TRANSPORTATION SCIENCES
CRASH DATA RESEARCH CENTER

Veridian Engineering
Buffalo, NY 14225

ON-SITE SIDE IMPACT OCCUPANT PROTECTION SYSTEM CRASH INVESTIGATION
SCI TECHNICAL SUMMARY REPORT

VERIDIAN CASE NO. CA01-048

VEHICLE - 1999 BMW 328i

LOCATION - STATE OF NEW JERSEY

CRASH DATE - OCTOBER 2001

Contract No. DTNH22-01-C-17002

Prepared for:

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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 performance of the side impact occupant protection system in a 1999 BMW 328i. The BMW was occupied by a 22-year-old male driver and a 21-year-old female front right passenger who were both restrained. The driver of the BMW lost control of the vehicle on the outboard lane of a divided state highway. The vehicle departed the right roadside in a counterclockwise (CCW) yaw and struck a luminaire with a frangible base with the right rear door area. The luminaire fractured at the base and the impact was sufficient to deploy the right front passenger's side air bag and the front right passenger's Head Protection System (HPS) which utilized Inflatable Tubular Structures (ITS). The occupants initiated lateral trajectories to the right and loaded the manual restraints. The front right passenger contacted the deployed right side HPS and the deployed right front passenger's side air bag which offered protection from the right side impact. The vehicle's rotation was redirected to clockwise (CW) around the pole, as the BMW's center of gravity was forward of the impact. The BMW rotated CW and the left rear wheel struck the raised curb on the right roadside. The secondary left side impact was sufficient to deploy the left side HPS and driver's side air bag. The occupants were deflected to the left and loaded the manual restraints. The driver contacted the deployed left side HPS and the deployed driver's side air bag which offered protection from the side impact. The BMW came to rest on the roadside. Neither occupant was injured, and both refused medical treatment at the scene.			
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TABLE OF CONTENTS

ON-SITE SIDE IMPACT OCCUPANT PROTECTION SYSTEM INVESTIGATION
SCI SUMMARY TECHNICAL REPORT
VERIDIAN CASE NO. CA01-048
SUBJECT VEHICLE - 1999 BMW 328i
LOCATION - STATE OF NEW JERSEY
CRASH DATE - OCTOBER 2001

BACKGROUND

Figure 1. Damaged 1999 BMW 328i

This on-site investigation focused on the performance of the side impact occupant protection system in a 1999 BMW 328i **(Figure 1)**. The BMW was occupied by a 22-year-old male driver and a 21-year-old female front right passenger who were both restrained. The driver of the BMW lost control of the vehicle on the outboard lane of a divided state highway. The vehicle departed the right roadside in a counterclockwise (CCW) yaw and struck a luminaire with a frangible base with the right rear door area. The luminaire fractured at the base and the impact was sufficient to deploy the right front passenger's side air bag and the front right passenger's Head Protection System (HPS) which utilized Inflatable Tubular Structures (ITS). The occupants initiated lateral trajectories to the right and loaded the manual restraints. The front right passenger contacted the deployed right side HPS and the deployed right front passenger's side air bag which offered protection from the right side impact. The vehicle's rotation was redirected to clockwise (CW) around the pole, as the BMW's center of gravity was forward of the impact. The BMW rotated CW and the left rear wheel struck the raised curb on the right roadside. The secondary left side impact was sufficient to deploy the left side HPS and driver's side air bag. The occupants were deflected to the left and loaded the manual restraints. The driver contacted the deployed left side HPS and the deployed driver's side air bag which offered protection from the side impact. The BMW came to rest on the roadside. Neither occupant was injured, and both refused medical treatment at the scene.

This crash was found by the Veridian SCI team during conversation with a tow operator regarding a separate crash. The tow operator indicated that the BMW was at their facility and that all of the side impact occupant protection systems had deployed due to a right side impact. Notification was forwarded to NHTSA and an on-site effort was assigned to the Veridian SCI team on Thursday, November 1, 2001. Contact with the investigating police agency was established. A police crash report was obtained subsequent to the on-site field activities. The crash location and vehicle information was confirmed verbally with the investigating agency. A partial interview with the driver was obtained following the field investigation, and after subsequent attempts to complete the interview the driver stated that he was unwilling to further cooperate.

SUMMARY

Crash Site

This single-vehicle crash occurred during the nighttime hours of October 2001 on the eastbound lane of a left curve on a six-lane divided highway. The luminaire was located on the right roadside east of an exit ramp. At the time of the crash, the weather was cloudy and the asphalt roadway surface was wet from a previous rainfall. The roadway was lighted by luminaires located on the south roadside. The east/west roadway was configured with three travel lanes in each direction that were separated by a curbed median barrier. The roadside environment consisted of raised curbs, grassy areas, and trees. The posted speed limit for the roadway was 89 km/h (55 mph). The police scene diagram in included as **Figure 15** on page 10 of this report.

Pre-Crash

The 22-year-old driver of the BMW 328i was operating the vehicle on the outboard lane of a six-lane divided highway **(Figure 2)** and a driver-estimated speed of 89 km/h (55 mph). The driver stated that due to wet road conditions, the rear aspect of the vehicle began to rotate. Although the BMW was equipped with All Season Traction control, the BMW initiated a counterclockwise (CCW) yaw. The driver attempted to regain control of the vehicle through right steer inputs and by applying the brakes, but was unsuccessful. The BMW departed the right roadside in a CCW yaw.

Figure 2. Eastbound approach for the BMW

Crash

The BMW 328i struck a luminaire with a frangible base **(Figure 3)** with the right rear door area. The direction of force was in the 3 o'clock sector. The impact fractured the luminaire at the base. Due to the yielding nature of the luminaire, the impact was out of the scope of the WinSMASH program. An estimated delta-V based on the damage to the BMW was approximately 13 - 16 km/h (8 - 10 mph). The impact was sufficient to deploy the right front passenger's side air bag and the right side HPS. The impact to the BMW was located behind the vehicle's center of gravity which reversed the rotation to CW. The BMW rotated in a CW direction around the pole and caused the luminaire to fracture from its base. The left rear wheel struck the raised concrete curb on the right roadside as the BMW had rotated 180 degrees in a CW direction. The direction of force for the secondary impact to the left rear wheel was in the 9 o'clock sector. The impact to the left rear wheel resulted in the deployment of the left front driver's side air bag and the left side HPS system.

Figure 3. Eastbound view showing replaced luminaire at the crash scene

Post-Crash

The 22-year-old male driver exited the vehicle under his own power through the left front door. It was not known how the 21-year-old female front right passenger exited the vehicle. Neither occupant sustained injury.

VEHICLE DATA - 1999 BMW 328i

The 1999 BMW 328i was identified by the Vehicle Identification Number: WBAAM5337XF (production sequence omitted). There was no power to the vehicle and the electronic odometer could not be read. The BMW 328i was a four-door sedan and was equipped with a 2.8 liter, 6 cylinder engine, a five-speed automatic transmission, All Season Traction control, four-wheel anti-lock disc brakes with electronic front/rear proportioning and Cornering Brake Control, variable-assist power rack and pinion steering, a tilt/telescoping steering wheel with fingertip cruise control and audio controls, keyless entry, power moonroof, power windows, power door locks, and rain-sensing windshield wipers. The BMW was also configured with a door anchoring system which had a reinforcing bar with a hook-like member within each door. In a side impact crash, the reinforcing bar was designed to hook the door to the body to preserve the passenger compartment integrity.

The BMW 328i was configured with a 10-way power adjustable leather front bucket seats with adjustable head restraints. A rear bench seat with split folding backs was equipped with an integrated fold-down arm rest. The rear seat integrated arm rest also incorporated a locking center pass-through space with an attached nylon ski bag. The electronic front left seat was adjusted to 10.8 cm (4.3") forward of full rear and 12.1 cm (4.8") rear of full forward with a total travel distance of 22.9 cm (9.0"). The front left seat back was reclined 30 degrees from vertical, and the adjustable head restraint was raised 2.5 cm (1.0") above the seat back and rotated 30 degrees forward from vertical. The electronic front right seat was adjusted to 12.7 cm (5.0) forward of full rear and 10.2 cm (4.0") rear of full forward with a total travel distance of 22.9 cm (9.0"). The front left seat back was reclined 35 degrees from vertical, and the adjustable head restraint was raised 5.1 cm (2.0") above the seat back and rotated 15 degrees rearward of vertical. Both front seat backs retained their pre-crash orientation.

The rear bench seat back was configured with adjustable head restraints for the outboard positions. The rear left head restraint was raised 1.9 cm (0.8") above the seat back and the rear right head restraint was full-down.

The BMW 328i was equipped with dual-stage advanced frontal air bags for the driver and front right passenger positions, door-mounted side impact torso air bags for the driver and front right passenger positions, and a HPS consisting of inflatable tubular structures (ITS) for the front left and front right passenger positions.

The driver of the BMW 328i stated that the vehicle had been involved in a previous crash approximately one year earlier. The driver of the BMW lost control of the vehicle upon exiting a tunnel and the right rear aspect of the BMW impacted the edge of the tunnel porthole. The side impact occupant protection system

in the BMW did not deploy in that crash. The driver expressed concern regarding the non-deployment event, and was advised by BMW that the impact was not located close enough to the side impact sensor to deploy the side impact occupant protection system. The driver reported that the vehicle had been repaired after the previous crash.

VEHICLE DAMAGE

Exterior Damage - *1999 BMW 328i*

The 1999 BMW 328i sustained moderate right side damage as a result of the luminaire impact **(Figure 4)**. The direct damage began 33.0 cm (13.0") aft of the leading edge of the right rear door and extended 48.3 cm (19.0") rearward. The height of the direct damage measured 80.0 cm (31.5") from the right sill to the top aspect of the door panel. The combined direct and induced damage began at the leading edge of the right rear door and extended rearward 194.9 cm (76.8") to the right rear bumper corner. The outline of the luminaire's frangible base was evident on the lower right aspect of the right rear door panel **(Figure 5)**. The maximum crush was located 39.1 cm (15.4") aft of the leading edge of the right rear door at C2, and measured 19.1 cm (7.5") along the mid-level trim area. The maximum crush along the right sill was located 34.3 cm (13.5") aft of the leading edge of the right rear door and measured 22.9 cm (9.0"). The right rear door panel was crushed laterally from the side impact. The mid-door trim (rub strip) was separated from the door and the sill trim was separated at the leading edge of the right rear door. The right rear door was abraded and deformed in the shape of the frangible base, and exhibited a 7.6 cm (3.0") vertical laceration in the door panel located 1.3 cm (0.5") aft of C2 and 2.5 cm (1.0") above the mid-door trim line. The leading edge of the right rear quarter panel was abraded from direct contact. Grass and dirt were deposited on the partially separated sill trim and were present in the right rear fender. The entire right rear door was displaced slightly due to the lateral crush and induced buckling and was jammed shut. The right front door sustained minor displacement from induced damage, but remained operational. The right rear wheel was displaced slightly CCW from direct contact to the forward aspect of the wheel. The Collision Deformation Classification for the impact to the luminaire was 03-RPEW-2. Six crush measurements were documented at the mid-door level and were as follows: C1 = 0.0 cm, C2 = 18.4 cm (7.3"), C3 = 9.5 cm (3.8"), C4 = 5.7 cm (2.3"), C5 = 3.2 cm (1.3"), C6 = 2.5 cm (1.0").

Figure 4. View of direct and induced right side damage from the luminaire impact

Figure 5. Direct damage showing outline of the luminaire's frangible base

The BMW 328i sustained left rear wheel damage as a result of the secondary curb impact **(Figure 6)**. The edge of the left rear wheel was heavily abraded from the lateral contact with the curb. The wheel and tire were coated with dirt and grass. Although the left rear suspension was damaged and the left rear aspect of the BMW was riding low on the left rear wheel, the wheel was not restricted. The rear aspect of the vehicle was shifted to the left slightly from the lateral force of the impact. The left rear quarter panel overlapped the outboard edge of the left rear wheel 9.5 cm (3.8"). An exemplar vehicle exhibited a 2.5 cm (1.0") overlap of the quarter panel. The sill trim was separated from the vehicle and the left rear door panel exhibited longitudinal abrasions on the mid-door area that measured 3.8 cm (1.5") in height. The CDC for the secondary impact was 09-LBWN-2.

Figure 6. View of left side damage

Interior Damage - *1999 BMW 328i*

Interior damage to the BMW 328i was minor and was attributed to passenger compartment intrusion **(Figure 7)**. The glazing in the rear right door was disintegrated from impact forces. The remaining glazing and windshield laminate was not damaged. The speaker cover on the forward aspect of the lower right front door was partially separated, although it could not be confirmed as resulting from occupant contact. The rear bench seat cushion was separated from the seat brackets at the time of the vehicle inspection. The right rear door had intruded into the rear right occupant space as a result of the side impact with the luminaire. The maximum lateral intrusion in to the rear right occupant space measured 7.6 cm (3.0") at the sill.

Figure 7. View of rear seat area showing the right rear door intrusion

Intrusions were documented and were as follows:

Position	Intruded Component	Intruded Value	Direction
23	Right rear door	4.5 cm (1.8")	Lateral
23	Right rear sill	7.6 cm (3.0")	Lateral

MANUAL RESTRAINT SYSTEM - 1999 BMW 328i

Figure 8. View of driver's lap and shoulder belt

The front seat positions in the 1999 BMW 328i were equipped with manual 3-point lap and shoulder belts with sliding latch plates and inertial lock/belt sensitive retractors. The front right lap and shoulder belt was also equipped with a switchable/automatic locking retractor (ALR). Both front seat manual restraints were also configured with buckle pretensioners which did not deploy as a result of the crash. The non-deployed pretensioner piston measurement was 6.4 cm (2.5") to the forward edge of each canister. At the time of the vehicle inspection, the front seat height adjustments were adjusted to positions where the driver's buckle height measured 10.2 cm (4.0") above the driver's seat cushion, and the front right buckle height measured 7.6 cm (3.0") above the front right seat cushion. The front seat manual restraints were configured with integrated adjustable D-rings. Both D-rings were found in the full-up position and the total vertical travel measured 7.6 cm (3.0"). The driver's and front right passenger's latch plates exhibited routine wear marks consistent with frequent usage. The driver's sliding latch plate also exhibited subtle abrasions on the rear aspect that were consistent with occupant loading against the manual belt webbing. The driver's shoulder belt webbing showed stretching that began approximately 12.7 cm (5.0") above the latch plate and continued upward along the shoulder belt **(Figure 8)**. The front right shoulder belt also exhibited stretching that began at the latch plate and continued upward along the shoulder belt.

The rear seat was configured with manual 3-point lap and shoulder belts with sliding latch plates and switchable/ALR, inertial lock/belt sensitive retractors for the outboard positions. The rear center position was equipped with a manual lap belt with a locking latch plate.

FRONTAL AIR BAG SYSTEM - 1999 BMW 328i

The 1999 BMW 328i was equipped with dual-threshold advanced frontal air bags for the driver and front right passenger positions. The front right seat cushion contained a sensor mat which detected seat occupancy. The driver's air bag module was located in the center of the steering wheel and the front right passenger's air bag was located in a mid-mount module on the right instrument panel. The frontal air bag system did not deploy as a result of the crash.

SIDE IMPACT OCCUPANT PROTECTION SYSTEM - 1999 BMW 328i

The 1999 BMW 328i was equipped with a side impact occupant protection system that included driver's and front right passenger's side torso air bags and driver's and front right passenger's HPS. Both the driver's and front right passenger's side air bags deployed, as well as both side HPS. Based on the crash

events, it was likely that the front right passenger's side air bag and HPS deployed as a result of the luminaire impact and the driver's side air bag and HPS deployed as a result of the secondary impact with the curb. The side impact occupant protection system utilized sensors located on the outboard aspects of the lower B-pillars.

Figure 9. Driver's door-mounted side air bag

The driver's side air bag deployed from a left front door-mounted module that was located above the driver's arm rest **(Figure 9)**. The module was configured with a single cover flap that was rectangular in shape and followed the contour of the interior door panel **(Figure 10)**. The cover flap measured 25.4 cm (10.0") in length and 12.1 cm (4.8") in height. The driver's side air bag measured 40.6 cm (16.0") in length, 17.8 cm (7.0") in height at the rear aspect, and 14.0 cm (5.5") in height at the forward aspect. The air bag was not tethered internally, and was not vented by external ports. The surface of the driver's side air bag exhibited dirt and discoloration, most likely as a result of post-crash handling. Longitudinal striation marks were present on the rear aspect of the inboard surface as a result of expansion against the cover flap. There was no occupant contact evidence on the surface of the driver's side air bag or module cover flap.

Figure 10. Driver's door-mounted side air bag cover flap

The right front passenger's side air bag deployed from the right front door-mounted module that was located above the right front passenger's arm rest. The cover flap and air bag measurements were consistent with those of the driver's side air bag. Longitudinal striation marks were present on the rear aspect of the inboard surface as a result of expansion against the cover flap. There was no occupant contact evidence on the surface of the right front passenger's air bag or module cover flap.

The HPS deployed from the left and right roof rails and A-pillar areas. The separation at the roof rail measured 106.7 cm (42.0") in length. The separation along the A-pillar measured 54.6 cm (21.5") in length. Five clips that measured 5.1 cm (2.0") in height and 2.5 cm (1.0") in width were used to secure the non-deployed HPS in the A-pillar and roof rail **(Figure 11)**. Two clips were located in the upper A-pillars and were spaced 15.2 cm (6.0") apart. Two clips were located at the forward edge of the front door frames and were spaced 15.2 cm (6.0") apart. The remaining clip was located aft of the B-pillars and measured a distance of 40.6 cm (16.0") aft of the fourth clip.

Figure 11. Clips in roof side rail used to secure the HPS

The HPS were positioned diagonally across the driver's and right front passenger's positions at the time of deployment, and extended rearward from the lower A-pillars at an upward angle to the roof rails 37.5 cm (14.8") aft of the B-pillars **(Figure 12)**. The nylon tubes were reinforced with Kevlar and were covered with a nylon mesh webbing. A clear plastic membrane cover was present around each HPS which had partially torn due to the deployment. A warning label was affixed to the clear plastic cover regarding the replacement of the deployed HPS. The diameter of the tubes measured 12.7 cm (5.0") and the lengths measured 101.6 cm (40.0"). The tubes were tethered by two reinforced external straps that measured 19.7 cm (7.8") in length and 2.5 cm (1.0") in width. The forward straps **(Figure 13)** were anchored to the interior aspect of each A-pillar and the rear straps were anchored to the roof rail 37.5 cm (14.8") aft of each B-pillar **(Figure 14)**. A smaller 3.2 cm (1.3") diameter inflator tube was attached to the forward aspect of each HPS and was connected to the inflator that was located in the A-pillar.

Figure 12. Deployed front right passenger's HPS

Figure 13. Forward tether strap and inflator tube for the right front HPS

Figure 14. Rear tether strap for the right front HPS

There was no occupant contact evidence on the driver's side HPS. The exterior mesh surface of the driver's HPS exhibited dirt and discoloration, most likely as a result of post-crash handling. The front right passenger's HPS exhibited a faint transfer that was located on the inboard aspect of the tube 78.8 cm (31.0") aft of the A-pillar. This occupant contact measured 7.6 cm (3.0) in length and 2.5 cm (1.0") in width, and was a result of the front-right passenger's head striking the deployed right side HPS.

OCCUPANT DEMOGRAPHICS - 1999 BMW 328i

Driver

Age/Sex:	22-year-old male
Height:	Unknown
Weight:	Unknown
Seat Track Position:	Mid-track
Manual Restraint Use:	Manual 3-point lap and shoulder belt
Usage Source:	Vehicle inspection
Eyewear:	Unknown
Type of Medical Treatment:	Not injured

Driver Kinematics

The 21-year-old male driver was seated in an upright posture with the seat adjusted to the mid-track position and the seat back reclined 30 degrees. He was restrained by the manual 3-point lap and shoulder belt. As the driver lost control of the BMW, he attempted to regain control through right steering inputs and by applying the brakes. The pre-crash CCW yaw caused him to be displaced slightly left. At impact with the luminaire, the right front passenger's side air bag and HPS deployed. The driver initiated a lateral trajectory to the right and loaded the manual restraint and contacted the center console. As the BMW's rotation changed to CW around the pole, the driver continued the lateral motion to the right. The rapid CW rotation resulted in a curb impact to the left rear wheel. The impact was sufficient to deploy the driver's side air bag and HPS. The driver was redirected to the left and loaded the manual restraint, driver's side air bag, and HPS. The driver exited the vehicle under his own power through the driver's door. He did not sustain injury and did not receive medical treatment.

Front Right Passenger

Age/Sex:	21-year-old female
Height:	Unknown
Weight:	Unknown
Seat Track Position:	Mid-track
Manual Restraint Use:	Manual 3-point lap and shoulder belt
Usage Source:	Vehicle inspection
Eyewear:	Unknown
Type of Medical Treatment:	Not injured

Front Right Passenger Kinematics

The 21-year-old female front right passenger was seated in an upright posture with the seat adjusted to the mid-track position and the seat back reclined 30 degrees. She was restrained by the manual 3-point lap and shoulder belt. The pre-crash CCW yaw caused her to be displaced slightly left. At impact with the luminaire, the right front passenger's side air bag and HPS deployed. The front right passenger initiated a lateral trajectory to the right and loaded the manual restraint, deployed right front passenger's side air bag, and HPS. Her head contacted the right front HPS which resulted in a faint transfer on the inboard aspect of the HPS mesh surface. As the BMW's rotation changed to CW around the pole, the front right passenger continued the lateral motion to the right. The rapid CW rotation resulted in a curb impact to the left rear wheel which was sufficient to deploy the driver's side air bag and HPS. The front right passenger was redirected to the left and loaded the manual restraint. She did not sustain injury and did not receive medical treatment.

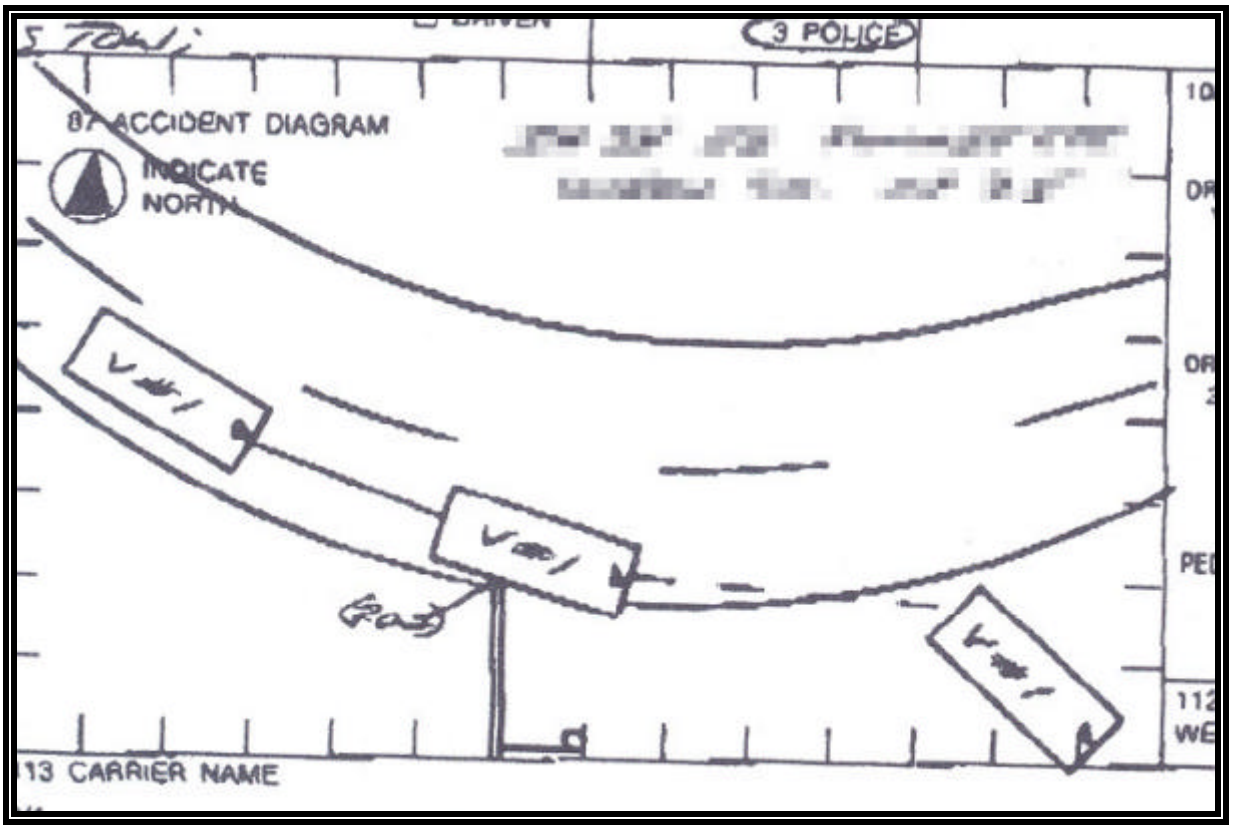

Figure 15. Police scene diagram