On-Site Side Air Bag Investigation
Dynamic Science, Inc. (DSI), Case Number DS09010
2007 BMW 335i Coupe
California
January 2009

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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 be 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 side air bag investigation focused on the dynamics and deployed air bags in a 2007 BMW 335i Coupe that was involved in a single vehicle crash. The crash occurred in January 2009 in the state of California. The subject vehicle was being driven by a 23-year-old female. The crash site was a raised median that separated a bus-only lane from a highway exit ramp. The BMW was traveling westbound on the highway exit ramp and the driver was negotiating a right curve. The vehicle departed the roadway to the left, entered the median, and after several minor impacts the right side of the vehicle impacted a tree. The vehicle came to rest facing northeast in an area of shrubbery. During the crash, the driver's frontal air bag and left and right inflatable curtain air bags deployed. The driver sustained moderate injuries including a cervical vertebra fracture. She was transported and treated at a local medical center, then arrested for driving under the influence of alcohol.

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Dynamic Science, Inc.
Crash Investigation
Case Number: DS09010

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Background

This on-site side air bag investigation focused on the dynamics and deployed air bags in a 2007 BMW 335i Coupe (**Figure 1**) that was involved in a single vehicle crash. The crash occurred in January 2009 in the state of California. The subject vehicle was being driven by a 23-year-old female. The crash site was a raised median that separated a bus-only lane from a highway exit ramp.

Figure 1. Subject vehicle, 2007 BMW 335i Coupe

The BMW was traveling westbound on the highway exit ramp and the driver was negotiating a right curve. The vehicle entered the raised median and after several minor impacts the right side of the vehicle impacted a tree. The vehicle came to rest on the median in an area of shrubbery.

The BMW was a Certified Advanced 208-Compliant (CAC) vehicle and was equipped with advanced dual stage frontal air bags, seat-mounted side air bags, side impact inflatable curtain (IC) air bags, and safety belt pretensioners. The frontal air bags were certified by the manufacturer to be compliant with the advanced air bag requirements of Federal Motor Vehicle Safety Standard (FMVSS) No. 208. During the crash, the driver's frontal air bag and left and right IC air bags deployed.

The driver sustained moderate injuries including a cervical vertebra fracture. She was transported and treated at a local medical center, and then arrested for driving under the influence of alcohol. The BMW was towed from the scene and later was declared a total loss by the insurance company.

This on-site side air bag investigation was initiated by the National Highway Traffic Safety Administration (NHTSA) during a review of General Estimates System (GES) police reports. On February 20, 2009, DSI was forwarded the police report with instructions to commence the investigation. DSI obtained permission to inspect the subject vehicle on March 3, 2009 and the case was assigned on March 4, 2009.

Summary

Crash Site

The crash site consisted of a raised median that separated a bus-only lane from a highway exit ramp. The exit ramp included two westbound lanes in its approach to the crash site. Approximately 22.9 m (75 ft) from the median, the exit ramp lanes split; the outboard lane curved right (west) and the inboard lane continued straight (south). The curve profile of the westbound lane decreased in radius as it approached the median. The median's eastern aspect marked the division of the exit ramp and the bus lane (**Figure 2**).

The westbound exit lane measured 5.1 m (16.6 ft) in width and was bordered on the north and south by solid white fog lines. A paved shoulder located north of the roadway measured 2.3 m (7.7 ft) in width and it was followed by an ascending grass-covered embankment. The median was located south of the roadway. The median was bordered on all sides by a raised concrete curb measuring 15 cm (5.9 in) in height. The east end of the median consisted of paved concrete and asphalt. The west end consisted of uneven ground, shrubbery, and trees.

Figure 2. Crash site showing approach to impact and skid marks

The roadway composition for the exit ramp was asphalt and it was dry at the time of the crash. The time of the crash was reported by police to be 0102 hours. Lighting conditions were dark with street lights illuminated and the weather was clear. The roadway profile was a negative 2.1 percent downhill grade. The posted speed limit for the state highway was 105 km/h (65 mph); there were no posted speed limit signs on the exit ramp.

Pre-Crash

The subject vehicle was traveling west and the driver was negotiating a right curve. Approximately 15 m (49.2 ft) from the median the driver braked hard with lockup. Two skid marks were documented on the roadway: a skid mark from the front left tire measured 15.2 m (49.9 ft) and a skid mark from the right front tire measured 15.7 m (51.5 ft). The skid marks were straight and terminated at the raised concrete curb (**Figure 3**).

Figure 3. Area of impact, Events 1 - 3

Crash

The front end of the BMW impacted a reflector post (Event 1) and the front tires impacted the raised concrete curb (Event 2). The reflector post composition was plastic and it was fractured and displaced from its mount. The left front tire impacted the curb with sufficient force to fracture the rim. Following Event 2, the vehicle's undercarriage impacted the concrete sidewalk (Event 3). The impact resulted in two scrape marks on the concrete measuring 1.5 m (4.9 ft) in length and 27 cm (10.6 in) apart. The scrape marks were parallel and consistent with the longitudinal trajectory of the vehicle. Following the undercarriage impact, the vehicle's rear tires contacted the curb resulting in a rim fracture to the left rear rim (Event 4).

Another group of scrape marks deposited by the undercarriage and left side rims began 1.5 m (4.9 ft) from the curb and measured 4.9 m (16.1 ft) in length. A group of scrape marks further to the

right began 3.4 m (11.1 ft) from the curb and measured 87 cm (34 in) in length. The marks were parallel and consistent with the longitudinal trajectory of the vehicle. Both groups of scrape marks ended at the transition between the concrete sidewalk and an asphalt and gravel surface.

Figure 4. Impacted tree, Event 5

The BMW traveled across the sidewalk for a distance of 6.7 m (22 ft), then traveled over a section of asphalt and gravel for a distance of 16.2 m (53 ft). The surface then changed from asphalt to uneven ground that was planted with grass, shrubbery, and trees. The vehicle traveled over an area of ground with a 2 percent downhill grade and then impacted a row of five shrubs measuring 34.1 m (111.9 ft) in length (Event 5). The contact damage to the vehicle was located at the front end, undercarriage, and left and right side tires.

After contacting the shrubbery the vehicle traveled for an additional 5 m (16.4 ft) and its right side impacted a tree (Event 6) (**Figure 4**). The direct damage to the vehicle was located on the passenger and rear sections including the right rear tire. The tree trunk measured 30.5 cm (12 in) in diameter at the area of impact. The impacted area was determined based on stripped bark and gouges on the tree trunk. The vertical extent of the damaged area began at the ground and extended upward 134 cm (52.8 in). The tree trunk was not cracked or bent; however, three limbs were fractured and detached near the upper aspect of the impacted area.

Following the tree impact, the vehicle initiated a clockwise rotation and was redirected approximately 30 degrees to the right. The vehicle traveled in a generally straight path for approximately 20 m (65.6 ft) over an area of ground and shrubbery that were flattened by the impact (Event 7). The vehicle rotated clockwise approximately 150 degrees, then came to rest facing east. From the reflector post impact (Event 1) to final rest, the vehicle traveled a distance of 83 m (272.3 ft).

The driver estimated her pre-crash travel speed to be between 72 - 89 km/h (45 - 55 mph). Based on the estimated speed range and the distance traveled from the first impact to final rest, the elapsed time of the crash sequence was approximately 4.1 - 3.3 seconds.[1]

For the tree impact (Event 6), the Barrier algorithm of the WinSMASH program computed a Total Delta-V of 19 km/h (11.8 mph); the longitudinal and lateral components were -18 km/h (-11.2 mph) and -6 km/h (-3.7 mph), respectively. Based on the BMW's crush profile and the vehicle's post impact trajectory, the results appear reasonable**.**

[1] Time = Distance/1.466 x Speed

Post-Crash

The driver exited through the vehicle's left front door under her own power and traveled on foot to the exit ramp, which was 13.4 m (44 ft) from the vehicle at its nearest point. A fire truck was dispatched to the scene and a fireman reportedly observed the driver running down the exit ramp toward the fire truck. The driver was transported by ground ambulance and arrived at a local medical center 52 minutes post-crash at 0154 hours. The driver's medical records did not report her Glasgow Coma Score, but stated that her sensory examination was normal. Her injuries included a cervical vertebra fracture (C7), cerebral concussion, right forearm abrasion, and unspecified contusions. The driver was treated in the emergency room, then admitted at 0641 hours due to her blood-alcohol concentration (BAC). According her medical records, she remained in the hospital for the next thirty-three hours and was then discharged. During the interview, the driver stated with certainty that she was hospitalized for five days, then discharged.

The driver received follow-up treatment for her head and neck injuries. Following her discharge from the hospital, she was examined twice by a private physician to monitor her concussion and associated memory loss. One week after her discharge, she was examined by a private physician to treat her C7 fracture and prescribe additional medication. She wore a rigid neck brace for 10 weeks, after which time she was again examined and her vertebral injury was determined to be fully healed. The driver did not undergo any physical or mental therapy but had to refrain from high impact activities for six months after the crash. Prior to the crash she was working and attending school full time. Due to her limited mobility she quit working until her neck injury healed. She was on a short break from school at the time of the crash and had recovered sufficiently to attend classes when they resumed.

The BMW was towed from the scene due to damage and was later declared a total loss by the insurance company.

Vehicle Data

The 2007 BMW 335i Coupe was identified by the Vehicle Identification Number (VIN): WBAWB73527Pxxxxxx. The vehicle's date of manufacture was June 2006. Based on auction facility photographs, the vehicle's odometer reading was 63,539 km (39,481 mi). The vehicle was equipped with a 3.0-liter, 6-cylinder engine, manual 6-speed transmission, rear wheel drive, power steering, power brakes, tilt and telescopic steering functionality, 4-wheel anti-lock disc brakes, low pressure tire warning, and fully automatic exterior lighting control with daytime lights. The fuel system was configured a single non-metallic fuel tank.

The vehicle manufacturer recommended P225/40R18 tires for the front and P255/35R18 tires for the rear, with a front tire pressure of 228 kPa (33 psi) and a rear tire pressure of 241 kPa (35 psi). The vehicle was equipped with Falken FK452 P225/40ZR18 tires on the front and Falken FK452 P255/35ZR18 on the rear. All the tires had a tire manufacturer's recommended maximum tire pressure of 345 kPa (50 psi). The specific tire information was as follows:

Position	Measured Pressure	Measured Tread Depth	Restricted	Damage
LF	Tire flat	6 mm (8/32 in)	No	Sidewall and tread cut and abraded, de-beaded
LR	Tire flat	5 mm (6/32 in)	No	De-beaded
RR	159 kPa (23 psi)	6 mm (8/32 in)	Yes	None
RF	200 kPa (29 psi)	6 mm (8/32 in)	No	None

The BMW's interior was configured with seating for four occupants. The front row seating consisted of leather-covered bucket seats that were equipped with folding backs and adjustable head restraints. The head restraints had the capacity to pivot for and aft in response to a shift in occupant posture; however, the feature was not an active head restraint. The second row seating consisted of a leather-covered bench seat with separate backs and adjustable head restraints. A center console with a fold-down armrest separated the second row seats.

Vehicle Damage

Exterior Damage

The BMW sustained direct and induced damage to the front end, left and right sides, and undercarriage. Event 1 was a front end impact to a yielding reflector post. The damage to the vehicle was masked by subsequent impacts and was not determined. The estimated CDC for the first impact was 12FLEN1.

Event 2 was a curb impact resulting in direct and induced damage to the vehicle's left front tire and rim. The rim sustained three fractures and a 4 x 17 cm (1.6 x 17 in) section of the rim was displaced. The tire sustained a cut beginning on the sidewall and extending across the tread as a result of contact with the fractured rim. The Collision Deformation Classification (CDC) for Event 2 was 12FLWN3.

After the Event 2, the vehicle sustained an undercarriage impact to the concrete sidewalk (Event 3). The impact was horizontal and resulted in surface scratches and minor crush to the undercarriage at the forward aspect. The CDC for Event 3 was 12UFCW2.

Event 4 was a frontal impact of the rear tires to the curb and involved direct and induced damage to the vehicle's left rear tire and rim. The rim sustained a circumferential fracture and the outboard flange was separated from the well. The rim sustained a second fracture at the outboard flange between two spokes. The CDC for Event 4 was 12FLWN9.

Event 5 consisted of a frontal impact of the vehicle's front bumper to shrubbery. The direct damage to the front end began at the front left bumper corner, extended 164 cm (64.6 in) to the right, and ended at the front right bumper corner. The damage consisted of surface scratching to the bumper fascia with no residual crush damage. Scene evidence consisted of tire furrows in the ground and damaged shrubbery. Possible damage to the vehicle's tires and undercarriage in Event 5 was masked

by prior or subsequent damage and was not be determined. The CDC for the Event 5 was 12FDLW1.

Figure 5. Right side crush profile measurement

Event 6 consisted of a tree impact resulting in direct damage and induced damage to the right side of the vehicle. The right rear tire was contacted resulting in a negative 15 degree camber. Additionally, the wheelbase was lengthened by 19 cm (7.5 in) and the tire was restricted. The direct damage began 14 cm (5.5 in) forward of the rear axle, extended forward 210 cm (82.7 in), and ended 2 cm (0.8 in) aft of the A-pillar. The Field L began at the rear axle, extended forward 226 cm (89 in), and ended at the A-pillar. The vertical extent of direct damage began at the sill and extended upward 104 cm (41 in) to the roof side rail. The maximum lateral crush to the roof side rail measured 11 cm (4.3 in), and was located 88 cm (34.7 in) forward of the rear axle, just aft of the B-pillar. Six crush measurements were taken at mid-door level (**Figure 5**) as follows: C_1 = 0 cm, C_2 = 20 cm (7.9 in), C_3 = 18 cm (7.1 in), C_4 = 13 cm (5.1 in), C_5 = 5 cm (2.0 in), C_6 = 0 cm. Maximum lateral crush measured 20 cm (7.9 in) and was located 42 cm (16.5 in) forward of the rear axle at C2. The CDC for Event 6 was 01RZAW2.

The vehicle contacted more shrubbery in its path to final rest. The vehicle was rotating clockwise, the plane of initial contact was the front end, and the damage extended to the undercarriage. The lower bumper and forward undercarriage exhibited evidence of contact in the form of surface scratches. The scene evidence included tire furrows on the ground and damaged shrubberies. The estimated CDC for Event 7 was 99F9LU1.

The BMW sustained damage resulting from post-crash salvage activities where the sheet metal of the right rear quarter panel was cut away in order to access the vehicle's battery.

Interior Damage

The BMW sustained moderate interior damage as a result of passenger compartment intrusion, occupant loading, and contacts during the crash. The right side door panel was jammed shut and the front row left and right side windows were disintegrated. Lateral intrusion was documented at the right side at the roof side rail, door panel, B-pillar, sill, and front row seat back. Vertical intrusion was documented at the front row passenger seat cushion, and longitudinal intrusion was documented at the front row passenger seat back. The seat back was deformed by the intruding B-pillar and was displaced forward. The recline adjustment mechanism was determined to be intact and there was no fore/aft or lateral movement of the seat. The intruding right side door panel and B-pillar were tight against the seat back at the time of the vehicle inspection.

The driver's frontal air bag, left IP, and left door panel exhibited evidence of loading and contact in the form of transfers and scuffs.

Manual Restraints

The BMW was equipped with 3-point manual lap and shoulder safety belts for the front row seat positions. The safety belts were configured with sliding latch plates, non-adjustable D-ring anchorages, and buckle pretensioners. The D-rings rotated up to 30 degrees fore and aft from their neutral position to enhance their functionality. Additionally, the front row was equipped with automatic safety belt handovers, which were located on the left and right side panels.[2] The driver's safety belt was equipped with an Emergency Locking Retractor (ELR). The front right position safety belt was equipped with an ELR/Automatic Locking Retractor (ALR). Both latch plates were scratched indicating historical usage.

No loading evidence to the driver's safety belt was observed to either the upper anchorage assembly, belt webbing, or latch plate. The safety belt buckle stalk measured 21 cm (8.3 in) which was its original length and the pretensioner did not actuate. None of the driver's injuries were attributed to safety belt restraint loading. According to the driver's medical records and the interview, the driver indicated that she was amnestic and could not recall if she was restrained at the time of the crash. Based on the vehicle inspection, medical records, and driver kinematics, it was determined that the driver was unrestrained at the time of the crash.

The front right safety belt was found in the stowed position and the webbing would not unspool from the retractor. It was determined that the belt was fixed in place due to the intruding B-pillar and its effect upon the safety belt retractor. The safety belt buckle was entrapped between the seat cushion and center console and was not visible or accessible.

The second row seats were equipped with 3-point manual lap and shoulder belts. The safety belt retractors were integrated in the seat back and the belts were configured with switchable ELR/ALR retractors. The safety belt latch plates exhibited no evidence of historical usage.

Supplemental Restraint Systems

The BMW's Supplemental Restraint System (SRS) included driver and passenger frontal air bags, IC air bags, seat-mounted side air bags, and safety belt buckle pretensioners with force limiters for the front row. The driver stated during the interview that the air bags were original to the vehicle and had not been serviced or replaced prior to the incident. The driver purchased the vehicle new and it had sustained no damage prior to the crash.

The BMW was a CAC vehicle equipped with advanced dual-stage frontal air bags. The driver's air bag deployed from the steering wheel hub (**Figure 6**) during the tree impact (Event 5), which resulted in the highest Delta-V of the six documented events. The module cover flaps opened at their tear points and were not damaged. The frontal air bag was round in shape and measured 60 cm (23.6 in) in diameter. It was configured with two vent ports measuring 2 cm (0.8 in) in diameter on

[2] Source: www.bmw.com; Electric seat belt handovers for the driver and front passenger facilitate reaching for the seat belt after entering the car, regardless of seat position and backrest angle.

the upper back panel and no internal tethers.

A 4 x 5 cm (1.6 x 2.0 in) area of dark-colored scuffs were located in the lower right quadrant near the seam. The source of the scuffs was probably from the driver's clothing when she loaded the air bag. The driver sustained a right forearm abrasion consistent with frontal air bag loading.

Figure 6. Deployed left frontal air bag

The vehicle's left and right IC air bags deployed from the roof side rails over the front doors and rear side panels at impact with the tree (**Figure 7**). The IC air bags measured 168 cm (66.1 in) in length and 36 cm (14.2 in) in height. They were configured without vent ports or tethers. The left IC air bag exhibited a horizontally oriented tear on its outboard panel measuring15 cm (5.9 in) in length. The tear was located 20 cm (7.9 in) forward of the left B-pillar and 20 cm (7.9 in) above the bottom edge of the air bag, and the damage was confined to the outboard panel. The source of the tear was probably from the side glass during the tree impact. The glass from the left side window disintegrated and was displaced to the right in response to the direction of force. There was no evidence of occupant loading or other damage to the inboard panel. The right IC air bag was identical in size and configuration to the left IC air bag and was unremarkable.

Figure 7. Deployed left IC air bag

The right passenger frontal air bag was located in the top instrument panel and did not deploy. The vehicle was equipped with an occupant sensor and indicator light for the passenger air bag. The front row seat-mounted side air bags were located in the outboard aspect of the seat backs and did not deploy.

Occupant Demographics

	Driver
Age/Sex:	23/Female
Height:	170 cm (67 in)
Weight:	59 kg (130 lb)
Seat Type:	Bucket
Seat Track Position:	Middle track
Manual Restraint Usage:	Lap and shoulder belt not used
Restraint Usage Source:	Vehicle inspection
Air Bag:	Frontal air bag, deployed; IC air bag, deployed; seat-mounted side air bag, not deployed
Eyewear:	None
Alcohol/Drug Involvement:	BAC: 0.247 %, drug screen was positive for opiates, however, drug screen was administered after driver had been given morphine for pain.
Type of Medical Treatment	Transported, admitted for one day, released

Occupant Kinematics

Driver

The 23-year-old female driver was seated in an unknown posture and was unrestrained. She was not wearing contact lenses or eyewear. According to the driver's medical records, she could not remember her seat position in the vehicle, yet she estimated her pre-impact speed to be 72 - 88 km/h (45 - 55 mph). The driver stated during the interview that she could not recall her seat adjustment settings or her hand and foot positions prior to impact. Based on her height and the vehicle inspection, her seat track was near the middle position and her seat back was slightly reclined. Based on her estimated speed, evidence of braking with lockup, and the pre-crash path of the vehicle, it was determined that the driver was actively steering the vehicle and her right foot was initially on the accelerator. As she negotiated a right curve, she moved her right foot from the accelerator to the brake pedal, resulting in lockup. The vehicle's front tires deposited skid marks that ended at the point of the curb impact.

In rapid succession, the vehicle's front end impacted a yielding reflector post, the front tires impacted the raised concrete curb, the undercarriage impacted the sidewalk, the rear tires impacted the curb, and the left side tires flattened. These were low Delta-V events of less than 10 km/h (6.2 mph), but since the driver was unrestrained she was displaced forward and upward in response to the direction of force and vertical displacement of the vehicle.

The BMW continued traveling in a straight path over ground and shrubbery. Due to the unevenness of the terrain, the vehicle was bouncing slightly and the undercarriage intermittently contacted the ground and shrubbery. The driver was displaced vertically in a bouncing type motion in response to the vehicle's movement. The right side of the vehicle then impacted a large tree. The forces acting upon the vehicle were more longitudinal than lateral. The right rear tire snagged on the tree resulting in further longitudinal deceleration and the vehicle initiated a clockwise rotation.

At impact with the tree, the driver's frontal air bag and IC air bag deployed. The driver was displaced forward and right in response to the 1 o'clock direction of force. She sustained a C7 spinal fracture from an unknown source. The driver's medical records indicated she was amnesic and the memory loss was attributed to a cerebral concussion. Additionally, the driver's right forearm contacted the deployed frontal air bag resulting in an abrasion.

Two scuffs were documented on the lower quadrant of the steering wheel rim that measured 1 cm (0.4 in) and 2 cm (0.8 in) in length and 1 cm (0.4 in) apart. The scuffs resulted from the driver's pelvis or torso loading the air bag, which in turn contacted the steering wheel rim.

The driver's left knee contacted the lower left IP depositing a tan-colored deposit and scuff measuring 3 x 3 cm (1.2 x 1.2 in). Ten cm (3.9 in) to the left of the scuff was a white transfer measuring 1 x 2 cm (0.4 x 0.8 in). The contact was located 4 cm (1.6 in) inboard of the left edge of the IP at the lower aspect and its source was unknown. A third contact to the lower left IP was documented at 5 cm (2.0 in) lateral right of the steering column. This contact comprised a scuff that measured 3 x 5 cm (1.2 x 2.0 in), was light in color, and was oriented vertically. The probable source was the driver's right knee. The driver's medical records did not document any specific injuries to her lower extremities, but did note multiple unspecified contusions.

The driver's left foot contacted the lower forward quadrant of the left door panel depositing a V-shaped scuff and 4 small gouges with an area that measured 10 x 13 cm (4 x 5 in). The flow of the damage indicated that the foot was displaced forward and upward while in contact with the door panel.

The driver's left shoulder loaded the left door panel in the rear upper quadrant depositing a white-colored scuff that measured 2 x 4 cm (0.2 x 1.2 in).

After the tree impact, the vehicle maintained a clockwise rotation and its trajectory was redirected to the left. During this phase the driver was displaced to the left in response to the vehicle's trajectory. The vehicle rotated 150 degrees while traveling over ground and shrubbery. Additionally, the vehicle was displaced vertically in response to the uneven ground.

The vehicle came to final rest on level ground and facing northeast. The driver exited the vehicle without assistance through the left side door. She walked a minimum distance of 13.4 m (44 ft) to the roadway and was then assisted by rescue personnel.

Occupant Injuries

Driver

The injury data was obtained from the driver's medical records.

Injury	OIC Code	Injury Mechanism	Confidence Level
Fracture, cervical spine, C7, involving spinous process, facet and lamina	650224.3,6	Unknown	Unknown
Cerebral Concussion	161000.2,0	Unknown	Unknown
Abrasion, right forearm	790202.1,1	Air bag	Probable
Multiple contusions NFS	990400.1,9	Unknown	Unknown

Attachment 1. Scene Diagram