

**TRANSPORTATION SCIENCES
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**GENERAL DYNAMICS ON-SITE ADVANCED OCCUPANT PROTECTION SYSTEM
(AOPS) INVESTIGATION
SCI TECHNICAL SUMMARY REPORT**

CASE NO. CA03-030

VEHICLE – 2001 VOLVO S40

LOCATION - STATE OF FLORIDA

CRASH DATE – MAY 2003

Contract No. DTNH22-01-C-17002

Prepared for:

U.S. Department of Transportation
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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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| <i>16. Abstract</i> This on-site investigation focused on the performance of the Advanced Occupant Protection System (AOPS) that was present in a 2001 Volvo S40. The AOPS consisted of dual-stage frontal air bags, safety belt pretensioners, and a Side Impact Protection System (SIPS), which included side impact air bags and inflatable side curtains. The S40 was also equipped with a Whiplash Head Impact Protection System (WHIPS). The S40 was involved in an intersection collision with a 2003 Buick Century. The front aspect of the S40 struck the right side aspect of the Century. The impact was sufficient to deploy the frontal air bags in the S40. The S40 rotated in a clockwise (CW) direction, which resulted in a sideslap with the Century. The sideslap impact was not sufficient to deploy the SIPS system in the S40. The driver of the S40 initiated a forward and lateral trajectory to his left in response to the frontal impact. He was redirected laterally to the left during the subsequent sideslap and sustained a head contusion from possible contact with the left B-pillar. He also sustained a neck strain as a result of head motion during the crash. He was transported by ambulance to a local hospital for treatment and released. | | | |
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**GENERAL DYNAMICS ON-SITE ADVANCED OCCUPANT PROTECTION SYSTEM
(AOPS) INVESTIGATION
SCI TECHNICAL SUMMARY REPORT
CASE NO. – CA03-030
VEHICLE – 2001 VOLVO S40
LOCATION - STATE OF FLORIDA
CRASH DATE – MAY 2003**

BACKGROUND

This on-site investigation focused on the performance of the Advanced Occupant Protection System (AOPS) that was present in a 2001 Volvo S40. The AOPS consisted of dual-stage frontal air bags, safety belt pretensioners, and a Side Impact Protection System (SIPS), which included side impact air bags and inflatable side curtains. The S40 was also equipped with a Whiplash Protection System (WHIPS). The S40 (**Figure 1**) was involved in an intersection collision with a 2003 Buick Century. The front aspect of the S40 struck the right side aspect of the Century. The impact was sufficient to deploy the frontal air bags in the S40. The S40 rotated in a clockwise (CW) direction, which resulted in a sideslap with the Century. The sideslap impact was not sufficient to deploy the SIPS system in the S40. The driver of the S40 initiated a forward and lateral trajectory to his left in response to the frontal impact. He was redirected laterally to the left during the subsequent sideslap and sustained a head contusion from possible contact with the left B-pillar. He also sustained a neck strain as a result of head motion during the crash. He was transported by ambulance to a local hospital for treatment and released.



Figure 1. Damaged 2001 Volvo S40

This crash was identified by the Crash Investigation Division of the National Highway Traffic Safety Administration (NHTSA) due to the AOPS present in the Volvo S40. An on-site investigation was assigned on May 22, 2003 and initiated on June 9, 2003.

VEHICLE DATA – 2001 VOLVO S40

The 2001 Volvo S40 was identified by the Vehicle Identification Number (VIN): YV1VS29571F (production sequence omitted). At the time of the vehicle inspection, the S40's odometer read 64,893 km (40,324 miles). The S40 was a four-door sedan equipped with a four-cylinder, 1.9 liter turbo-charged engine, automatic five-speed transmission, front wheel drive, four-wheel power disc brakes with anti-lock (ABS), power steering, and a tilt steering wheel.

The Volvo S40 was equipped with Toyo Spectrum Touring Radial P195/60R15 tires on aluminum/alloy wheels for the left rear, right front, and right rear wheel positions. The manufacturer's recommended tire pressure was 207 kPa (30 psi). A temporary T125/90R15 spare tire was installed on the left front wheel, but it was not known if it was on at the time of the crash or installed post-crash. The Original Equipment Manufacturer (OEM) wheel and tire was not found with the vehicle. The specific tire data is as follows:

| Tire | Measured Pressure | Tread Depth | Restricted | Damage |
|-------------|--------------------------|--------------------|-------------------|---------------|
| LF* | 0.0 kpa | 4 mm (5/32") | No | None |
| LR | 193.1 kpa (28.0 psi) | 9 mm (11/32") | No | None |
| RF | 210.3 kpa (30.5 psi) | 9 mm (11/32") | No | None |
| RR | 196.5 kpa (28.5 psi) | 9 mm (11/32") | No | None |

* Temporary spare

The front seating positions in the Volvo S40 were configured with 8-way power bucket seats with manual lumbar support adjustments and fixed head restraints. The front bucket seats were equipped with the WHIPS system. Per the Volvo website, WHIPS is a mechanical system that is built into the front seats. It consists of a spring-suspended wire frame in the backrest and a special mechanism that holds the backrest and seat together. In a rear impact, the system helps to prevent the occupant from being pressed too deeply into the backrest and provides support for the spine. The WHIPS mechanism prevents the occupant from being thrown forward, supports the back and head, and absorbs the force generated by the crash. The driver's seat was adjusted between the mid-track and full-rear positions, at 3.8 cm (1.5") forward of the full-rear position. The front right seat was positioned in the full-rear position. The rear seating positions were configured with a bench seat with a 60/40 split folding back and a center fold-down armrest.

VEHICLE DATA – 2003 BUICK CENTURY

The 2003 Buick Century was a rental vehicle, and was identified by the VIN listed on the PAR: 2G4WS52J631 (production sequence omitted). The vehicle had been repaired at the time of the case assignment and was not inspected. The Buick Century was equipped with a 3.1 liter, V-6 engine, automatic four-speed transmission, power brakes, power steering, and a tilt steering wheel.

CRASH SITE

This two-vehicle crash occurred during the daytime hours of May 2003 in the state of Florida. At the time of the crash, the weather was clear and the asphalt roadway surface was dry. The crash occurred at a four-leg intersection of a service road that was separated from a local four-lane roadway and a four-lane local roadway that was configured with a center turn lane. The north/south service road was located on the west aspect of a tunnel entrance for the adjacent six-lane roadway. A northbound service road was located on the east side of the tunnel entrance. The tunnel width measured 19.3 m (63.3'). A concrete wall (adjacent to the curbs) that measured 1.5 m (4.9') in height extended along the inboard aspects of each service road and over the tunnel

entrance adjacent to the north sidewalk. The southbound service road was configured with a single southbound travel lane and parking spaces on the right aspect. The roadway was bordered by concrete curbs. The southbound travel lane expanded to two opposite turning lanes as it approached the intersection, and terminated at the east/west roadway. The south leg of the intersection was offset slightly east. The east/west roadway consisted of four travel lanes separated by an asphalt center turn lane. The center turn lane terminated at the intersection of the southbound service road and converted to a left turn lane over the tunnel entrance for traffic traveling onto the northbound service road. Traffic flow through the intersection was controlled by overhead three-phase traffic signals for each roadway. The posted speed limit was 48 km/h (30 mph).

CRASH SEQUENCE

Pre-Crash

The driver of the 2001 Volvo S40 was operating the vehicle southbound on the service road on approach to the four-leg intersection (**Figure 2**). It was not known what phase the overhead traffic signal was in as the Volvo approached the intersection. The driver of the 2003 Buick Century was operating the vehicle westbound on the inboard lane of the four-lane roadway (**Figure 3**). As the Century approached the intersection, the overhead traffic signal changed to the red phase. The driver of the Century did not realize the traffic signal had changed and continued into the intersection. The driver stated to police that he was distracted because he was looking for a particular address. As the traffic signal was in the green phase for the Volvo S40, the driver of the Volvo proceeded into the intersection but did not detect the approaching Buick Century traveling through the intersection. There was no evidence at the scene to support pre-crash braking from either vehicle.

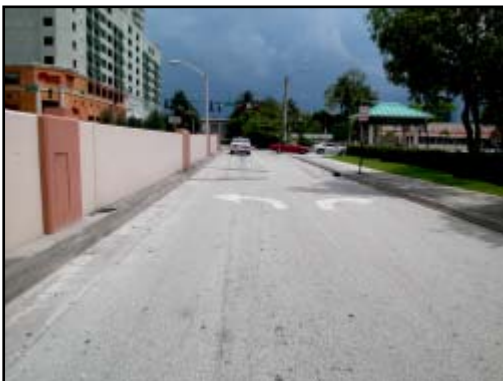


Figure 2. Southbound approach for the Volvo S40



Figure 3. Westbound approach for the Buick Century

Crash

The front of the Volvo S40 struck the right side of the Buick Century. The impact was sufficient to deploy the frontal air bag system in the Volvo S40. The Missing Vehicle algorithm of the WinSMASH program computed a total delta-V of 25 km/h (15.5 mph) for the Volvo S40 based on the Volvo's documented frontal crush profile and a total delta-V of 21 km/h (13 mph) for the Buick Century. The forward motion of the Century across the frontal plane of the S40 resulted in the rapid clockwise (CW) rotation of the S40 in the intersection and a slight counterclockwise

(CCW) deflection of the Century. The left rear of the S40 subsequently impacted the right side of the Century in a sideslap configuration. The Missing Vehicle algorithm of the WinSMASH program computed a delta-V for the Volvo of 12 km/h (7.5 mph) as a result of the sideslap. The sideslap event was not severe enough to warrant deployment of the SIPS system in the Volvo S40. The vehicles came to rest in the intersection, although the exact positions of final rest were not reported.

Post-Crash

The restrained driver of the Volvo S40 was transported by ambulance to a local hospital for treatment of his minor injuries and released. The restrained driver of the Buick Century did not sustain any injuries. The unrestrained front right passenger of the Century was transported by ambulance for treatment of police-reported possible injuries. His admission status was not reported.

VEHICLE DAMAGE

Exterior Damage – 2001 Volvo S40

The 2001 Volvo S40 sustained moderate frontal damage (**Figure 4**) as a result of the initial impact with the Buick Century. The direct damage abrasions and paint transfers began at the front left corner and extended laterally across the entire width of the bumper fascia. The direct damage across the leading edge of the hood began at the left front corner, extended 94 cm (37”), and terminated 27 cm (10.5”) right of the centerline. The direct contact on the bumper fascia included abrasions and paint transfers and measured 140 cm (55.0”) across the entire width of the fascia. The entire bumper fascia was separated. The bumper beam was crushed rearward, and deflected to the right and downward at the right front corner. The hood was displaced and buckled to the right and slightly rearward. The left front fender was deflected inward at the front aspect. Six crush measurements were documented across the front bumper beam and were as follows: C1 = 18 cm (7”), C2 = 16 cm (6.3”), C3 = 13 cm (4.5”), C4 = 11 cm (4.3”), C5 = 15 cm (5.8”), C6 = 11 cm (4.1”). The Collision Deformation Classification (CDC) for the frontal impact to the S40 was 10-FYEW-1.

The sideslap impact to the Volvo S40 resulted in minor damage (**Figure 5**) to the left side aspect of the vehicle. The original information obtained during the SCI inspection was later revised. The field investigation overemphasized the length of the direct and induced damage by including damage incurred during the initial impact. The revised direct damage and Field L began approximately 125 cm (50”) rear of the left front axle and continued rearward



Figure 4. Frontal view of damaged Volvo S40



Figure 5. View of left side damage to the Volvo S40

along the entire length of the vehicle for a distance of approximately 225 cm (88"). A semi-circular abrasion began 6 cm (2.5") forward of the rear edge of the left front door and extended 71 cm (28") rearward, 15 cm (6") below the beltline. Paint transfers from the Century were present along the entire length of the left aspect of the S40. An area of deformation was also located on the left rear door area at the location of the semi-circular abrasion. The maximum lateral crush was located approximately 130 cm (51.2") aft of the left front axle on the left rear door and measured 6.0 cm (2.4") in depth. The revised CDC for the sideslap event was 09-LZEW-1. Six crush measurements were documented along the left side of the Volvo and were estimated to be as follows: C1 = 6 cm (2.4"), C2 = 6 cm (2.4"), C3 = 5 cm (3"), C4 = 3 cm (1"), C5 = 5 cm (3"), C6 = 2 cm (0.8").

Exterior Damage – 2003 Buick Century

The 2003 Buick Century was a rental vehicle and was repaired at the time of this investigation. The Buick Century was not inspected.

Interior Damage -2001 Volvo S40

The 2001 Volvo S40 sustained minor interior damage as a result of the impacts with the Buick Century. All of the doors on the Volvo were operational. The side and rear glazing did not sustain damage, however, the windshield fractured as a result of crash forces. Post-crash, the windshield sagged under hot temperature conditions. The fractured laminate could not support the weight of the windshield due to the heat-sag, which caused a large portion of the windshield to separate and fall onto the instrument panel and deployed front right passenger air bag (**Figure 6**). There was no passenger compartment intrusion. Two scuff marks (**Figure 7**) were present on the left front interior door panel from occupant contact. One scuff mark measured 8.9 cm (3.5") in length and 5.1 cm (2.0") in height and was located at the rear aspect of the door handle and 7.6 cm (3.0") below the beltline, possibly from the driver's left arm. A second scuff mark was located on the forward face of the armrest, 3.8 cm (1.5") below the top aspect of the electronic window controls, possibly from the driver's left leg. The scuff mark measured 12.7 cm (5.0") in length and 7.6 cm (3.0") in height. An area of abrasion was located on the headliner at the aft edge of the driver's sun visor. The abrasion began 8.9 cm (3.5") left of the centerline and 20.3 cm (8.0") aft of the windshield header. The abrasion measured 6.4 cm (2.5") in length and 10.2 cm (4.0") in width. A dark transfer was also present on the front left corner of the interior sunroof sliding cover. The transfer measured 13.3 cm (5.3") in length and 8.9 cm (3.5") in width, and was located 21.6 cm (8.5") left of the centerline and 8.9 cm (3.5") from the leading edge of



Figure 6. View of holed windshield



Figure 7. View of scuff marks on driver's door

the cover, from possible post-crash handling. The front center armrest on the top aspect of the center console was slightly displaced to the right from probable occupant loading.

MANUAL RESTRAINT SYSTEMS – 2001 VOLVO S40

The 2001 Volvo S40 was equipped with manual 3-point lap and shoulder belts for each seating position. The driver's safety belt was configured with continuous loop webbing, a sliding latch plate, and a belt-sensitive, emergency locking retractor. The remaining safety belts were configured with continuous-loop webbing, a sliding latch plate, and belt-sensitive switchable ELR/Automatic Locking Retractors (ALR). The front safety belts were also configured with automatic height adjusters for the shoulder belts. Both height adjusters exhibited a small notch on the forward aspect, although they appeared to have resulted from historical use. The driver's safety belt webbing (**Figure 8**) exhibited stretch marks that began 48.3 cm (19.0") above the anchor and extended 42.5 cm (16.8") along the webbing. The latch plate cover exhibited minor abrasions from engagement against the safety belt webbing and the latch plate showed abrasions consistent with historical use.



Figure 8. View of driver's safety belt

ADVANCED OCCUPANT PROTECTION SYSTEM (AOPS) – 2001 VOLVO S40

The 2001 Volvo S40 was equipped with an AOPS that included dual-stage frontal air bags, safety belt pretensioners, and a Side Impact Protection System (SIPS), which included side impact air bags and inflatable side curtains. The driver's air bag (**Figure 9**) deployed from the center of the steering wheel hub as a result of the initial impact with the Buick Century. The air bag module was configured with symmetrical H-configuration cover flaps that measured 5.1 cm (2.0") in height and 16.5 cm (6.5") in width. The air bag measured 66.0 cm (26.0") in diameter and was vented by one circular port located at the 12 o'clock sector of the air bag. The vent port measured 2.5 cm (1.0") in diameter and was located 19.1 cm (7.5") from the circumferential seam. A faint green/blue transfer was present on the lower right quadrant of the face of the air bag. The transfer was located 17.8 cm (7.0") below the horizontal centerline and 14.0 cm (5.5") to the right of the vertical centerline. The transfer measured 7.6 cm (3.0") in length and 5.1 cm (2.0") in width. The air bag was tethered by four internal straps that measured 6.4 cm (2.5") in width and were located at the 12, 3, 6, and 9 o'clock positions.



Figure 9. Deployed driver's air bag

The front right passenger's air bag deployed from a top-mount module. The module was configured with symmetrical H-configuration cover flaps that measured 31.8 cm (12.5") in width and 5.1 cm (2.0") in height. The air bag (**Figure 10**) measured 35.6 cm (14.0") in width and 55.9

cm (22.0") in height. The air bag was vented by two circular ports located at the 3 and 9 o'clock positions of the air bag. The vent ports measured 3.8 cm (2.5") in diameter and were located 22.9 cm (9.0") forward of the face of the air bag. The face of the front right passenger's air bag exhibited three white transfers (**Figure 11**), although the source was not known and the front right passenger's seat was unoccupied at the time of the crash. The first transfer began 2.5 cm (1.0") left of the vertical centerline and 2.5 cm (1.0") below the horizontal centerline, measured 5.1 cm (2.0") in length, and extended at a downward angle to the right. The second transfer began 3.8 cm (1.5") to the right of the vertical centerline, 17.8 cm (7.0") below the horizontal centerline, and measured 3.8 cm (1.5") in width. The third transfer was located 14.0 cm (5.5") below the horizontal centerline, 10.2 cm (4.0") right of the vertical centerline, and measured 3.8 cm (1.5") in width.

The top right corner of the front right passenger's air bag was torn as a result of engagement with the damaged windshield, which had collapsed post-crash. Minor tears and abrasions were present



Figure 10. Deployed front right passenger's air bag



Figure 11. Close-up of white transfers on the front right passenger's air bag

on the top right corner of the air bag face, which extended to the right side panel. The top aspect of the air bag sustained abrasions and minor tears as a result of contact with the fractured windshield.

The Volvo S40 was equipped with retractor safety belt pretensioners for the driver and front right positions. The pretensioners did not actuate during the crash. At the time of the vehicle inspection, both front safety belt retractors were operational.

The S40 was equipped with a Side Impact Protection System (SIPS) that included side impact air bags in the outboard aspects of the front seat backs and side impact inflatable curtains, which were designed to deploy from the roof side rails. The SIPS system did not deploy in this crash.

OCCUPANT DEMOGRAPHICS – 2001 VOLVO S40

Driver

Age/Sex: 22-year-old male
Height: Unknown
Weight: Unknown
Seat Track Position: 2.5 cm (1.0”) forward of full-rear
Manual Restraint Use: Manual 3-point lap and shoulder belt
Usage Source: Vehicle inspection
Eyewear: Unknown
Type of Medical Treatment: Transported by ambulance to a local hospital for treatment and released

Driver Injuries

| Injury | Injury Severity (AIS 90/Update 98) | Possible Injury Source |
|---------------------|---|-------------------------------|
| Head contusion, NFS | Minor (190402.1,9) | Left B-pillar |
| Neck strain | Minor (640278.1,6) | Impact force |

Injury source: Emergency room records

Driver Kinematics

The 22-year-old male driver of the 2001 Volvo S40 was presumed to have been seated in an upright posture. He was restrained by the manual 3-point lap and shoulder belt. At impact with the Buick Century, the frontal air bag system deployed and the driver initiated a forward and lateral trajectory to the left. Based on the faint green/blue transfer on the bottom right quadrant of the air bag, the clothing on the driver’s right arm or right leg may have sustained contact with the expanding air bag. He loaded the manual restraint, evidenced by stretch marks present on the safety belt webbing and subsequently loaded the deployed driver’s air bag. As the S40 rotated CW and was involved in the secondary sideslap impact, the driver was redirected laterally to the left. The secondary sideslap was not sufficient to deploy the left side SIPS system in the S40. Scuff marks were present on the interior surface of the driver’s door, which supported probable occupant loading to the door. His head may have struck the interior aspect of the left B-pillar, which resulted in a non-specified head contusion. He rebounded to the right and may have loaded the armrest located on the center console, evidenced by lateral displacement. He sustained a neck strain as a result of head motion during the crash. It was not known how the driver exited the vehicle. He was transported by ambulance to a local hospital for treatment and released.

SCI
Case No.: CA03-030
State of Florida
May 2003



Scale 1.0 cm = 2.5 m

Posted Speed Limit: 48 km/h (30 mph)

Vehicle 1: 2001 Volvo S40
Vehicle 2: 2003 Buick Century

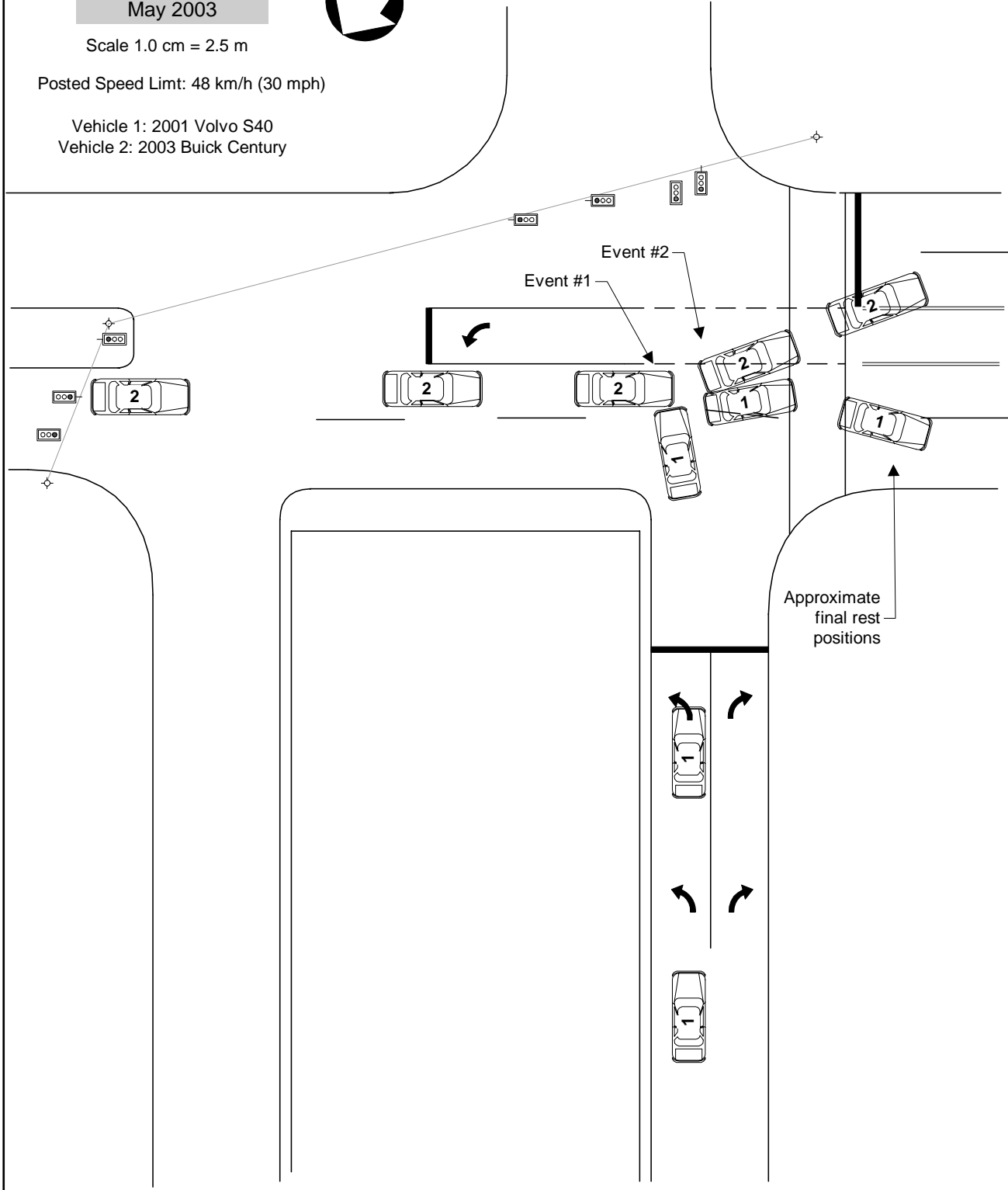


Figure 12. Scene schematic