CRASH DATA RESEARCH CENTER
Calspan Corporation
Buffalo, NY 14225

CALSPAN ON-SITE HYBRID VEHICLE CRASH INVESTIGATION
SCI CASE NO: CA09064

VEHICLE: 2010 TOYOTA PRIUS

LOCATION: PENNSYLVANIA

CRASH DATE: AUGUST, 2009

Contract No. DTNH22-07-C-00043

Prepared for:

U.S. Department of Transportation
National Highway Traffic Safety Administration
Washington, D.C. 20590

DISCLAIMER

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no responsibility for the contents or use thereof.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

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.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. CA09064	*2. Government Accession No.*	*3. Recipient's Catalog No.*	
4. Title and Subtitle Calspan On-Site Hybrid Vehicle Crash Investigation Vehicle: 2010 Toyota Prius Location: Pennsylvania		*5. Report Date*: May 2010	
		6. Performing Organization Code	
7. Author(s) Crash Data Research Center		*8. Performing Organization Report No.*	
9. Performing Organization Name and Address Calspan Corporation Crash Data Research Center P.O. Box 400 Buffalo, New York 14225		*10. Work Unit No.*	
		11. Contract or Grant No. DTNH22-07-C-00043	
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration Washington, D.C. 20590		*13. Type of Report and Period Covered* Technical Report Crash Date: August 2009	
		14. Sponsoring Agency Code	
15. Supplementary Note An investigation of the intersection crash of a 2010 Toyota Prius and a 1997 Ford F250 pickup truck.			

16. Abstract

This investigation will focus on the multiple event crash of a 2010 Toyota Prius Hybrid vehicle. The Toyota was stopped at an intersection waiting for opposing traffic to clear in order to complete a left turn. A 1997 Ford F250 pickup truck traveling behind the Toyota struck the right aspect of the Toyota's back plane (Event 1). The Toyota Prius was a gasoline-electric hybrid vehicle powered by a 1.8-liter, in-line 4-cylinder internal combustion engine and a 60-kilowatt electric motor. The vehicle's electrical power was supplied by a stack of nickel-metal hydride batteries located behind the rear seat. The Toyota was equipped with Certified Advanced 208-Compliant (CAC) frontal air bags, a driver knee air bag, front seat-mounted side impact air bags, and side impact Inflatable Curtains (IC).

The crash occurred at a four-leg intersection in a suburban setting. The Toyota was driven by a 54-year-old restrained female. The Ford was driven by a 53-year-old unrestrained male. The rear impact displaced the Toyota forward and left across the centerline into the opposing traffic lane where the front plane of the Toyota was struck by a 2000 Kia Sephia (Event 2). The Kia was driven by a 24-year-old restrained female. The frontal impact resulted in the deployment of the Toyota's CAC driver air bag and the driver's knee air bag. The frontal air bags in the Kia also deployed. The Toyota and Kia sustained disabling damage and were towed from the crash site. The driver of the Toyota sustained minor injuries and was transported to a local hospital. The Kia driver was also transported. The Ford was driven from the crash site. The Ford driver was not injured.

17. Key Words Hybrid Vehicle Certified Advanced 208-Compliant frontal air bags		*18. Distribution Statement* General Public	
19. Security Classif. (of this report) Unclassified	*20. Security Classif. (of this page)* Unclassified	*21. No. of Pages* 11	*22. Price*

TABLE OF CONTENTS

CALSPAN ON-SITE HYBRID VEHICLE CRASH INVESTIGATION
SCI CASE NO: CA09064
VEHICLE: 2010 TOYOTA PRIUS
LOCATION: PENNSYLVANIA
CRASH DATE: AUGUST, 2009

BACKGROUND

This investigation will focus on the multiple event crash of a 2010 Toyota Prius Hybrid vehicle. The Toyota was stopped at an intersection waiting for opposing traffic to clear in order to complete a left turn. A 1997 Ford F250 pickup truck traveling behind the Toyota struck the right aspect of the Toyota's back plane (Event 1). The Toyota Prius was a gasoline-electric hybrid vehicle powered by a 1.8-liter, in-line 4-cylinder internal combustion engine and a 60-kilowatt electric motor. The vehicle's electrical power was supplied by a stack of nickel-metal hydride batteries located behind the rear seat. The Toyota was equipped with Certified Advanced 208-Compliant (CAC) frontal air bags, a driver knee air bag, front seat-mounted side impact air bags, and side impact Inflatable Curtains (IC). The crash occurred at a four-leg intersection in a suburban setting. The Toyota was driven by a 54-year-old restrained female. The Ford was driven by a 53-year-old unrestrained male. **Figure 1** is a right rear oblique view depicting the back plane damage of the Toyota. The rear impact displaced the Toyota forward and left across the centerline into the opposing traffic lane where the front plane of the Toyota was struck by a 2000 Kia Sephia (Event 2). The Kia was driven by a 24-year-old restrained female. The frontal impact resulted in the deployment of the Toyota's CAC driver air bag and the driver's knee air bag. The frontal air bags in the Kia also deployed. The Toyota and Kia sustained disabling damage and were towed from the crash site. The driver of the Toyota sustained minor injuries and was transported to a local hospital. The Kia driver was also transported. The Ford was driven from the crash site. The Ford driver was not injured.

Figure 1: Right rear oblique view of the Toyota. (Image supplied by the insurance salvage facility).

This crash was identified through the weekly sampling of police reported crashes conducted by the General Estimates System (GES) of the National Automotive Sampling System (NASS). The Crash Investigation Division of the National Highway Traffic Safety Administration (NHTSA) forwarded the police report to the Calspan Special Crash Investigations (SCI) team on September 18, 2009. Calspan SCI initiated a follow-up investigation and established cooperation with the Toyota's insurance company. The Toyota was considered a total loss and was available

for inspection at an insurance salvage yard. Based on the availability of the vehicle, the NHTSA assigned an on-site investigation of the crash on September 25, 2009. The Ford F250 and the Kia were not insured and these vehicles could not be located. The inspection of the Toyota and crash site took place October 2, 2009.

SUMMARY

VEHICLE DATA

2010 Toyota Prius

The Toyota Prius was identified by the Vehicle Identification Number (VIN): JTDKN3DU5A0 (production sequence deleted). The front-wheel drive, 4-door hatchback was manufactured in May 2009. The driver of the Toyota had purchased the vehicle new in July 2009 and indicated that the vehicle's odometer read approximately 4,800 km (3,000 miles) at the time of the crash. The Toyota was powered by a 1.8-liter internal combustion engine that operated in series-parallel with a 60-kilowatt electric motor. The hybrid power train was linked to a Continuously Variable Transmission (CVT). The service brakes were a front disc/rear drum system with four-wheel ABS. The vehicle was equipped with manual 3-point safety belts in the five seat positions, front safety belt retractor pretensioners, Certified Advanced 208-Compliant (CAC) frontal air bags, a driver knee air bag, front seat-mounted side impact air bags and side impact Inflatable Curtain (IC) air bags. The Toyota was equipped with Yokohama Avid S33 P185/65R15 tires mounted on OEM alloy rims. The vehicle manufacturer's recommended cold tire pressure was 240 kPa (35 PSI) front and 230 kPa (33 PSI) rear. The specific measured tire data at the time of the SCI inspection was as follows:

Tire	Measured Pressure	Tread Depth	Restricted	Damage
LF	221 kPa (32 PSI)	7 mm (9/32 in)	No	None
LR	214 kPa (31 PSI)	8 mm (10/32 in)	No	None
RF	214 kPa (31 PSI)	7 mm (9/32 in)	No	None
RR	214 kPa (31 PSI)	8 mm (10/32 in)	No	None

1997 Ford F250 Pickup

The 1997 Ford F250 was identified by the Vehicle VIN: 1FTHX25H0VE (production sequence deleted). The 2-door, 4x2, ¾ ton, super cab pickup was powered by a 5.7-liter, V8 engine. The service brakes were front disc/rear drum with rear-wheel ABS. The manual restraint system consisted of 3-point safety belts and the air bag system consisted of driver and front right passenger air bags that did not deploy as a result of the crash. The vehicle was driven from the crash site by the uninjured driver. It was not inspected.

2000 Kia Sephia

The 2000 Kia Sephia was identified by the VIN: KNAFB1217Y5 (production sequence deleted). The front-wheel drive, 4-door sedan was equipped with a 1.8-liter, I4 engine linked to

a 4-speed automatic transmission. The vehicle was equipped with manual 3-point restraints for the five seat positions. The frontal air bag system consisted of redesigned driver and front right passenger air bags that deployed during the crash. This vehicle was not inspected for this investigation.

CRASH SITE

This three-vehicle crash occurred at the four-leg intersection of a two-lane east/west road and a two-lane north/south road located in a suburban commercial setting. At the time of the crash, it was daylight and raining; the asphalt road surface was wet. The east/west road was a collector roadway leading to other areas within the city limits. The north and south legs of the intersection were dead-end roads that were populated by single family homes. The traffic flow through the area was controlled by stop signs for the north/south traffic. The total width of the east/west road measured 10.3 m (33.8 ft). The traffic lanes were separated by a double-yellow centerline and bordered by 15 cm (6 in) concrete curbs. The posted speed limit was 40 km/h (25 mph). There was no physical evidence of the crash observed at the time of the SCI scene inspection. The points of impact in the multiple event crash and final rest positions of the vehicles were unknown. **Figure 2** is an eastbound view of the intersection.

Figure 2: Eastbound view of the intersection.

CRASH SEQUENCE

Pre-Crash

The Toyota Prius was driven by a 54-year-old restrained female. She was returning to her residence located on the north leg of the intersection at the end of the work day. The vehicle was eastbound and had come to a complete stop with the left turn signal on. The driver was waiting for opposing traffic to clear in order to execute a left turn. She indicated that she was stopped for approximately 10 seconds. The Ford F250 was also eastbound driven by a 53-year-old unrestrained male. The driver of the Ford reported that he attempted to brake but could not stop because of the wet pavement. He steered his vehicle to the right in an attempt to avoid the stopped Toyota and pass it on the right. The Kia Sephia was westbound driven by a 24-year-old female. A schematic of the crash is attached to the end of this report as **Figure 11**.

Crash

The left aspect of the Ford's frontal plane struck the right aspect of the Toyota's back plane in a 12/6 o'clock impact configuration (Event 1). The momentum of the Ford displaced the Toyota forward and left into the opposing traffic lane. The Ford came to a controlled stop after the

impact. The severity of the rear impact (delta-V) was calculated by the Missing Vehicle Algorithm of the WinSMASH program. The total rear impact delta-V of the Toyota was 14 km/h (8.7 mph). The longitudinal and lateral components of the delta-V were 14 km/h (8.7 mph) and 2 km/h (1.2 mph), respectively. The total delta V of the Ford was 8.0 km/h (5.0 mph) with the longitudinal and lateral delta-V components of -7.9 km/h (-4.9 mph) and -1.4 km/h (-0.9 mph), respectively.

The Toyota was displaced forward directly into the path of the Kia. The front plane of the Kia struck the right aspect of the Toyota's frontal plane (Event 2). This impact resulted in the deployment of the driver's frontal air bag and the driver's knee air bag in the Toyota. The frontal air bags in the Kia also deployed. The frontal impact delta-V was calculated by the Missing Vehicle Algorithm of the WinSMASH program. The total frontal delta-V of the Toyota was 12 km/h (7.5 mph). The longitudinal and lateral components of the delta-V were -11 km/h (-6.8 mph) and -4 km/h (-2.5 mph), respectively. The total delta V of the Kia was 13 km/h (8.1 mph) with the longitudinal and lateral delta-V components of -13 km/h (-8.1 mph) and 0, respectively.

The force of the offset frontal impact resulted in a counterclockwise rotation of the Toyota as the vehicle slid to final rest. The Toyota driver reported to the SCI investigator that her vehicle came to rest in the westbound lane at the mouth of the intersection, facing northeast. The Kia came to rest facing west, forward and adjacent to the Toyota Prius.

Post-Crash

The police and ambulance personnel responded to the crash. The driver of the Toyota released her safety belt and waited in her vehicle until the arrival of the ambulance personnel. She exited the vehicle under her own power after their arrival and was then transported to the emergency room of a local hospital. She was examined, treated and released approximately two hours post-crash. She sustained a left forehead contusion, a right forearm abrasion/contusion, a right lower extremity contusion and safety belt related chest and abdominal contusions. The male driver of the Ford was not injured. The female driver of the Kia was transported to a local hospital with police-reported minor injuries.

2010 TOYOTA PRIUS

Exterior Damage

The back and front planes of the Toyota Prius sustained impact damage consistent with the multiple event crash sequence. **Figure 3** is a rear view of the Toyota's back plane damage. **Figure 4** is a right lateral view at the back plane depicting the extent of crush. The direct contact damage began 36 cm (14 in) right of center and extended 43 cm (17 in) to the right rear corner. The combined width of the direct and induced damage extended across the full 157 cm (62 in) end width of the vehicle. Crush profiles were measured along the bumper reinforcement bar and

along rear body structure immediately below the rear hatch opening. The maximum crush at the bumper elevation was located at the right corner (C6) and measured 2 cm (0.8 in). The primary impact damage was above the level of the bumper. The maximum crush at the corner of the right quarterpanel measured 35 cm (13.8 in). An average of the measured crush profiles was used as input data in the WinSMASH model to calculate the severity of the crash. The averaged crush profile was as follows: C1 = 0, C2 = 0, C3 = 1 cm (0.4 in), C4 = 1 cm (0.4 in), C5 = 9 cm (3.5 in), C6 = 19 cm (7.5 in). The backlight glazing was disintegrated. The side glazing was intact. There was no change in the wheelbase dimensions. The Collision Deformation Classification (CDC) was 06-BREW6.

The Toyota sustained minor severity damage as a result of the front impact with the Kia, **Figures 5 and 6**. The direct contact damage began 24 cm (9.5 in) right of center and extended 42 cm (16.5 in) to the right corner. The combined width of the direct and induced damage extended across the entire 142 cm (52 in) front end width. The offset angular impact force deformed the right end of the front bumper reinforcement 5 cm (2 in) to the left. The crush profile documented at the bumper elevation was as follows: C1 = 0, C2 = 0, C3 = 0, C4 = 2 cm (0.8 in), C5 = 3 cm (1.2 in), C6 = 2 cm (0.8 in). The maximum crush was located above the bumper elevation on the upper radiator support, 34 cm (13.2 in) right of center. The maximum crush measured 10 cm (4 in). The windshield was not fractured. All the doors remained closed during the crash and were operational at the time of the SCI inspection. The CDC was 01-FREW1.

Figure 3: Back view of the Toyota Prius.

Figure 4: Right view at the back plane depicting the extent of crush.

Figure 5: View of the frontal damage to the Toyota.

Figure 6: Overhead view of the frontal deformation.

Interior Damage

The damage to the vehicle's interior consisted of the deployment of the driver's frontal and knee air bags. There was no intrusion into the vehicle's occupant compartment. The driver seat was located in a full-rear track position. The total seat track travel was 26 cm (10.2 in). The seat back was reclined 12 degrees aft of vertical. There was no deflection or deformation to the seat back. The horizontal distance from the seat back to the driver air bag module located in the center hub of the steering wheel measured 71 cm (28 in). The head restraint was adjusted 6 cm (2.5 in) above the seat back. The four-spoke steering wheel was mounted to a tilt and telescoping column that was adjusted to the full-up/full-back positions. The flange-connection between the steering wheel and the steering column was deformed. The gap between the wheel and column was closed at the 12 o'clock sector and measured 1 cm (0.5 in) at the 6 o'clock sector. There was no steering column compression. A 3 cm (1 in) diameter contact scuff was identified on the left roof side rail that resulted from probable head contact. The scuff was located 97 cm (15 in) forward of the left B-pillar.

The force of the impact above the level of the Toyota's rear bumper resulted in deformation of the right interior trim panels in the cargo area that initially appeared significant. However, after inspection it was determined that the deformation of these soft structures did not pose a threat to the integrity of the hybrid battery compartment. The right floor area of the cargo area was not significantly buckled or damaged. Only minor structural intrusion was identified at the right rear aspect of the cargo area. **Figure 7** is an overhead view down through the disintegrated backlight of the rear cargo area. **Figure 8** is a left lateral view depicting the minor right floor deformation in relation to the location of the hybrid battery. The distance between the second row seat backs and the back wall of the cargo area was reduced 4 cm (1.5 in) on the right.

Figure 7: Overhead view through the disintegrated backlight of the cargo area and hybrid battery.

Figure 8: Left lateral view of the right floor deformation aft of the hybrid battery.

Hybrid Battery Performance - Federal Motor Vehicle Safety Standard No: 305

The hybrid battery stack was housed in an aluminum compartment that measured 29 cm x 79 cm x 14 cm (11.5 in x 31 in x 5.5 in) length x width x height. The battery stack was manufactured by Panasonic. The battery compartment was located behind the second row seat backs 64 cm (25 in) forward of the hatch opening [81 cm (32 in) forward of the rear bumper]. It was mounted to the floor of the cargo space, forward and above the 66 cm (26 in) diameter spare tire well. Heating, ventilation, and cooling (HVAC) duct work was located along the right side of the cargo area.

Figure 9 is a view of the hybrid battery and deformed cargo area. Calibrated reference sticks and tape measures were use to quantify the extent of the deformation relative to the battery compartment location. The tape measures depict the intrusion along the structural back wall of the cargo area. The reference sticks depict the 11 cm (4.5 in) extent of the intrusion of the soft trim panels above the level of the back wall (on the rear hatch door).

Figure 9: View depicting the relationship of the hybrid battery to the rear deformation of the

Federal Motor Vehicle Safety Standard (FMVSS) No. 305, Electric Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection is the standard applied to vehicles that use more than 48 nominal volts of electricity as propulsion and whose speed on a level paved surface is more than 40 km/h (25 mph). FMVSS No. 305 specifies performance requirements of electrolyte spillage,

retention of propulsion batteries, and electrical isolation of the chassis from the high-voltage system during a crash event. The standard test requirements are summarized as follows:

- Not more than 5.0 liters (1.3 gal) of electrolyte from propulsion batteries shall spill outside the passenger compartment, and none shall spill in the passenger compartment, within 30 minutes after a barrier impact test.
- No propulsion battery system component located inside the passenger compartment shall move from its installed location.
- No propulsion battery system component located outside the passenger compartment shall enter the passenger compartment.
- Electrical isolation shall exist between the propulsion battery system and the vehicle electricity-conducting structure.

The Toyota was visually inspected for compliance with FMVSS No. 305. The rear impact damage did not involve the area of the propulsion battery. There was no damage of the general area surrounding the battery compartment mounting points, nor was there damage to the battery cover or battery cells. There was no leakage detected during the SCI vehicle inspection. The battery propulsion system components were not displaced or damaged by this impact event. Disassembly of the battery compartment was not allowed by the salvage facility. The electrical isolation test was not conducted. Observations of the inspection indicated the battery propulsion system was in compliance with FMVSS 305.

Manual Restraint Systems

The driver's manual restraint consisted of a 3-point lap and shoulder safety belt with continuous loop webbing, a sliding latch plate, an adjustable D-ring and an Emergency Locking Retractor (ELR). The D-ring was adjusted to the full-up position. The restraint was equipped with a retractor pretensioner that actuated during the frontal impact (Event 2). The webbing was locked in its extended position at initial inspection. The length of the extended webbing measured 188 cm (74 in). Historical use evidence was observed on the latch plate that was consistent with the mileage of the vehicle. Examination of the friction surface of the latch plate revealed an abrasion. A corresponding 8 cm (3 in) webbing abrasion was also identified. Based on the physical evidence observed during the SCI vehicle inspection, the driver was restrained at the time of the crash.

Air Bag Systems

The Toyota Prius was equipped with CAC frontal air bags, seat-mounted side impact air bags for the driver and front right passenger and side impact IC air bags. A CAC vehicle is certified by the vehicle manufacturer to be compliant with the advanced air bag portion of FMVSS No 208. The driver air deployed from an H-configuration module located in the center hub of the steering wheel rim. There was no occupant contact to the flaps. The diameter of the deployed air bag measured 61 cm (24 in). It was tethered and vented by two 4 cm (1.5 in) diameter ports located

on the back side of the air bag in the 1/11 o'clock sectors. No physical evidence of contact was noted on the face of the air bag.

The vehicle was equipped with a knee bolster air bag in the lower left aspect of the instrument panel. The air bag was concealed behind the vinyl bolster panel by two symmetrical cover flaps that measured 24 cm x 4 cm (9.6 in x 1.6 in), width by height. The trapezoidal-shaped knee air bag measured 30 cm (12 in) in height. The width of the bag at the bolster interface was 30 cm (12 in) and expanded to 56 cm (22 in). There was no contact evidence observed on the knee air bag. **Figure 10** is a view of the deployed knee air bag. The seat-mounted side impact air bags and side impact IC air bags did not deploy.

Figure 10: Deployed driver knee air bag.

DRIVER DEMOGRAPHICS

Age/Sex:	54-year-old / Female
Height:	175 cm (69 in)
Weight:	118 kg (260 lb)
Manual Safety Belt Use:	3-point lap and shoulder belt system
Usage Source:	SCI vehicle interior inspection
Seat Track Position:	Full-rear track
Egress from Vehicle:	Unassisted, after the arrival of EMS
Type of Medical Treatment:	Treated and released from the Emergency Room

DRIVER INJURIES

Injury	Injury Severity (AIS90/Update 98)	Injury Source
Chest wall contusion	Minor (490402.1,9)	Safety belt webbing
Right forearm contusion	Minor (790402.1,1)	Forward upper aspect door panel
Right forearm abrasion	Minor (790202.1,1)	Driver air bag
Source: Emergency Room Records		

Injury	Injury Severity (AIS90/Update 98)	Injury Source
Left forehead contusion	Minor (290402.1,7)	Left roof side rail
Right lower extremity contusions	Minor (890402.1,1)	Knee bolster
Abdominal contusions	Minor (590402.1,0)	Safety belt webbing
Source: Driver Interview		

DRIVER KINEMATICS

The 54-year-old female driver of the Toyota was restrained and seated in an upright posture. The seat was adjusted in a full-rear track position and the head restraint was adjusted 6 cm (2.5 in) above the seat back. The vehicle was stopped waiting to execute a left turn. The driver's right foot was on the brake pedal and her hands were on the steering wheel at 1 and 10 o'clock positions.

At impact with the Ford (Event 1), the safety belt retractor locked. The driver initiated a rearward trajectory in response to the 6 o'clock direction of the impact force and loaded the seat back with her torso. Her head loaded the head restraint. The Toyota accelerated forward and left into the opposing traffic lane. The driver rode down the force of the impact and then began to rebound forward, due to the compression of the seat back and cushion.

At impact with the Kia (Event 2), the force of the impact (again) engaged the emergency locking retractor, and deployed the driver's CAC and knee air bags. The retractor pretensioner was also actuated. The deploying driver air bag contacted and abraded the anterior aspect of the driver's right forearm. Her hand was displaced from the wheel and her arm contacted the left door panel. The driver responded to the 1 o'clock direction of the impact by loading the locked safety belt webbing with her chest and abdomen. This loading resulted in the related contusions to her torso. She contacted deployed driver air bag with her head and chest. This loading was evidenced by the steering wheel flange deformation. The driver's right lower extremity contacted and loaded the knee air bag and bolster resulting in a contusion. The driver then rebounded rearward. During the rebound phase, her left forehead contacted the left roof side rail resulting in a contusion. She came to rest within the driver's seat. She released her safety belt and waited for the arrival of the first responders.

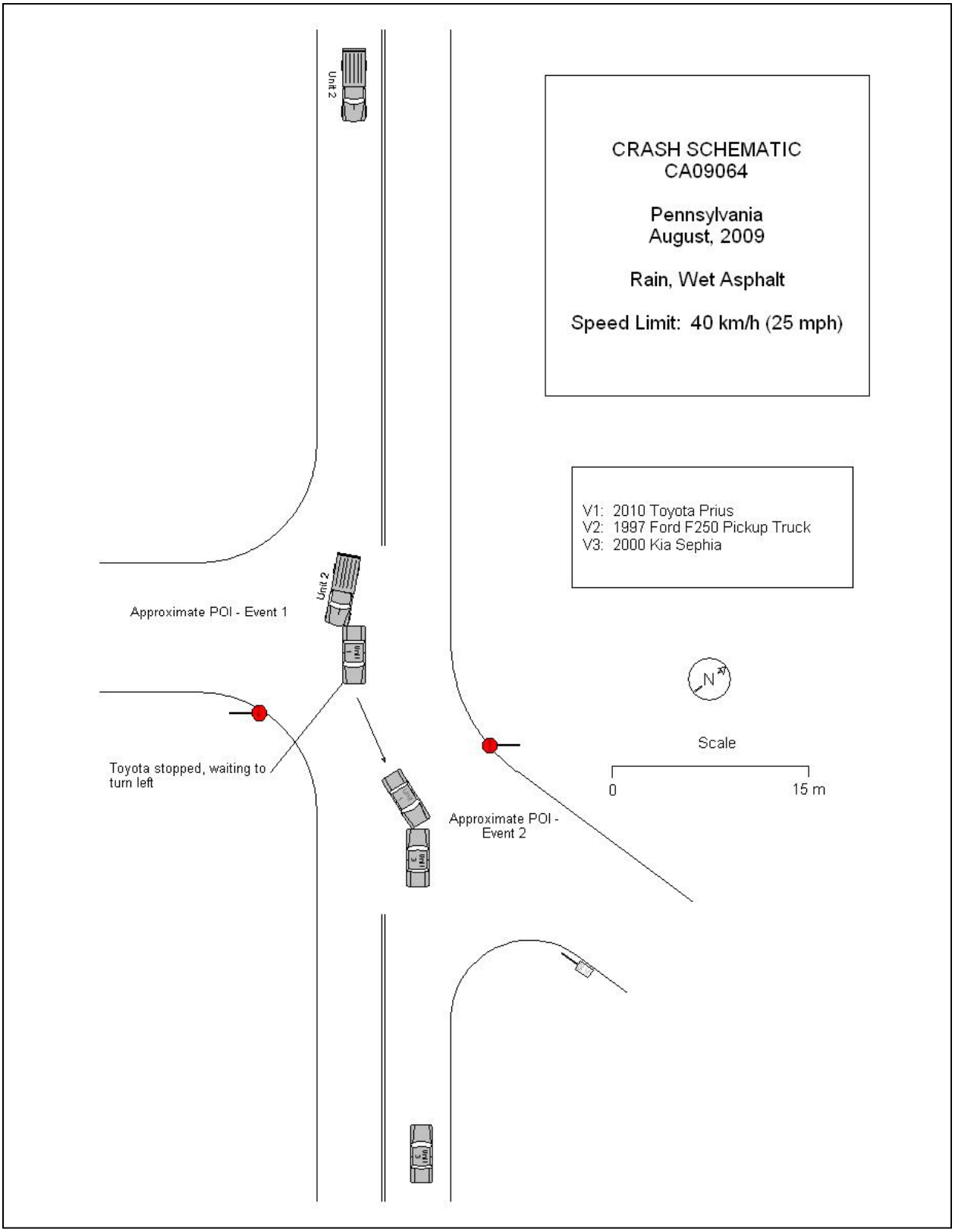

Figure 11: Crash schematic.