, the left side impact air bag, and the left IC in the BMW. The Damage Algorithm of the WinSMASH program was used to calculate the severity of the crash (delta-V). The total delta-V of the BWM was 31 km/h (19.3 mph). The respective longitudinal and lateral delta-V components were -24 km/h (-14.9 mph) and 20 km/h (12.4 mph). The total delta-V of the Toyota was 34 km/h (21.1 mph) with a longitudinal and lateral delta-V component of -32 km/h (-19.9 mph) and -12 km/h (7.5 mph), respectively.

The impact force redirected the BMW to its right. A 16.7 m (54.8 ft) left rear tire mark evidenced the BMW's post-crash trajectory. The BMW departed the roadway to the right where it impacted and overrode a highway sign (Event 2). The BMW traversed the steep embankment, rotated clockwise and traveled to the bottom where the front plane of the vehicle impacted the back side of the ditch. **Figure 3** depicts the impact locations with the sign and the embankment. The Barrier Algorithm of the WinSMASH program calculated a total delta-V of 17 km/h (10.6 mph) for the embankment impact. The longitudinal and lateral components of the delta-V were -16.7 km/h (10.4 mph) and 3 km/h (1.9 mph), respectively. The BMW came to rest against the west ditch embankment, facing west 21 m (69 ft) from the initial

Figure 3: Location of impacts with the sign (Event 2) and the embankment (Event 3).

POI with the Toyota. The Toyota separated from the initial impact with a counterclockwise rotation. The Toyota came to rest facing east, straddling the west fog line, 11 m (36 ft) north of the POI.

Post-Crash

Police, emergency medical and tow personnel responded to the crash site. At final rest, the left plane of the BMW was adjacent to a group of trees on the west roadside. This prevented the operable left rear door from being opened. The driver was unable to climb out through the disintegrated left windows. Emergency medical personnel pried the front right door of the BMW open to allow the driver to exit the vehicle. The driver of the BMW sustained minor-severity soft tissue injuries and was not medically treated. Both vehicles were towed from the scene due to disabling damage. The vehicles were transferred to a regional salvage facility where they were inspected for this SCI investigation.

2007 BMW 525i

Exterior Damage

The left side and frontal areas of the BMW sustained moderate damage as a result of this multiple event crash sequence. The primary damage was located on the left side of the BMW. The direct contact damage began 159 cm forward of the left rear axle and extended forward 174 cm (68.5 in) to the left front bumper corner **(Figure 4)**. The combined direct and induced damage (Field L) began 116 cm (45.7 in) forward of the left rear axle and extended forward 217 cm (85.4 in). Lateral crush was present to the left front fender, left A-pillar and left front door. The maximum crush measured 26 cm (10.2 in) and was located at C3, 202 cm (79.5 in) forward of the left rear axle. A residual crush profile was measured at the lower door level and was as follows: C1 = 0 cm, C2 = 13 cm (5.1 in), C3 = 26 cm (10.2 in), C4 = 21 cm (8.3 in), C5 = 19 cm (7.5 in), C6 = 20 cm (7.9 in). The height of the maximum crush was 41 cm (16.1 in) above the ground and the BMW's door sill height was 28 cm (11 in). The Door Sill Differential (DSD) was measured at 17 cm (6.7 in). The Collision Deformation Classification (CDC) assigned for the Event 1 impact was 11LYEW2. The front doors and rear right door were jammed closed post-crash. The front right door had been pried open by EMS to allow the driver to exit the vehicle. The left rear door remained closed during the crash and was operational post-crash. The windshield was fractured and the left front and left rear window glazing were

Figure 4: Left side damage sustained by the BMW in the initial impact.

disintegrated in the initial impact. The driver stated during the interview that the right front door glazing was disintegrated post-crash by emergency medical personnel during the rescue efforts.

The damage from the second impact with the highway warning sign post (Event 2) overlapped the damage from the embankment. This damage could not be separated from the front profile. The partial CDC for this event was 12F99999 with the 9's denoting unknown fields.

The direct and induced damage resulting from the impact with the ditch bank (Event 3) extended across the full width of the front plane. **Figure 5** depicts the frontal damage. The maximum crush was located at C1, the front left bumper corner. A residual crush profile was measured at the level of the bumper and was as follows: C1 = 13 cm (5.1 in), C2 = 2 cm (0.8 in), C3 = 3 cm (1.2 in), C4 = 3 cm (1.2 in), C5 = 5 cm (2 in), C6 = 2 cm (0.8 in). The CDC assigned for this impact was 12FDEW1.

Figure 5: Frontal damage to the BMW resultant to Event 3.

Interior Damage

The BMW sustained moderate severity damage that was attributed to passenger compartment intrusion and air bag deployment. There were no identified interior occupant contacts. The intrusion to the BMW is listed in the following table:

Position	Component	Direction	Magnitude
Row 1 Left	Side panel forward of the A-pillar	Lateral	13 cm (5.1 in)
Row 1 Left	A-pillar (lower)	Lateral	14 cm (5.5 in)
Row 1 Left	Left door Forward Lower Quarter	Lateral	9 cm (3.5 in)
Row 1 Left	Left door Forward Upper Quarter	Lateral	5 cm (2 in)

Manual Restraint Systems

The BMW was equipped with 3-point manual lap and shoulder belts for the five designated seating positions. All of the belt systems utilized continuous loop webbing. The front left belt system utilized a sliding latch plate and retractor and buckle mounted pretensioners, which actuated during the crash. The driver's D-ring was fixed and the belt retracted onto an Emergency Locking Retractor (ELR). The driver used the safety belt at the time of the crash, which was supported by loading evidence on the belt webbing. This evidence consisted of a 4 cm (1.6 in) frictional abrasion on the belt webbing near the latch plate. This frictional abrasion was located 80-84 cm (31.5-33.1 in) above the lower seat anchor. Additionally, the actuated retractor pretensioner locked the safety belt in the used position. The total length of spooled out

and locked webbing measured 166 cm (65.4 in). The actuated buckle pretensioner retracted downward a distance of 7 cm (2.8 in).

The front right and second row safety belt systems utilized a switchable ELR/Automatic Locking Retractor (ALR) with a sliding latch plate. In addition, the front right belt system utilized retractor and buckle pretensioners which did not actuate during the crash.

Frontal Air Bag System

The BMW was equipped with a CAC frontal air bag system. The CAC system consisted of dual-stage frontal air bags for the driver and right front passenger positions, seat track positioning and buckle switch sensors, retractor pretensioners, and a front right occupant presence sensor. The driver's air bag was concealed within the center hub of the 3-spoke steering wheel by a quad-flap. The upper flaps measured 5 cm (2 in) in width at the upper side, 5 cm (2 in) in height, and 7 cm (2.8 in) in width at the horizontal tear seam. The lower flaps were triangular in shape and were 7 cm (2.8 in) in width and 9 cm (3.5 in) in height at the vertical tear seam. The driver's air bag (**Figure 6)** measured 56 cm (22 in) in diameter in its deflated state. The air bag was vented by two circular ports located on the upper rear aspect of the air bag at the 11 and 1 o'clock positions. The front left air bag was tethered by two straps attached to the face of the air bag at the 12 and 6 o'clock positions on a 14 cm (5.5 in) tether circle sewn to the face of the air bag. No contact evidence or crash-related damage was present on the driver's air bag. The air bag was labeled with the following nomenclature: >PA 6.6< 602491701006940201.

Figure 6: Driver's frontal 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; therefore the CAC system suppressed the deployment of this air bag.

Side Impact Air Bag System

The BMW was equipped with front door-mounted side impact air bags and roof side rail-mounted IC air bags. The IC consisted of tubular air bags contained within a sling. The left IC air bag and the left door-mounted side impact air bag deployed during the initial impact event with the Toyota. The right side impact air bags did not deploy.

The left side impact air bag deployed from the rear aspect of the left front door panel. The H-configuration cover flaps measured 17 cm (6.7 in) in width and 8 cm (3.1 in) in height. The air bag measured 50 cm (19.7 in) in width and 20 cm (7.9 in) in height (**Figure 7)**. There were no vent ports and the air bag was tethered by a horizontal panel that extended the length of the air bag 9 cm (3.5 in) above the bottom edge. There was no contact evidence or damage to the left side air bag.

Figure 7: Left side impact air bag.

The left IC air bag deployed from the left roof side rail. The IC consisted of a tubular air bag contained in a sling, forming a curtain type air bag. The IC air bag measured 198 cm (78 in) in length and 10 cm (3.9 in) in diameter and was attached to the A- and C-pillars providing complete longitudinal coverage across the length of the left side glazing. The sling held the air bag 14 cm (5.5 in) above the belt line at the front and rear seating positions. The air bag was located 24 cm (9.4 in) below the roof side rail at the front seating position and 22 cm (8.7 in) below the roof side rail at the rear seating position. The IC air bag was labeled with the number - 06063806. There was no occupant contact or damage to the left IC air bag. **Figures 8 and 9** depict the left IC air bag.

Figure 8: Left IC air bag at front left seating position.

Figure 9: Left IC air bag at the rear left seating position.

1996 Toyota Avalon

Exterior Damage

The front plane of the Toyota Avalon sustained moderate-severity damage from the impact with the BMW. The direct contact damage extended the full width of the front bumper. The front bumper fascia and bumper beam separated from the vehicle and were unavailable for inspection. A crush profile estimated from the location of the bumper mounting brackets and the damage to the chassis and radiator was documented along the full width of the front of the Toyota. **Figure 10** depicts this crush profile. The maximum crush measured 37 cm (14.6 in) and was located at C3, 45 cm (17.7 in) inboard of the left front bumper corner. The estimated crush profile was as follows: C1 = 22 cm (8.7 in), C2 = 34 cm (13.4 in), C3 = 37 cm (14.6 in), C4 = 33 cm (13 in), C5 = 28 cm (11 in), C6 = 19 cm (7.5 in). The CDC assigned for this impact was 01FDEW2.

Figure 10: Frontal damage to the Toyota.

2007 BMW 525i Occupant Demographics/Data

Driver Age/Sex:	39-year-old/Male
Height:	180 cm (71 in)
Weight:	93 kg (205 lb)
Eyewear:	None
Seat Track Position:	Rear-track, adjusted 2 cm (0.8 in) forward of full-rear
Manual Safety Belt Use:	3-point lap and shoulder belt
Usage Source:	Vehicle Inspection
Egress from Vehicle:	Assisted from vehicle by emergency personnel
Mode of Transport from Scene:	Not medically transported
Type of Medical Treatment:	None

Driver Injuries

Injury	Injury Severity (AIS 90/Update 98)	Injury Source
5 cm (2 in) abrasion on front aspect of top of left shoulder	Minor (790202.1,2)	Safety belt webbing
8 cm (3 in) contusion across lower abdomen	Minor (590402.1,4)	Safety belt webbing
5 cm (2 in) abrasion on outside of left elbow	Minor (790202.1,2)	Left side air bag

Injury	Injury Severity (AIS 90/Update 98)	Injury Source
Cervical strain	N/A (Interview injury not codable under AIS rules)	Impact force
Shoulder strain	N/A (Interview injury not codable under AIS rules)	Safety belt loading

Source of Injury Data – Driver interview

Driver Kinematics

The 39-year-old male driver was seated in an upright posture with the seat track adjusted 2 cm (0.8 in) forward of full-rear. He was restrained by the manual 3-point lap and shoulder belt system. The driver of the BMW detected the Toyota prior to the impact and initiated an avoidance action by braking and steering to the right.

The initial impact to the forward aspect of the left plane actuated the driver's retractor and buckle pretensioners and deployed the driver's frontal air bag, the left door-mounted side impact air bag, and the left IC air bag. In response to the 11 o'clock impact force, the driver initiated a forward and left trajectory within the front left seating position. He loaded the belt system and deployed air bags and rode down the force of the multiple event crash. His safety belt loading resulted in an abrasion to his left shoulder and a contusion across his abdomen. The driver's left elbow contacted and was abraded by the left side impact air bag. The driver stated that he sustained cervical strain and shoulder strain that manifested the following day. These injuries were attributed to the impact force and belt loading; however these injuries are not codeable under AIS rules since they were not medically verified. The combination of safety belt use and the deployment of multiple air bags prevented the driver from sustaining more serious injury.

The vehicle came to rest with its left side in close proximity to a group of trees. The driver was unable to open the front left or rear left doors and was unable to climb out of the disintegrated window due to the trees. According to the driver interview, police and emergency medical personnel arrived on-scene and advised the driver to remain in the vehicle. Emergency personnel pried open the front right door with a Hurst spreader and disintegrated the front right window in the process. The driver exited the vehicle under his own power after the door was opened.

The driver refused medical treatment at the scene and did not seek treatment at a later time. He treated the neck and shoulder pain with massage, rehabilitation stretching and exercise.

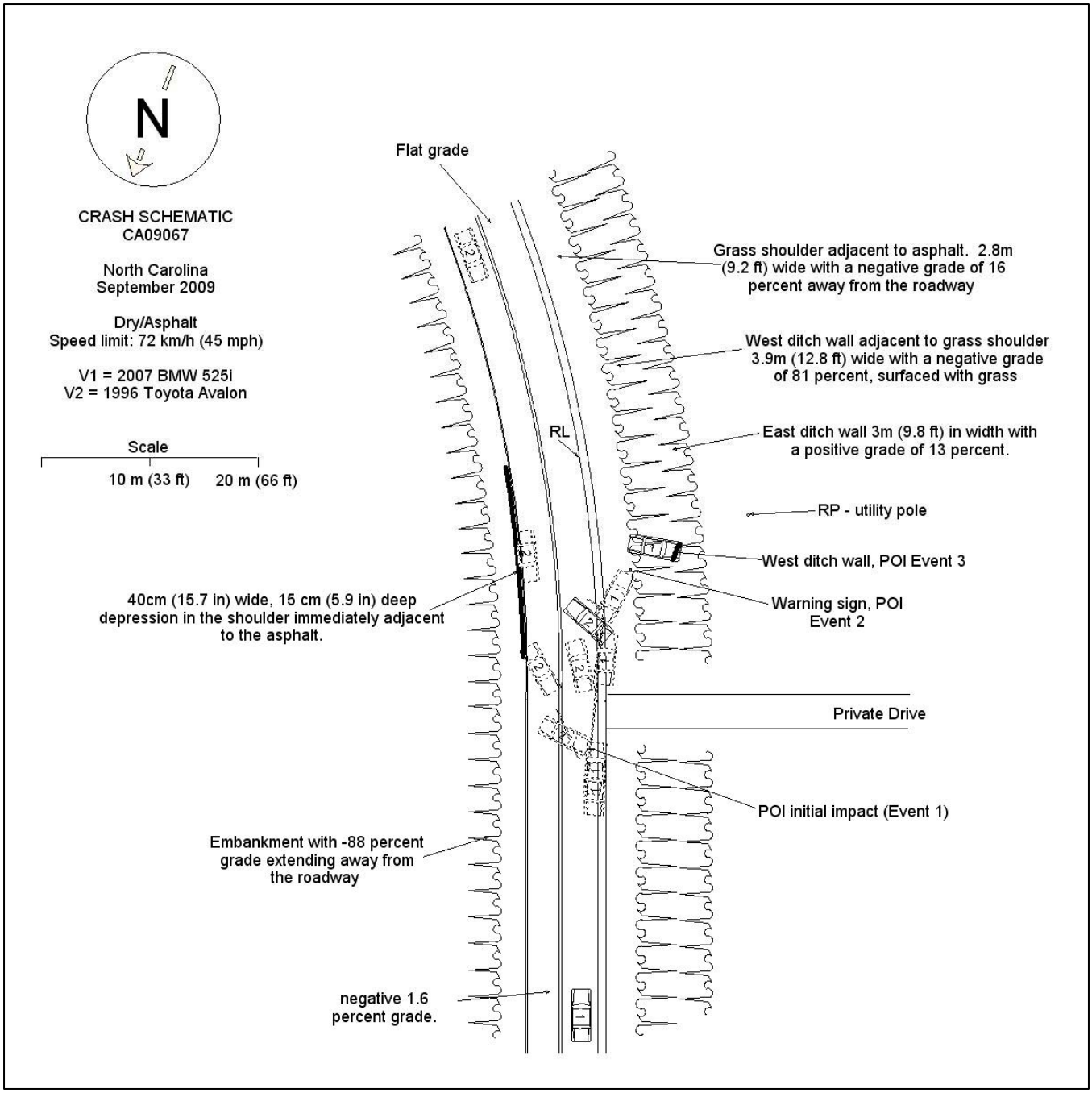

Figure 11: Crash Schematic