

On-Site Hybrid Vehicle Investigation
Dynamic Science, Inc. (DSI), Case Number DS09037
2008 Toyota Prius
Washington

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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.

1. Report No. DS09037	2. Government Accession No.		3. Recipient Catalog No.	
4. Title and Subtitle On-Site Hybrid Vehicle Investigation		5. Report Date July 7, 2010		
		6. Performing Organization Report No.		
7. Author(s) Dynamic Science, Inc.		8. Performing Organization Report No.		
9. Performing Organization name and Address Dynamic Science, Inc. 299 West Cerritos Avenue Anaheim, CA 92805		10. Work Unit No. (TRAIS)		
		11. Contract or Grant no. DTNH22-07-00045		
12. Sponsoring Agency Name and Address U.S. Dept. of Transportation (NVS-411) National Highway Traffic Safety Administration 1200 New Jersey Ave, SE Washington, DC 20590		13. Type of report and period Covered [Report Month, Year]		
		14. Sponsoring Agency Code		
15. Supplemental Notes				
16. Abstract This on-site investigation focused on the hybrid fuel system in a 2008 Toyota Prius that was involved in a two-vehicle crash. The Toyota was equipped with a nickel-metal hydride (NiMH) high-voltage propulsion battery pack using potassium and sodium hydroxide electrolyte. The battery pack was located aft of the second row bench seat. The vehicle was equipped with a Certified Advanced 208-Compliant (CAC) frontal air bag system. A CAC vehicle is certified by the manufacturer to be compliant with the Advanced Air Bag portion of Federal Motor Vehicle Safety Standard (FMVSS) No. 208. The Toyota was equipped with frontal air bags, seat-mounted side air bags, and side impact inflatable curtain (IC) air bags. During the crash, the driver's seat-mounted side air bag and the left IC air bag deployed. The crash site was an uncontrolled four-leg intersection and the other vehicle was a 2008 Chevrolet Malibu. The Toyota being driven by a 24-year-old female and was traveling north, and the Chevrolet was being driven by a 35-year-old male and was traveling east. The vehicles entered the intersection at the same time and the front end of the Chevrolet impacted the left side of the Toyota. The driver of the Toyota sustained minor injuries and refused transport, and the driver of the Chevrolet was not injured. Both vehicles were towed from the scene and were later declared total losses by their respective insurance companies.				
17. Key Words Hybrid vehicle, side air bag, IC air bag, injury		18. Distribution Statement		
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of pages	22. Price	

Dynamic Science, Inc.
Crash Investigation
Case Number: DS09037

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Background

This on-site investigation focused on the hybrid fuel system in a 2008 Toyota Prius (**Figure 1**) that was involved in a two-vehicle crash. The Toyota was equipped with a nickel-metal hydride (NiMH) high-voltage propulsion battery pack using potassium and sodium hydroxide electrolyte. The battery pack was located aft of the second row bench seat. The vehicle was equipped with a Certified Advanced 208-Compliant (CAC) frontal air bag system. A CAC vehicle is certified by the manufacturer to be compliant with the Advanced Air Bag portion of Federal Motor Vehicle Safety Standard (FMVSS) No. 208. The Toyota was equipped with frontal air bags, seat-mounted side air bags, and side impact inflatable curtain (IC) air bags. During the crash, the driver's seat-mounted side air bag and the left IC air bag deployed.

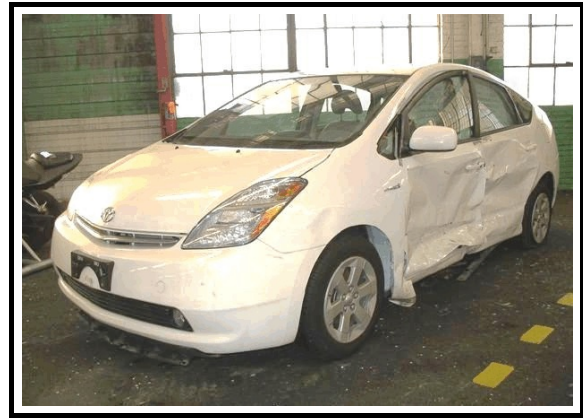


Figure 1. Subject vehicle, 2008 Toyota Prius

The crash site was an uncontrolled four-leg intersection and the other vehicle was a 2008 Chevrolet Malibu. The Toyota being driven by a 24-year-old female and was traveling north, and the Chevrolet was being driven by a 35-year-old male and was traveling east. The vehicles entered the intersection at the same time and the front end of the Chevrolet impacted the left side of the Toyota.

The driver of the Toyota sustained minor injuries and refused transport, and the driver of the Chevrolet was not injured. Both vehicles were towed from the scene and were later declared total losses by their respective insurance companies.

This hybrid vehicle crash was identified by the National Highway Traffic Safety Administration (NHTSA) during a review of General Estimates System (GES) police reports. On December 7, 2009 DSI was sent the police report with instructions to locate the subject vehicle and obtain cooperation. The vehicle was not available for inspection for several days due to negotiations between the vehicle owner and the insurance company. On December 23, 2009, permission to inspect the vehicle was obtained and the case was assigned. The vehicle inspection was completed on December 29, 2009. Permission to remove the vehicle's Event Data Recorder (EDR) was denied by the insurance company. The Chevrolet was sold to a private party on December 9, 2009. Photographs were obtained from the auction facility and were used to complete a partial inspection based on photographs only.

Summary

Crash Site

The crash occurred during daylight hours in November 2009 in the state of Washington. The crash site was the uncontrolled intersection of a north/south roadway and an east/west roadway (**Figure**

2). It was raining intermittently and the concrete roadways were wet at the time of the crash. The north/south roadway was configured with two undivided lanes. The lanes were not delineated and the roadway measured 7.6 m (25.0 ft) in total width. Approaching the intersection, the northbound roadway was straight with a positive uphill profile. At 61.0 m (200.0 ft) south of the intersection the slope was 2.2 percent and 30.5 m (100.0 ft) the slope was 2.8 percent. At the estimated point of impact in the intersection the slope was 2.3 percent.



Figure 2. Crash site, northbound approach to intersection

The east/west roadway was configured with two undivided lanes. The lanes were not delineated and the roadway measured 7.6 m (25.0 ft) in total width. Approaching the intersection, the eastbound roadway was straight with a negative downhill profile. At 61.0 m (200.0 ft) south of the intersection the slope was -5.1 percent and at 30.5 m (100.0 ft) the slope was negative -5.0 percent. At the estimated point of impact in the intersection the slope was almost level at -0.8 percent.

Both roadways were bordered by raised concrete curbs measuring 14.0 cm (5.5 in) in height. The posted speed limit at this location was 40 km/h (25 mph). Curb parking was allowed on all the roadsides.

Pre-Crash

The Toyota was traveling in the northbound lane at a driver-estimated speed and of 40 km/h (25 mph) and the Chevrolet was traveling eastbound at an unknown speed. While approaching the intersection the driver of the Toyota looked left and observed the Chevrolet approaching the intersection. When the driver of the Toyota entered the intersection and realized the Chevrolet was also present in the intersection she accelerated as an avoidance maneuver.

Crash

The crash sequence included four events: Events 1 and 2 were vehicle-to-vehicle impacts and Events 3 and 4 were tire-to-curb impacts. Initially, the front end of the Chevrolet impacted the left side of the Toyota (Event 1). The point of impact was estimated to be near the center of the intersection, based on the scene inspection and the driver interview. The impact to the Toyota was slightly rearward of the vehicle's longitudinal center of gravity and consequently the vehicle initiated a counterclockwise rotation and was displaced to the right. The Chevrolet was displaced left and initiated a post-impact trajectory toward the northeast corner of the intersection.

The left front corner of the Chevrolet impacted the left side front of the Toyota in a secondary impact (Event 2). The Toyota then traveled to the east leg of the intersection and its right rear tire and rim impacted the concrete curb (Event 3), fracturing the rim; and then the right front tire and rim

impacted the curb (Event 4), scuffing the tire and rim. The curb impacts damaged the curb including a scraped section measuring 1.6 m (5.3 ft) in length that began 6.9 m (22.6 ft) east of the northeast curb apex and extended east.

The Toyota came to rest facing west in the westbound lane. The at-rest location was approximately 11.5 m (37.7 ft) from the initial vehicle-to-vehicle impact. The Chevrolet came to rest adjacent to the Toyota and facing east in the westbound lane.

For the Toyota in Event 1, the Collision Deformation Classification (CDC)-only algorithm of the WinSMASH program computed a Total Delta-V of 35.0 km/h (21.7 mph), based on the vehicle's left side crush profile. The longitudinal and lateral components were -22.5 km/h (-14.0 mph) and 26.8 km/h (16.7 mph), respectively. The WinSMASH results appear reasonable, based on the vehicle's crush profile.

For the Chevrolet in Event 1, the program computed a Total Delta-V of 31.0 km/h (19.3 mph). The longitudinal and lateral components were -23.7 km/h (-14.7 mph) and -19.9 km/h (-12.4 mph), respectively. The WinSMASH results for the Chevrolet appear reasonable based on the vehicle's estimated CDC.

For the Toyota in Event 2, the Missing vehicle algorithm of the WinSMASH program computed a Total Delta-V of 5.0 km/h (3.1 mph), based on the Toyota's left side crush profile. The longitudinal and lateral components were -0.9 km/h (-0.6 mph) and 4.9 km/h (3.0 mph), respectively. The WinSMASH results appear reasonable, based on the vehicle's crush profile.

For the Chevrolet in Event 2, the program computed a Total Delta-V of 4.0 km/h (2.5 mph). The longitudinal and lateral components were -2.6 km/h (-1.8 mph) and 3.1 km/h (1.9 mph), respectively. For Event 2, the WinSMASH results for the Chevrolet should be considered to be borderline.

Post-Crash

The Toyota's left front door was jammed shut. The driver of the Toyota unbuckled her safety belt, opened the right side door and exited the vehicle without assistance. She did not request medical treatment at the scene and was not transported. She complained of back pain and minor hearing impairment in her left ear. The following day she was examined by her private physician and was prescribed massage therapy for her thoracic and lumbar muscle strains. Within 24 hours after the crash her hearing was normal and later she underwent six massage therapy sessions for pain management.

During the interview the driver of the Toyota stated that the vehicle's engine shut off immediately after the impact with the Chevrolet. There was no evidence of electrolyte spillage at the scene. Based on the vehicle inspection, electrical power to the instrument panel was intact following the crash.

According to the police report, the driver of the Chevrolet was not injured. Both vehicles were towed due to damage and were later declared total losses by their respective insurance companies.

Vehicle Data - 2008 Toyota Prius

The subject vehicle was a 2008 Toyota Prius 5-door hatchback identified by the Vehicle Identification Number (VIN): JTDKB20U783xxxxxx. The vehicle's date of manufacture was May 2008 and the odometer reading was 28,080 km (17,449 mi). The driver had purchased the Toyota the previous year and she estimated the vehicle's odometer reading at the time of purchase to be 24,140 - 32,186 km (15,000 - 20,000 mi). Standard equipment for this vehicle included a 1.5-liter, 4-cylinder engine, electric motor, continuously variable transmission, sealed NiMH propulsion battery, front wheel drive, and 4-wheel anti-lock braking system (ABS). The NiMH battery was concealed aft of the rear bench seat and was protected by an aluminum cover and a removable carpeted panel. The vehicle sustained a minor rear end impact from another vehicle a few days prior to the crash with the Chevrolet. The damage sustained by the Toyota in the earlier crash was limited to bumper surface scratches and paint deposits. The NiMH battery pack was not damaged in the rear end crash.

The vehicle manufacturer recommended P185/65R15 tires for the front and rear, with tire pressures of 241 kPa (35 psi) for the front and 228 kPa (33 psi) for the rear. The vehicle was equipped with Goodyear Integrity P185/65R15 tires that were manufactured in March 2008 and they were mounted to original equipment six-spoke aluminum rims. The tire manufacturer's recommended maximum tire pressure was 303 kPa (44 psi). The specific tire information was as follows:

Position	Measured Pressure	Measured Tread Depth	Restricted	Damage
LF	221 kPa (32 psi)	6 mm (8/32 in)	No	None
LR	Tire flat	6 mm (8/32 in)	No	None
RR	214 kPa (31 psi)	6 mm (8/32 in)	No	None
RF	221 kPa (32 psi)	5 mm (6/32 in)	No	None

The Toyota's interior was configured with leather-covered five-passenger seating. The front bucket seats were separated by a center console and equipped with adjustable head restraints. The driver's head restraint was adjusted to full-up position and was 7.0 cm (2.8 in) above the seat-back. The seat cushion was adjusted between mid- and full-rear track and the seat-back was slightly reclined. The second row seating consisted of a 60/40 split bench seat with folding backs and adjustable head restraints.

Vehicle Damage - 2008 Toyota Prius

Exterior Damage

The Toyota sustained direct and induced damage to the left side resulting from the two impacts with the Chevrolet. For Event 1 the direct damage began 27.0 cm (10.6 in) aft of the rear axle, extended forward 255.0 cm (100.4 in), and ended 42.0 cm (16.5 in) aft of the front axle. The Field L

measurement was identical to the direct damage measurement. Six crush measurements were taken at mid-door level (**Figure 3**) as follows: $C_1 = 0$, $C_2 = 1.0$ cm (0.4 in), $C_3 = 9.0$ cm (3.5 in), $C_4 = 11.0$ cm (4.3 in), $C_5 = 8.0$ cm (3.1 in), $C_6 = 0$. Maximum crush was located 118.0 cm (46.5 in) forward of the rear axle between C_3 and C_4 at the left B-pillar and measured 14.0 cm (5.5 in). The CDC for Event 1 was 10LZEW2.



Figure 3. Left side crush profile

The Toyota sustained direct damage to the left side door panels from the impact with the Chevrolet. The Toyota's sill height measured 22.0 cm (8.7 in), height of maximum door crush measured 52.0 cm (20.5 in), and the Door Sill Differential (DSD) measured 6.0 cm (3.1 in). The sill sustained 2.0 cm (0.8 in) of lateral crush.

For Event 2 the direct damage began 34.0 cm (13.4 in) aft of the front axle, extended forward 92.0 cm (36.2 in), and ended 58.0 cm (22.8 in) forward of the front axle. The Field L measurement was identical to the direct damage measurement. Six crush measurements were taken at mid-door level as follows: $C_1 = 0$, $C_2 = 1.0$ cm (0.4 in), $C_3 = 2.0$ cm (0.8 in), $C_4 = 3.0$ cm (1.2 in), $C_5 = 1.0$ cm (0.4 in), $C_6 = 0$. Maximum crush was located 18.0 cm (7.1 in) forward of the front axle between C_3 and C_4 and measured 4.0 cm (1.6 in). The CDC for Event 2 was 09LFMW1.



Figure 4. Rim fracture (Event 3)

For Event 3 the direct damage to the tire and rim began 26.0 cm aft of the rear axle, extended 52.0 cm forward, and ended 26.0 cm forward of the rear axle. A 3.0 x 15.0 cm (1.2 x 5.9 in) section of rim was fractured and displaced from the flange (**Figure 4**). Additionally, the impact resulted in a negative cant measuring 5.0 cm (2.0 in) inboard of its original position. The tire was abraded circumferentially and dirt and grass were embedded at the bead. The CDC for Event 3 was 04RBWN1.

For Event 4 the direct damage to the tire and rim began 26.0 cm aft of the rear axle, extended 52.0 cm forward, and ended 26.0 cm forward of the rear axle. The rim was scuffed and the tire sidewall was scuffed circumferentially. The CDC for Event 4 was 03RFWN1.

Interior Damage - 2008 Toyota Prius

The Toyota sustained minor severity interior damage as a result of intrusions, occupant loading and contacts, and post-crash salvage activity. The front and second row interior door panels were removed during post-impact salvage activities and were replaced by the DSI investigator during the

vehicle inspection. Lateral intrusion into the front row passenger compartment resulted from deformation of the left door panel and armrest in the rear lower quadrant, and the sill; and in the second row from the left door panel and left B-pillar. The storage area containing the NiMH traction battery was not reduced in size by intrusion. Evidence of occupant loading and contacts was located on the left IC air bag, left seat-mounted side air bag, and left door panel.

At the time of the inspection the vehicle's left front door would not close or latch due to deformation after having been jammed shut during the crash. The remaining doors and the rear hatch remained closed and operational. The vehicle's glazing remained intact and the vehicle sustained no integrity loss.

Manual Restraints - 2008 Toyota Prius

The Toyota was equipped with manual three-point lap and shoulder safety belts for the five designated seating positions. All the safety belts utilized continuous loop webbing with sliding latch plates. The driver's safety belt retracted into an Emergency Locking Retractor (ELR) with a retractor pretensioner. The remaining safety belts were equipped with ELR/Automatic Locking Retractors (ALR).

The driver's safety belt D-ring anchorage was set to the full-up position and the latch plate was scratched indicating historical usage. The retractor functionality was compromised probably due to B-pillar deformation. The retractor was not fully locked but the belt webbing would not retract completely. The driver's safety belt components did not reveal evidence of occupant loading. The driver stated during the interview that she sustained a left hip contusion when she loaded the lap belt. Based on the vehicle inspection, and driver kinematics and injuries, it was determined the safety belt was used to restrain the driver during the crash.

Supplemental Restraint System - 2008 Toyota Prius

The Toyota was equipped with a CAC frontal air bag system consisting of dual-stage driver and right passenger air bags, seat track positioning systems, front right passenger presence sensor, and retractor pretensioners.

The vehicle's Supplemental Restraint System (SRS) included an air bag control module (ACM), driver and passenger frontal air bags, seat-mounted side air bags for the front row, and side impact IC air bags. At impact with the Chevrolet, the left seat-mounted side air bag and IC air bag deployed (**Figure 5**).

The left seat-mounted side air bag deployed from the outboard aspect of the left seat-back. The air bag was oval in shape with a rectangular tab at the leading edge. It measured 34.0 cm (13.4 in) in



Figure 5. Deployed IC air bag and seat-mounted side air bag

height and 32.0 cm (11.8 in) in width. The air bag's bottom edge was level with the bottom of the arm rest and it extended upward above the bottom of the side glass. The air bag was configured with three 0.5 cm (0.2 in) vent ports located in a non-inflatable section of the air bag. It was configured without internal tethers.

The seat-mounted side air bag was scuffed from occupant loading on the upper aspect of the inboard panel. A 2.0 cm (0.8 in) scuff was located 6.0 cm (2.4 in) below the upper edge and 15.0 cm (5.9 in) aft of the leading edge, placing the scuff midway between the leading edge of the air bag and the seat back. A second scuff measuring 2.0 x 8.0 cm (0.8 x 3.1 in) began at the leading edge and extended rearward. The scuffs resulted from loading of the air bag from the driver's left shoulder and flank. The outboard panel of the air bag was unremarkable.

The left IC air bag deployed from the left roof side rail above the front and second rows. The IC air bag measured 188.0 cm (74.0 in) in length and 45.0 cm (17.7 in) in height. It was configured with 20 horizontal pleats and no vent ports or tethers. A triangular sail measuring 22.0 (8.7 in) in length connected the air bag's leading edge to the A-pillar.

The IC air bag revealed a hair and skin oil transfer measuring 8.0 x 24.0 cm (3.1 x 9.4 in) that was deposited by the driver when her head and face loaded the air bag. The IC air bag revealed no additional damage and the outboard panel was unremarkable.

Hybrid Electrical System - 2008 Toyota Prius

The Toyota was configured with a hybrid powertrain that consisted of a gasoline engine, generator, electric motor, and NiMH high-voltage propulsion battery pack. The battery pack consists of 28 low-voltage (7.2-volts) NiMH modules connected in series to produce approximately 201-volts.¹ The gasoline engine is linked to the drive wheels and when it is running it drives the generator that keeps the propulsion battery charged. The generator supplies power to the electric motor and charges the battery as well.²

Federal Motor Vehicle Safety Standard (FMVSS) 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.³ 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

¹ Source: Toyota Prius 2nd Generation (2004-2009) Emergency Response Guide

² How Hybrid Vehicles Work, <http://pressroom.toyota.com>

³ U.S. Dept. Of Transportation, 49 CFR 571.305

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 not checked for compliance with FMVSS No. 305 but this was observed based on the following evidence:

1. There were no indications of electrolyte spillage from the propulsion battery either outside or inside the passenger compartment (**Figure 6**).

2. There was no movement of the propulsion battery or other system components including the service plug (**Figure 7**). The service plug was removed from the propulsion battery by the DSI investigator and the receptacle was unremarkable. With the service plug removed, the propulsion battery failed to register any reading on voltage meters.

The electrical isolation test was not conducted. The insurance company required that no mechanical tear down or invasive inspection of the vehicle occur. The vehicle's 12-volt auxiliary battery was jumped in an attempt the start the vehicle. The electronic odometer and other controls illuminated on the IP and the power door locks were activated. The video screen on the IP displayed systems status and maintenance details pertaining to the vehicle. Additionally, the start button illuminated. The attempt to start the vehicle was unsuccessful and the reason was unknown.

Vehicle Data - 2008 Chevrolet Malibu LS

The other vehicle was a 2008 Chevrolet Malibu LS identified by the VIN: 1G1ZG57B784xxxxxx. The vehicle was manufactured in May 2008. Standard equipment for this model included a 2.4-liter, 4-cylinder engine, automatic transmission, power steering, front wheel drive, 4-wheel anti-lock brakes, traction control, and daytime lights.



Figure 6. NiMH Propulsion battery pack encased in aluminum cover

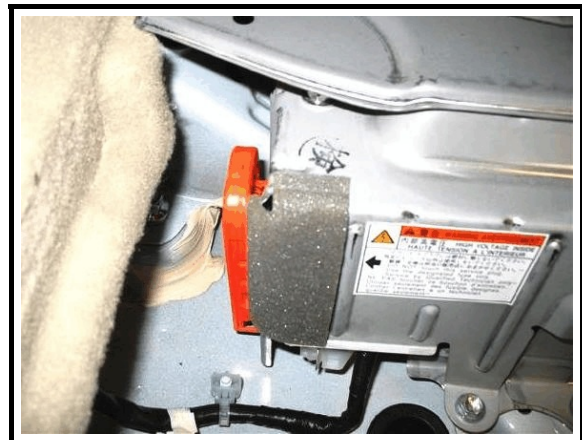


Figure 7. Propulsion battery service plug in place (orange component)

Exterior Damage - 2008 Chevrolet Malibu LS

The Chevrolet sustained direct and induced damage to the frontal plane (**Figure 8**), and induced damage to the top and side planes. The front bumper fascia was displaced and the grille and front fender panels were missing. Based on the photographs the damage to the front end was distributed from bumper corner to bumper corner encompassing the vehicle's undeformed end with of 148.0 cm (58.3 in). For Event 1, the estimated CDC for the Chevrolet was 01FDEW2. For Event 2, the estimated CDC was 10FL9999.



Figure 8. Other vehicle, 2008 Chevrolet Malibu LS (auction facility photo)

Occupant Demographics - 2008 Toyota Prius

Driver

Age/Sex:	24 years/Female
Height:	170.0 cm (67.0 in)
Weight:	61.0 kg (135.0 lb)
Seat type:	Bucket with adjustable head restraint
Seat track position:	Between mid- to full-rear track
Manual restraint usage:	Lap and shoulder belt used
Usage source:	Vehicle inspection
Air bags:	IC air bag and seat-mounted side air bag, deployed; frontal air bag, not deployed
Alcohol, drug involvement:	None present
Type of medical treatment:	Examined by private physician one day after the crash, and sought follow-up treatment from a massage therapist.

Occupant Kinematics - 2008 Toyota Prius

Driver

The 24-year-old female driver was seated in an upright posture and was restrained by the vehicle's lap and shoulder belt. Her seat back was slightly reclined and her seat cushion was set between mid- to full-rear track. She was actively steering the vehicle but during the interview could not recall if she was using one or both hands. Her right foot was on the accelerator and her left foot was on the

floor. She was wearing prescription contact lenses and all the windows in the vehicle were closed or fixed.

As she approached the intersection the driver observed the Chevrolet also approaching the intersection from the crossing roadway. Her intent was to reach the intersection first and proceed straight through to continue northbound. Once she entered the intersection she again observed the Chevrolet and accelerated in an evasive maneuver to avoid contact.

At impact with the Chevrolet, the left IC air bag and left seat-mounted side air bag deployed. The driver was displaced left in response to the 10 o'clock direction of force. She loaded the lap belt webbing resulting in a left hip contusion. The driver's left face and head loaded the IC air bag depositing a skin and hair oil transfer on the air bag. The driver sustained temporary hearing impairment to her left ear that possibly resulted from the loading of the IC air bag; another possible cause was the sound created by the initial impact and deployed air bags.

The driver's left shoulder and flank loaded the seat-mounted side air bag and the left door panel, depositing two scuffs onto each of the components. The driver sustained thoracic and lumbar muscle strains as a result of impact forces.

After the initial impact, a secondary vehicle-to-vehicle impact resulted as the left front of the Chevrolet impacted the left side of the Toyota. This was a low Delta-V event (less than 10.0 km/h (6.2 mph)) and had little effect on the driver's kinematics. The driver was displaced rearward and left in response to the vehicle's rotational movement and the post-impact trajectory of the Toyota.

The Toyota traveled to the north curb and the right rear tire impacted the curb. The driver was displaced rearward and right in response to the direction of force but was held in place in her seat by the seat back and safety belt. The vehicle came to rest facing west at the curb.

Occupant Injuries

Driver

The injury data was obtained from the driver interview.

<u>Injury</u>	<u>Injury Severity</u> <u>AIS 1990 / Update 1998</u>	<u>Injury Mechanism</u>	<u>Confidence Level</u>
Thoracic muscle strain	640478.1,7	Impact forces	Probable
Lumbar muscle strain	640678.1,8	Impact forces	Probable
Hip contusion, left	890402.1,2	Safety belt webbing	Probable

Attachment 1. Scene Diagram

