BLIND SPOT INTERVENTION SYSTEM CONFIRMATION TEST
NCAP-DRI-BSI-20-10-1

2020 Volvo S60 T6 AWD Momentum

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11 January 2021

Final Report

Prepared Under Contract No. DTNH22-14-D-00333

U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
1200 New Jersey Avenue, SE
West Building, 4th Floor (NRM-110)
Washington, DC 20590

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These tests were conducted on the subject 2020 Volvo S60 T6 AWD Momentum in accordance with the specifications of the National Highway Traffic Safety Administration’s most current Test Procedure in docket NHTSA-2019-0102-0001, BLIND SPOT INTERVENTION SYSTEM CONFIRMATION TEST, to confirm the performance of a Blind Spot Intervention system. The vehicle met the requirements of the test for Test 3: SV Lane Change, Constant Headway, False Positive, but did not meet the requirements for the remaining scenarios. The preliminary BSI requirements were met for 9 out of 21 valid trials.</td></tr>
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Section I

INTRODUCTION

There are presently two commercially available crash avoidance technologies designed to directly address the “changing lanes/same direction” pre-crash scenario: Blind Spot Detection (BSD) and Blind Spot Intervention (BSI). BSD is a warning-based passive technology designed to help the driver recognize that another vehicle is approaching, or being operated within, the blind spot of their vehicle in an adjacent lane. Should the driver initiate a lane change towards this other vehicle, the BSD presents an alert before a collision is expected to occur. BSI systems are designed to actively help the driver avoid a collision with another vehicle that is approaching, or being operated within, the blind spot of their vehicle in an adjacent lane.

This research test evaluates BSI systems on light vehicles with SAE automation levels 0, 1, 2, or 3, as specified in the National Highway Traffic Safety Administration’s “Blind Spot Intervention System Confirmation Test”, July 2019. The subject light vehicles have gross vehicle weight ratings (GVWR) under 10,000 pounds. BSI technology uses sensors to detect the presence of other vehicles in the equipped vehicle’s left and right blind spot and then intervene to avoid a collision. The procedures described herein emulate three straight-road, real-world scenarios in which the Subject Vehicle (SV) operating under SAE automation levels 0, 1, 2, or 3 attempts to perform a lane change. The adjacent destination lane is occupied by a single Principal Other Vehicle (POV) in the first two scenarios, and not in the third. Although it is impossible to predict what technologies could be used by future BSI systems, it is believed that minor modifications to these procedures, when deemed appropriate, could be used to accommodate the evaluation of alternative or more advanced BSI systems.

Section II

DATA SHEETS

BLIND SPOT INTERVENTION

DATA SHEET 1: TEST RESULTS SUMMARY

(Page 1 of 1)

2020 Volvo S60 T6 AWD Momentum

VIN: *7JRA22TK5LG06xxxx*

Test Date: *8/3/2020*

System Setting(s): *BLIS on*

		Number of valid test runs for which acceptability[1] criteria were: Met	Not met	Valid trials
Test 1 -	**Subject Vehicle Lane Change, Constant Headway**	*1*	*6*	*7*
Test 2 -	**Subject Vehicle Lane Change, Closing Headway**	*1*	*6*	*7*
Test 3 -	**Subject Vehicle Lane Change, Constant Headway, False Positive**	*7*	*0*	*7*
	Overall:	***9***	***12***	***21***

Notes: *All tests were performed at Level 0 automation.*

[1] The acceptability criteria listed herein are used only as a guide to gauge system performance, and are identical to the Pass/Fail criteria given in NHTSA's most current Test Procedure in docket NHTSA-2019-0102-0001, BLIND SPOT INTERVENTION SYSTEM CONFIRMATION TEST.

BLIND SPOT INTERVENTION

DATA SHEET 2: VEHICLE DATA

2020 Volvo S60 T6 AWD Momentum

TEST VEHICLE INFORMATION

VIN: *7JRA22TK5LG06xxxx*

Body Style: *Sedan* Color: *Fusion Red Metallic*

Date Received: *7/16/2020* Odometer Reading: *17 mi*

DATA FROM VEHICLE'S CERTIFICATON LABEL

Vehicle manufactured by: *VOLVO CAR CORPORATION*

Date of manufacture: *02/20*

Vehicle Type: *PC (Passenger Car)*

DATA FROM TIRE PLACARD

Tires size as stated on Tire Placard:	Front:	*235/40 R19*
	Rear:	*235/40 R19*
Recommended cold tire pressure:	Front:	*250 kPa (36 psi)*
	Rear:	*250 kPa (36 psi)*

TIRES

Tire manufacturer and model: *Pirelli P Zero*

Front tire size: *235/40 R19 96V*

Rear tire size: *235/40 R19 96V*

Front tire DOT prefix: *1UN FC507K*

Rear tire DOT prefix: *1UN FC507K*

BLIND SPOT INTERVENTION

DATA SHEET 3: TEST CONDITIONS

(Page 1 of 2)

2020 Volvo S60 T6 AWD Momentum

GENERAL INFORMATION

Test date: *8/3/2020*

AMBIENT CONDITIONS

Air temperature: *28.9 C (84 F)*

Wind speed: *1.5 m/s (3.5 mph)*

X Windspeed ≤ 10 m/s (22 mph)

X Tests were not performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, or ash.

X Tests were conducted during daylight hours with good atmospheric visibility (defined as an absence of fog and the ability to see clearly for more than 5000 meters). The tests were not conducted with the vehicle oriented into the sun during very low sun angle conditions, where the sun is oriented 15 degrees or less from horizontal, and camera "washout" or system inoperability results.

All tests were also conducted such that there were no overhead signs, bridges, or other significant structures over, or near, the testing site. Except for the POV, each trial shall be conducted with no vehicles, obstructions, or stationary objects within one lane width of either side the SV path.

VEHICLE PREPARATION

Verify the following:

All non-consumable fluids at 100% capacity: **X**

Fuel tank is full: **X**

Tire pressures are set to manufacturer's recommended cold tire pressure: **X**

Front: *250 kPa (36 psi)*

Rear: *250 kPa (36 psi)*

WEIGHT

Weight of vehicle as tested including driver and instrumentation

Left Front:	*561.5 kg (1238 lb)*	Right Front:	*526.6 kg (1161 lb)*
Left Rear:	*435.9 kg (961 lb)*	Right Rear:	*428.2 kg (944 lb)*
		Total:	*1952.2 kg (4304 lb)*

BLIND SPOT INTERVENTION

DATA SHEET 4: BLIND SPOT INTERVENTION SYSTEM OPERATION

2020 Volvo S60 T6 AWD Momentum

General Information

Name of the BSI option, option package, etc., as shown on the Monroney label:

Blind Spot Information System with Steer Assist (BLIS); included in the Premium Package which is available on all trims.

Type and location of sensors the system uses:

Radar sensors (2) located in the left and right side of the rear bumper and mono camera mounted near the rearview mirror.

System setting used for test (if applicable):

BLIS on

Method(s) by which the driver is alerted

X Visual

	Type	Location	Description
X	Symbol	*Top corners of outside mirrors*	*Orange symbol*
____	Word		
X	Graphic	*Information display*	

X Audible - Description

High pitch warning.

____ Haptic

____	Steering Wheel	____	Seatbelt
____	Pedals	____	Steering Torque
____	Seat	____	Brake Jerk

Description of alert:

Visual indicators are located in the upper-outside corners of the outside mirrors. When a vehicle is in the blind spot and the driver has not activated the turn signal, these indicators will light steady orange. If the driver turns on the turn signal and a vehicle is present in the blind spot, the alert flashes orange. See Figure A14 in Appendix A.

Please describe the method of intervention for the BSI system. For example, if the intervention is turning of the steering wheel, application of braking to one or more wheels of the vehicle, or a combination. If the intervention has different phases, please describe and provide information for each of these.

If the driver attempts to leave the lane creating a possibility of collision with a vehicle in the blind spot the steering system will activate and will steer the vehicle back to its original lane. During this steering intervention the BLIS warning lights will flash repeatedly on the intervention side. Also, a warning message and symbol will be displayed in Driver Information Module accompanied with a repeated high pitch warning sound.

System Function

What is the speed range over which the system operates?

Minimum: *65.6 km/h (41 mph) activation, deactivation if activated and speed drops below 60 km/h (37.5 mph)*

Maximum: *140 km/h (87.5 mph)*

If the system requires an initialization sequence/procedure, please provide a description of the process required to initialize the system.

Initialization is not required.

If the system requires the driver to operate their turn signal indicator during lane change in order to activate, please provide a description.

The system does not require the turn signal to be activated, but if the driver turns on the turn signal and a vehicle is present in the blind spot the visual alert flashes orange.

If the vehicle is equipped with a method to activate/deactivate the system(s) please provide a description of how this is accomplished. If the system is deactivated by this method, does it reactivate upon each ignition cycle?

Menus are presented on the vehicle's center display. Swiping across the screen changes the top-level views. From the Function view, the BLIS and steering assistance functions can be activated or deactivated. See Owner's Manual, pages 322 and 344 shown in Appendix B, page B-3 and B-7.

The system does not automatically reactivate upon each ignition cycle.

If the vehicle is equipped with a method to adjust the range setting/sensitivity or otherwise influence the operation of BSI, please provide a description.

No range/sensitivity adjustments are provided.

If the system deactivates due to damage to the sensors, how is this indicated to the driver?

Warning messages are described on page 324 of the Owner's Manual, shown in Appendix B, Page B-5.

If the system deactivates due to repeated BSI activations:

- How is this indicated to the driver?
- Can deactivation be avoided (e.g., by cycling the ignition after each BSI activation)?
- How can the system be reactivated?

No, the system remains operational.

If the system deactivates or its effectiveness is reduced due to periods of inactivity:

- How is this indicated to the driver?
- Can deactivation be avoided?
- How can the system be reactivated?

Warning messages are described on page 324 of the Owner's Manual, shown in Appendix B, Page B-5.

2020 Volvo S60 T6 AWD Momentum

If there are other driving modes or conditions (such as weather) that render the system inoperable or reduce its effectiveness please provide a description.

> *Potential system limitations are described in the Owner's Manual on page 323 shown in Appendix B, page B-4.*

Notes:

Section III

TEST PROCEDURES

A. Test Procedure Overview

Three test scenarios were used, as follows:

Test 1.	SV Lane Change with Constant Headway
Test 2.	SV Lane Change with Closing Headway
Test 3.	SV Lane Change with Constant Headway, False Positive

An overview of each of the test procedures follows.

1. TEST 1 – SV LANE CHANGE WITH CONSTANT HEADWAY

The SV Lane Change with Constant Headway (SVLC_Constant_HW) test evaluates the ability of the BSI system to detect and respond to a POV in an adjacent lane blind spot by preventing the SV from changing lanes or colliding with the POV. For this scenario, the POV resides in the SV blind spot with a constant headway. This test scenario is depicted in Figure 1.

The test begins with the POV in the left lane adjacent to the SV. After both vehicles have reached their designated speeds and headway overlap, the SV driver engages the left turn signal indicator and initiates a single lane change maneuver into the lane occupied by the POV. Specific details of the lane change method depended on the automation level as summarized in Table 1. The BSI system was then expected to intervene and prevent the SV from contacting the POV.

This test scenario was performed with the highest available SV automation level (0, 1, 2, or 3).

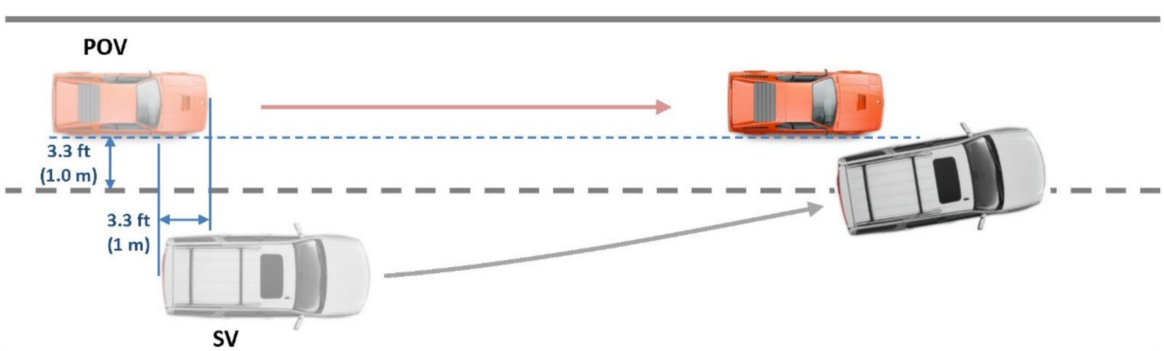


Figure 1. SV Lane Change with Constant Headway Test Scenario

a. Procedure for Automated Vehicle Level 0 or 1 Operation

The tests with SV automated vehicle level 0 or 1 were performed with manual steering input from a robotic steering controller. The SV and POV began in their respective travel lanes with their longitudinal axes oriented parallel to the roadway edge. The initial SV path was offset in the lane as shown in Figure 2 . Both vehicles then accelerated to an initial speed of 45 mph (72.4 km/h). This speed and specified headway overlap between the front-most point of the POV and the rear-most point of the SV were maintained throughout the test. The headway overlap is specified with the front bumper of the POV located 1.0 ± 0.5 m (3.3 ± 1.6 ft) ahead of the rear of the SV (therefore the specified headway distance is a negative value indicating longitudinal overlap).

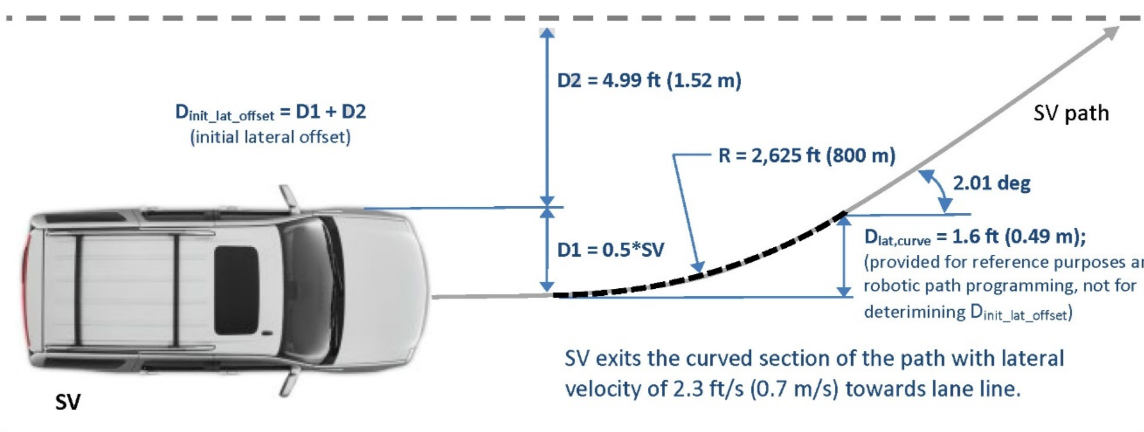


Figure 2. Input Parameters Used to Define the SV Path During the SV Level 0 and 1 Lane Change with Constant Headway Scenario

Once the speeds of both vehicles and the specified headway overlap were stabilized, the vehicles held this formation from the beginning of the test validity period until the SV lane change was initiated, as follows. After at least 3 seconds from the onset of the validity period, the SV driver activated the left turn signal indicator. Then within 1 ± 0.5 seconds after the turn signal was activated, the SV robotic steering controller began the lane change shown in Figure 2. The steer torque applied by the SV robotic steering controller stopped[2] within 250 ms of achieving the desired SV heading angle after the SV exited the 2,625 ft (800 m) radius curve during the lane change. The POV used open loop control to maintain the initial speed indicated in Table 1 (i.e., 45 mph).

[2] To emulate the situation where a human driver is operating the vehicle with their hands removed from the steering wheel.

b. Validity Period

The valid test interval began 3 seconds before the SV driver activated the left turn signal indicator.

For trials where the BSI system intervened, the valid test interval ended when one of the following conditions occurred:

- The SV impacted the POV; or
- five seconds after the SV had established a heading away from the POV and was completely within its original travel lane; or
- one second after the SV traveled ≥ 1 ft (0.3 m) beyond the inboard edge of the lane line separating the SV travel lane from the lane adjacent and to the right of it, as shown in Figure 3.

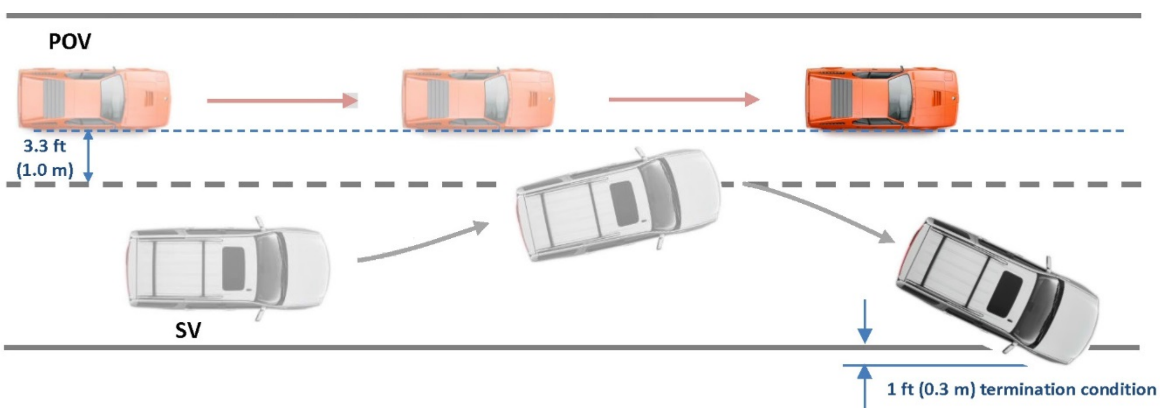


Figure 3. Valid SV Lane Change Intervention Test Interval End Condition 3

For trials where the BSI did not intervene, the valid test interval ended when the SV impacted the POV.

In addition to the procedure and timing described above, for an individual test trial to be valid, the following was required throughout the test:

- The general test validity criteria specified in Section III.B.1 were satisfied.
- The test parameters specified in Table 1 were within the allowable limits specified in Table 1 during the entire test interval or the epoch indicated.
- After initiation of the SV lane change, the POV used open loop control to maintain the constant speed specified in Table 1.

After the test validity period ended, the SV driver manually applied force to the brake pedal, bringing the vehicle to a stop, and placed the transmission in park. The POV also braked to a stop, and the SVLC_Constant_HW test trial was complete.

c. Number of Test Trials

Seven valid SVLC_Constant_HW test trials were performed for the SV automation condition listed in Data Sheet 1.

If no intervention was detected on the first three of the seven valid trials, testing was stopped after three trials in order to mitigate damage to both the POV and SV.

d. Evaluation Criteria

The BSI system performance requirements for the SVLC_Constant_HW tests depended on the level of automation the SV was operating in during that trial. Passing BSI test criteria were:

- The SV did not impact the POV during any valid test performed in automation level 0 or 1 (i.e., those performed with the timing and inputs described in Section III.A.1.a), or

- the SV did not initiate the lane change commanded by the turn signal indicator during any valid test performed with automation level 2 or 3 (i.e., those described in Section III.A.1.b), and

- the SV BSI intervention did not cause the SV to travel ≥ 1 ft (0.3 m) beyond the inboard edge of the lane line separating the SV travel lane from one adjacent and to the right of it within the validity period defined in Section III.A.1.c during any valid test (i.e., with automation level 1, 2, or 3).

Table 1. SV Lane Change with Constant Headway Test Specifications

SV Automation Condition	Initial Speed		Lateral Lane Position		SV-to-POV Longitudinal Orientation	SV Left Turn Signal Activation	SV Lane Change			SV Path Tolerance	Number of Trials
	SV	POV	SV	POV			Initiation Timing	Steering Release Timing	Lateral Velocity		
Manual speed control, LCC off (Level 0)	45 ± 1 mph (72.4 ± 1.6 km/h)	45 ± 1 mph (72.4 ± 1.6 km/h)	Manually offset within travel lane, then manual lane change towards left adjacent lane	Constant; 3.3 ± 0.8 ft (1 ± 0.25 m) from the right side of the POV to the inboard edge of the lane line immediately to its right	Constant; front-most point of the POV 3.3 ± 1.6 ft (1 ± 0.5 m) ahead of the rear-most point of the SV	At least 3 seconds after all pre-SV lane change test validity criteria have been satisfied	1.0 ± 0.5 s after the SV turn signal is activated	Within 250 ms of achieving desired SV heading angle after exiting the 2,625 ft (800 m) radius curve during the lane change	2.3 ± 0.3 ft/s (0.7±0.1 m/s)	± 0.8 ft (± 0.25 m) until SV steering wheel is released	7
Cruise control, LCC off (Level 0)											7
ACC on, LCC off (Level 1)											7

2. TEST 2 – SV LANE CHANGE WITH CLOSING HEADWAY

The SV Lane Change with Closing Headway (SVLC_Closing_HW) test evaluates the ability of the BSI system to detect a POV approaching a blind spot in an adjacent lane and prevent the SV from changing lanes and colliding with it. The POV is approaching the SV blind spot from the rear, as depicted in Figure 4. In this scenario, the test begins with the POV in the left lane adjacent to the SV. After both vehicles have reached their designated speeds, the SV driver engages the left turn signal indicator and initiates a single lane change maneuver into the lane occupied by the POV. Specific details of the lane change method depended on the automation level as summarized in Table 2. The BSI system was then expected to intervene and prevent the SV from contacting the POV.

This test scenario was performed with the highest available SV automation level (0, 1, 2, and 3).

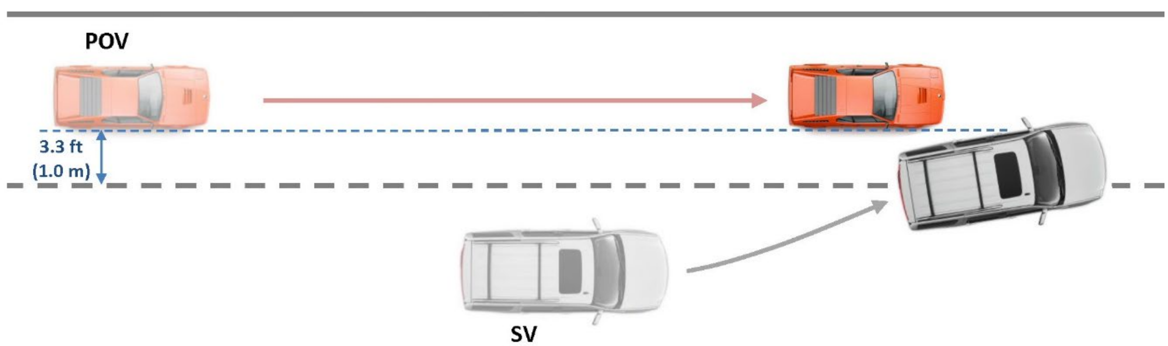


Figure 4. SV Lane Change with Closing Headway Test Scenario

a. Procedure for Automated Vehicle Level 0 or 1 operation

The tests with SV automated vehicle level 0 or 1 were performed with manual steering input from a robotic steering controller. The SV and POV began in their respective travel lanes with their longitudinal axes oriented parallel to the roadway edge, with the POV behind the SV as shown in Figure 4. The initial SV path was offset in the lane as shown in Figure 2 . The SV then accelerated to an initial speed of 45 mph (72.4 km/h) while the POV accelerated to an initial speed of 50 mph (80.5 km/h). These speeds were then maintained throughout the test.

The SV driver then activated the left SV turn signal indicator when the front of the POV was 4.9 ± 0.5 seconds from a vertical plane defined by the rear of the SV and perpendicular to the SV travel lane. This event nominally occurs when the longitudinal SV-to-POV headway is 35.6 ft (10.8 m) if the speed differential is 5 mph (8 km/h).

Then, when the POV is 3.9 ± 0.5 seconds from a vertical plane defined by the rear of the SV and perpendicular to the SV travel lane, the SV robotic steering controller began the lane change shown in Figure 2. This event nominally occurs when the longitudinal SV-to-POV headway is 28.2 ft (8.6 m) if the speed differential is 5 mph (8 km/h). The steer torque applied by the SV robotic steering controller stopped within 250 ms of achieving the desired SV heading angle after the SV exited the 2,625 ft (800 m) radius curve during the lane change. The POV used open loop control to maintain the initial speed indicated in Table 2 (i.e., 50 mph).

b. Validity Period

The valid test interval began 3 seconds before the SV driver activated the left turn signal indicator.

For trials where the BSI system intervened, the valid test interval ended when one of the following conditions occurred:

- The SV impacted the POV; or

- five seconds after the SV had established a heading away from the POV and was completely within its original travel lane; or

- one second after the SV traveled ≥ 1 ft (0.3 m) beyond the inboard edge of the lane line separating the SV travel lane from the lane adjacent and to the right of it, as shown in Figure 3.

For trials where the BSI did not intervene, the valid test interval ended when the SV impacted the POV.

In addition to the procedure and timing described above, for an individual test trial to be valid, the following was required throughout the test:

- The general test validity criteria specified in Section III.B.1 were satisfied.
- After the test validity period ended, the SV driver manually applied force to the brake pedal, bringing the vehicle to a stop, and placed the transmission in park. The POV was also braked to a stop, and the SVLC_Closing_HW test trial was complete.

c. Number of Test Trials

Seven valid SVLC_ Closing _HW test trial were performed for the SV automation condition listed in Data Sheet 1.

If no intervention was detected on the first three of the seven valid trials, testing was stopped after three trials in order to mitigate damage to both the POV and SV.

d. Evaluation Criteria

The BSI system performance requirements for the SVLC_Closing_HW tests depended on the level of automation the SV was operating in during that trial. Passing BSI test criteria were:

- The SV did not impact the POV during any valid test performed in automation level 0 or 1 (i.e., those performed with the timing and inputs described in Section III.A.2.a), or
- the SV did not initiate the lane change commanded by the turn signal indicator during any valid test performed with automation level 2 or 3 (i.e., those described in Section III.A.2.b), and
- the SV BSI intervention did not cause the SV to travel ≥ 1 ft (0.3 m) beyond the inboard edge of the lane line separating the SV travel lane from one adjacent and to the right of it within the validity period defined in III.A.2.c during any valid test (i.e., with automation level 1, 2, or 3).

Table 2. SV Lane Change with Closing Headway Test Specifications

SV Automation Condition	Initial Speed		Lateral Lane Position		SV-to-POV Longitudinal Orientation	SV Left Turn Signal Activation	SV Lane Change			SV Path Tolerance	Number of Trials
	SV	POV	SV	POV			Initiation Timing	Steering Release Timing	Lateral Velocity		
Manual speed control, LCC off (Level 0)	45 ± 1 mph (72.4 ± 1.6 km/h)	50 ± 1 mph (80.5 ± 1.6 km/h)	Manually offset within travel lane, then manual lane change towards left adjacent lane	Constant; 3.3 ± 0.8 ft (1 ± 0.25 m) from the right side of the POV to the inboard edge of the lane line immediately to its right	POV approaches the rear of the SV with a constant 5 mph (8.1 km/h) relative velocity	When the front-most point of the POV is 4.9 ± 0.5 seconds from a vertical plane defined by the rear-most point of the SV and perpendicular to the SV travel lane	When the front-most point of the POV is 3.9 ± 0.5 seconds from a vertical plane defined by the rear-most point of the SV and perpendicular to the SV travel lane	Within 250 ms after exiting the 2,625 ft (800 m) radius curve during the lane change	2.3 ± 0.3 ft/s (0.7±0.1 m/s)	± 0.8 ft (± 0.25 m) until SV steering wheel is released	7
Cruise control, LCC off (Level 0)											7
ACC on, LCC off (Level 1)											7

Note: Columns 3, 6, 7, and 8 in Table 2 are different from Table 1.

3. TEST 3 – SV LANE CHANGE WITH CONSTANT HEADWAY, FALSE POSITIVE ASSESSMENT

The SV Lane Change with Constant Headway, False Positive (SVLC_Constant_HW_FP) test assesses whether or not a BSI system detects and responds to a non-threatening POV during a single lane change. In this scenario, the POV is two lanes away from the SV, adjacent to the SV blind spot, and traveling with constant headway. This test scenario is depicted in Figure 5. In this scenario, the test begins with the POV in the second lane to the left of the SV After both vehicles have reached their designated speeds and headway overlap, the SV driver engages the left turn signal indicator and initiates a single lane change maneuver into the lane between the initial SV and POV travel lanes. Specific details of the lane change method depended on the automation level as summarized in Tables 3a and 3b.

This test scenario was performed in two parts comprised of "baseline" and "evaluation" trials, with SV automation level 0, 1, 2, or 3 depending on the highest SAE automation level available on the SV. The main difference between the baseline and evaluation trials is that evaluation trials were performed with the POV present and the baseline trials were performed without the POV. The BSI system was expected to not respond any differently to the presence of the POV compared to a similar baseline test trial without the POV.

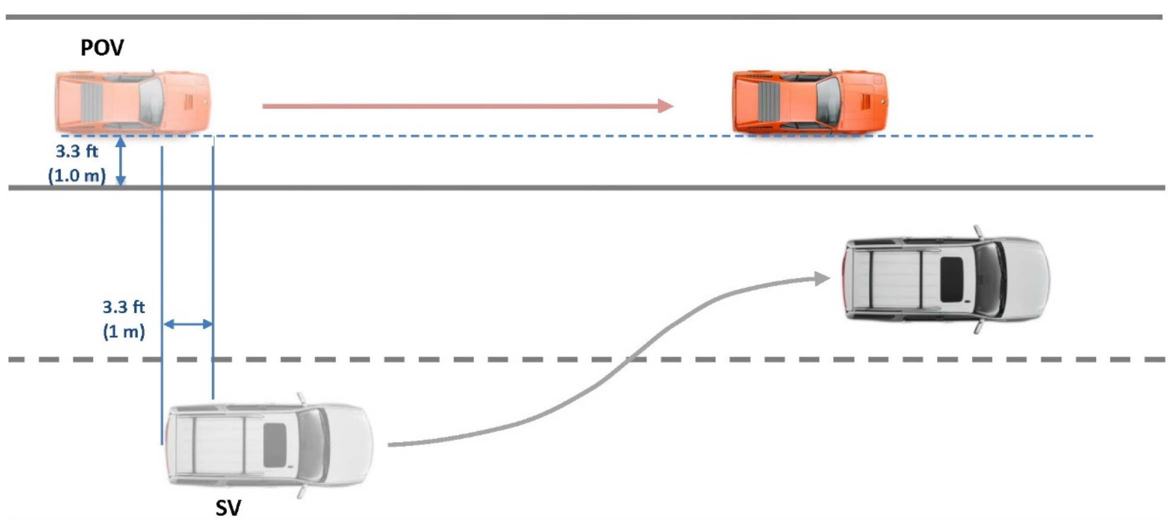


Figure 5. Lane Change with Constant Headway, False Positive Test Scenario

a. Procedure for Automated Vehicle Level 0 or 1 Operation

The SVLC_Constant_HW_FP tests with level 0 and 1 operation were performed in a similar manner as the SVLC_Constant_HW tests described in Section III.A.1.a with the following exceptions:

- The initial SV and POV lanes of travel were separated by a lane of travel in between them as shown in Figure 5.
- The SV driver did not release the steering wheel (or robotic steering control equivalent) at any time during the baseline test trial.
- The SV driver did not release the steering wheel (or robotic steering control equivalent) at any time during the evaluation test trial unless system intervention was detected.
- The manual steer input included a lane change completion phase as shown in Figure 6.
- The tests were conducted both with and without the POV present.
- There were 3 baseline trials without the POV, as specified in Table 3a. The SV was driven at the initial speed of 45 mph (72.4 km/h) either manually or using the cruise control after it was enabled and initialized. After maintaining this initial speed (there was no initial SV-POV vehicle formation as depicted in Figure 5 during the trial because the POV was not present), the SV driver engaged the left turn signal indicator and initiated the single lane change into the left adjacent lane. No BSI system interventions were expected in the baseline trials because no POV was present.
- There were 7 evaluation trials with the POV, as specified in Table 3b. The SV and POV were both driven at the initial speed of 45 mph (72.4 km/h) and established the initial longitudinal and lateral formation shown in Figure 5. The SV speed was achieved either manually or with the cruise control enabled and initialized. After maintaining the initial formation shown in Figure 5 for 3 seconds, the SV driver engaged the left turn signal indicator and initiated the single lane change into the left adjacent lane. No BSI system interventions were expected in the evaluation trial because a single lane change should not result in a collision with the POV.
- The validity period is defined in Section III.A.3.c.

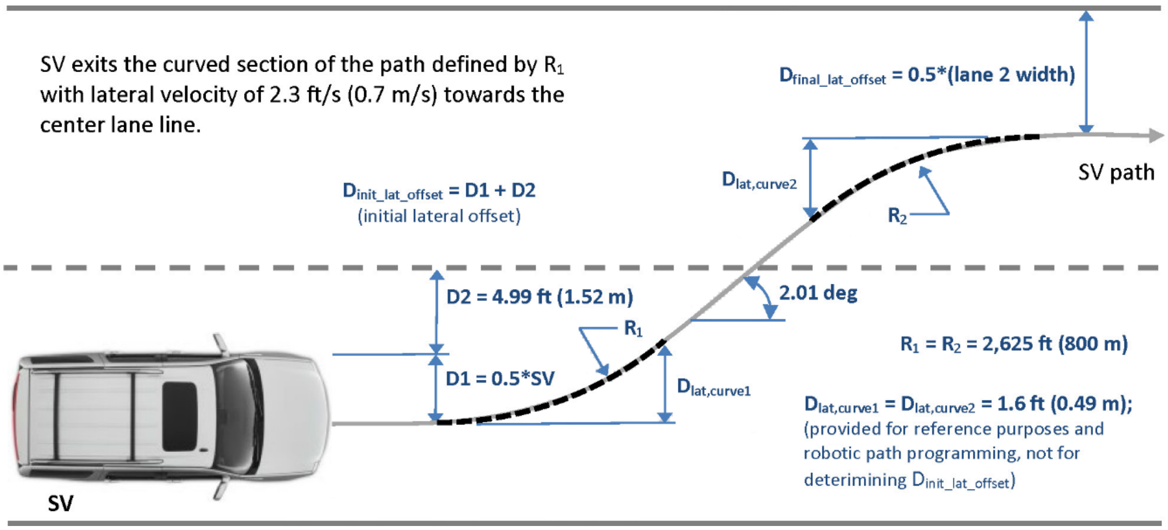


Figure 6. Input Parameters used to define the SV path during the SV Lane Change with Constant Headway, False Positive Scenario

b. Validity Period

The valid test interval began 3 seconds before the SV driver activated the left turn signal indicator.

The valid test interval ended when one of the following conditions occurred:

1. The SV impacted the POV; or

2. Five seconds after the SV had completed the single lane change into the left lane adjacent to the SV's original travel lane without a BSI intervention; or

3. One second after a BSI intervention caused the SV to travel ≥ 1 ft (0.3 m) beyond the inboard edge of the lane line separating the post lane change SV travel lane and the lane adjacent and to the right of it, as shown in Figure 7.

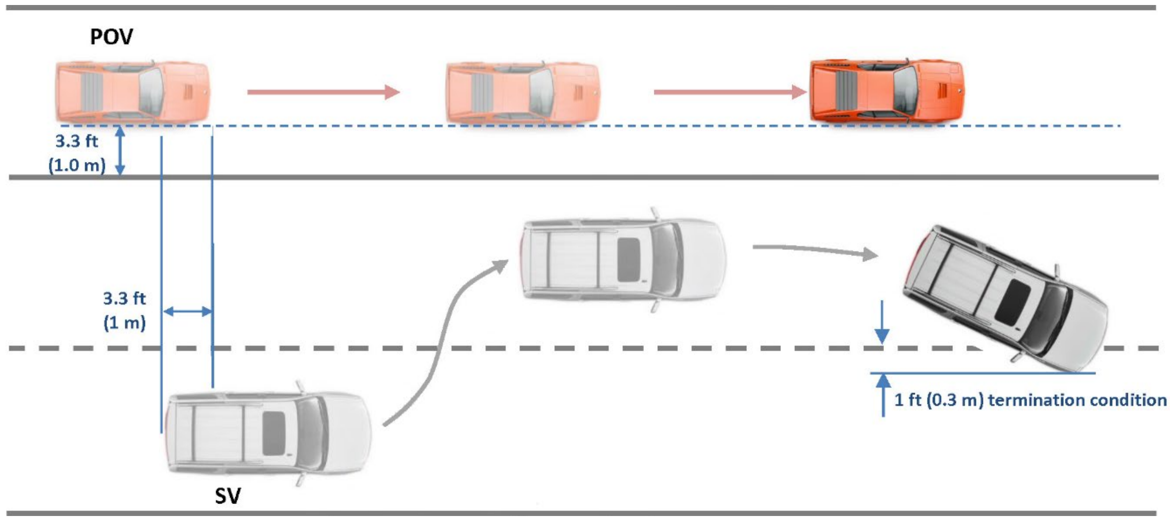


Figure 7. Valid SV Lane Change False Positive Test Interval End Condition 3

In addition to the procedure and timing described above, for an individual test trial to be valid, the following was required throughout the test:

- The general test validity criteria specified in Section III.B.1 were satisfied.
- The test parameters specified in Tables 3a and 3b were within the allowable limits specified in Tables 3a and 3b during the entire test interval or the epoch indicated.
- For evaluation trials, after initiation of the SV lane change, the POV used open-loop control to maintain the constant speed specified in Table 3b.

After the test validity period ended, the SV driver manually applied force to the brake pedal, bringing the vehicle to a stop, and placed the transmission in park. The POV was also braked to a stop for evaluation trials. The SVLC_Constant_HW_FP test trial was then complete.

c. Evaluation Method and Criteria

Determination of whether a false positive BSI intervention occurred during a SVLC_Closing_HW_FP evaluation required the comparison of the SV yaw rate data collected during the evaluation trial with the acceptability corridor defined by the corresponding composite data from the baseline trials. This was accomplished in two steps.

The first step was to determine an acceptable yaw rate time history corridor for each SV automation condition, as illustrated by the hypothetical example in Figure 8. The yaw rate time histories for the 3 baseline trials were first synchronized in time so that the onsets of the respective lane changes occurred within 20 ms of each other. The baseline composite yaw rate was then calculated by averaging the yaw rates from the 3 baseline trials, at each time point in the synchronized time history. The acceptability corridor was then the baseline composite yaw rate value ± 1 deg/s.

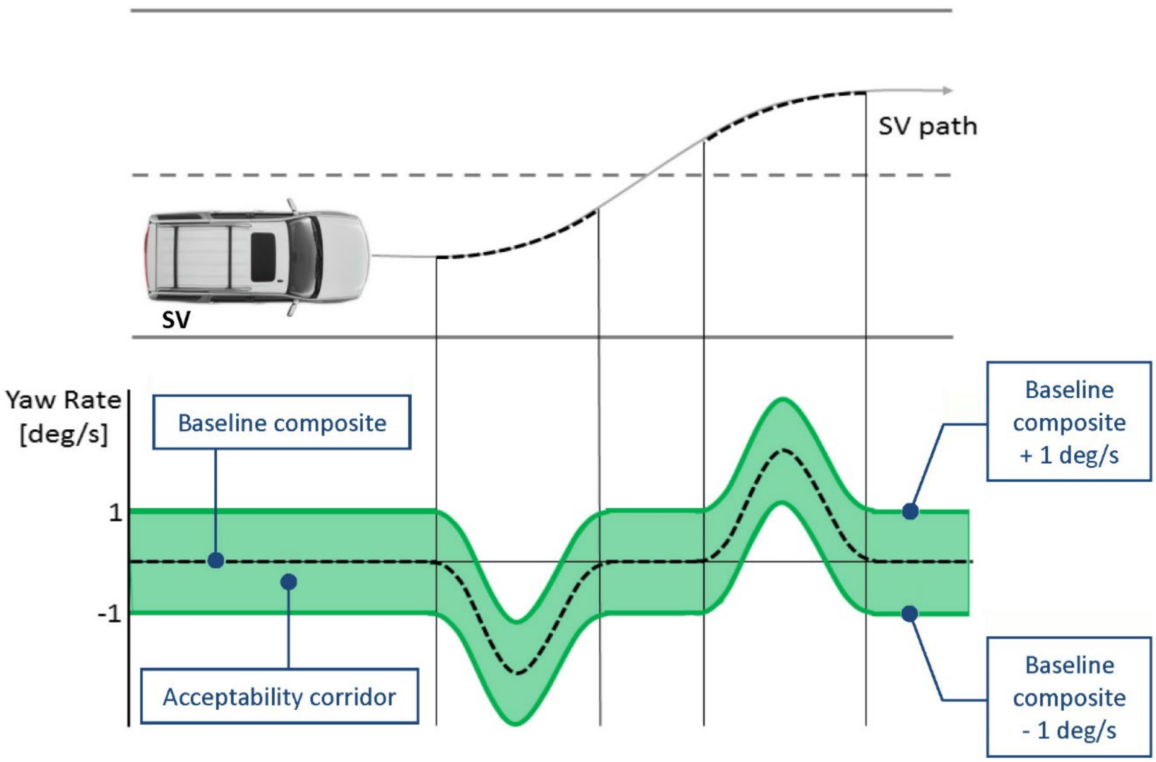


Figure 8. Definition of a Yaw Rate Acceptability Corridor

The second step was to compare the SV yaw rate from each evaluation trial to the acceptable yaw rate time history corridor, as illustrated by the hypothetical example in Figure 9. If, after data synchronization, the SV yaw rate exceeded the acceptability corridor any time during the test validity period defined in Section III.A.3.c, then a false positive intervention test result was determined to have occurred.

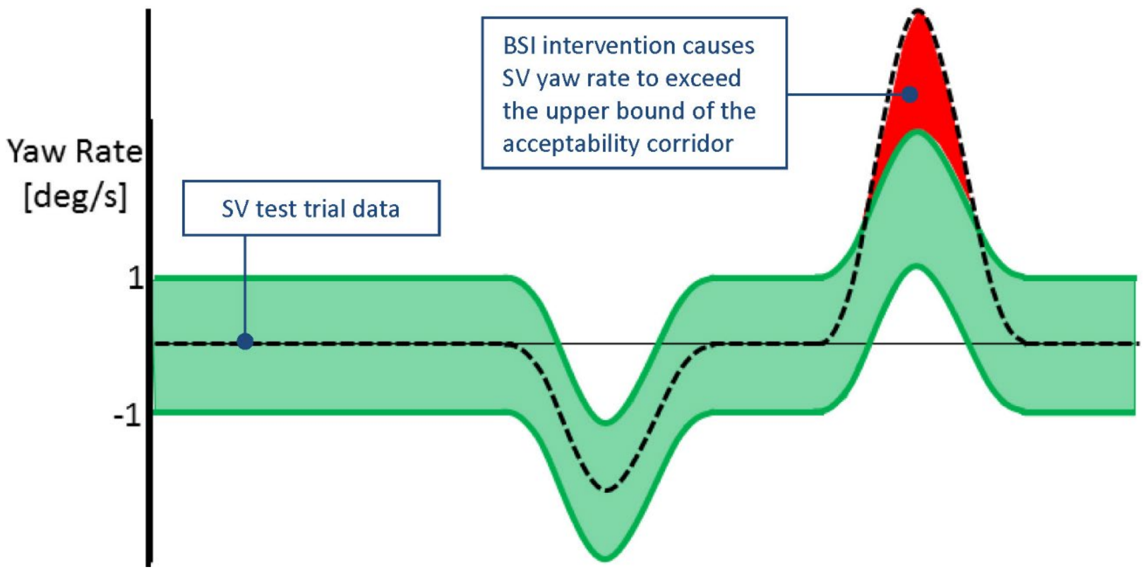


Figure 9. BSI False Positive Example

Table 3a. SV Lane Change with Constant Headway, False Positive Test Specifications (Baseline Trials)

SV Automation Condition	Initial Speed		Lateral Lane Position		SV-to-POV Longitudinal Orientation	SV Left Turn Signal Activation	SV Lane Change			SV Path Tolerance	Number of Trials
	SV	POV	SV	POV			Initiation Timing	Steering Release Timing	Lateral Velocity		
Manual speed control, LCC off (Level 0)	45 ± 1 mph (72.4 ± 1.6 km/h)	N/A	Manually offset within travel lane, then manual lane change into a lane left and adjacent to that of the SV	N/A	N/A	At least 3 seconds after all pre-SV lane change test validity criteria have been satisfied	1.0 ± 0.5 s after the SV turn signal is activated	N/A (the SV driver does not release the steering wheel)	2.3 ± 0.3 ft/s (0.7±0.1 m/s)	± 0.8 ft (± 0.25 m)	3
Cruise control, LCC off (Level 0)											3
ACC on, LCC off (Level 1)											3

Table 3b. SV Lane Change with Constant Headway, False Positive Test Specifications (Evaluation Trials)

<table>
<tr><th rowspan="2">SV Automation Condition</th><th colspan="2">Initial Speed</th><th colspan="2">Lateral Lane Position</th><th rowspan="2">SV-to-POV Longitudinal Orientation</th><th rowspan="2">SV Left Turn Signal Activation</th><th colspan="3">SV Lane Change</th><th rowspan="2">SV Path Tolerance</th><th rowspan="2">Number of Trials</th></tr>
<tr><th>SV</th><th>POV</th><th>SV</th><th>POV</th><th>Initiation Timing</th><th>Steering Release Timing</th><th>Lateral Velocity</th></tr>
<tr><td>Manual speed control, LCC off (Level 0)</td><td rowspan="3">45 ± 1 mph (72.4 ± 1.6 km/h)</td><td rowspan="3">45 ± 1 mph (72.4 ± 1.6 km/h)</td><td rowspan="3">Manually offset within travel lane, then manual lane change into a lane left and adjacent to that of the SV</td><td rowspan="3">Constant; 3.3 ± 0.8 ft (1.0 ± 0.25 m) from the right side of the POV to the inboard edge of the lane line immediately to its right

Note: The POV travel lane is two lanes to the left of the initial SV travel lane.</td><td rowspan="3">Constant; POV front located 3.3 ± 1.6 ft (1 ± 0.5 m) ahead of the SV rear</td><td rowspan="3">At least 3 seconds after all pre-SV lane change test validity criteria have been satisfied</td><td rowspan="3">1.0 ± 0.5 s after the SV turn signal is activated</td><td rowspan="3">N/A (SV driver does not release the steering wheel)</td><td rowspan="3">2.3 ± 0.3 ft/s (0.7 ± 0.1 m/s)</td><td rowspan="3">± 0.8 ft (± 0.25 m) unless a BSI intervention occurs</td><td>7</td></tr>
<tr><td>Cruise control, LCC off (Level 0)</td><td>7</td></tr>
<tr><td>ACC on, LCC off (Level 1)</td><td>7</td></tr>
</table>

B. General Information

1. GENERAL VALIDITY CRITERIA

In addition to any validity criteria described above for the individual test scenarios, for an individual trial to be valid, it must have met the following criteria throughout the test:

- The SV driver seatbelt was latched.
- If any load had been placed on the SV front passenger seat (e.g., for instrumentation), the vehicle's front passenger seatbelt was latched.
- When operating the SV in automation level 0 within the validity period, SV speed was maintained by (1) the SV driver manually modulating the SV accelerator pedal, or (2) use of conventional cruise control unless the SV BSI system automatically terminated its operation.
- Operating the SV in automation level 1 required the SV ACC (i.e., not the vehicle's lane centering system) to be enabled and in operation unless the SV BSI system automatically terminated its operation.
- Operating the SV in automation level 2 or 3 required the SV ACC and lane centering systems both be enabled and in operation.
- The SV driver did not provide manual inputs to the SV accelerator or brake pedals while the SV was being operated in automation level 1 (i.e., while ACC was actively modulating the SV speed), 2, or 3.
- The POV was driven at constant speed.
- The lateral distance between the right side of the POV and the inboard edge of the lane line immediately to its right was 3.3 ± 0.8 ft (1.0 ± 0.25 m).
- When the SV was being operated in automation level 0 or 1, the SV yaw rate did not exceed ± 1.0 deg/s from the onset of the validity period until the initiation of the SV lane change.

2. PRE-TEST INITIALIZATION AND CALIBRATION

A zero calibration was performed to align the lateral and longitudinal zero for the vehicles immediately before and after testing. The "zero position" was determined by positioning the SV and POV such that the centerline of the front-most location of the POV is aligned with the centerline of the rear-most location of the SV. Longitudinally, the front of the front bumper of the POV was placed at the rear of the rear bumper of the SV.

Static calibrations were then performed by placing the SV and POV transmissions in park, or with the system brake enabled, where applicable. Data were then collected for approximately 10 seconds using data from at least six GPS satellites.

C. Principal Other Vehicle

For tests in which a vehicle-to-vehicle collision will not occur, such as the False Positive tests, a high production, mid-sized passenger car was used as the POV. The tests reported herein made use of a 2006 Acura RL.

For tests in which a collision may occur, BSI testing requires a POV that realistically represents typical vehicles, does not suffer damage or cause damage to a test vehicle in the event of collision, and can be accurately positioned and moved during the tests. The tests reported herein made use of the Global Vehicle Target (GVT) secured to a low-profile robotic vehicle (LPRV).

This GVT system was designed for a wide range of pre-crash scenarios including scenarios which BSI systems address. The key components of the GVT system are:

- A soft GVT, which is visually and dimensionally similar to a 2013 Ford Fiesta hatchback. It is designed to appear realistic to the sensors used by automotive safety systems and automated vehicles: radar, camera, and lidar. Appropriate radar characteristics are achieved by using a combination of radar-reflective and radar-absorbing material enclosed within the GVT's vinyl covers. Internally, the GVT consists of a vinyl-covered foam structure. If a test vehicle impacts the GVT at low speeds, it is designed to separate, and is typically pushed off and away from the supporting LPRV platform. At higher impact speeds, the GVT breaks apart as the SV essentially drives through it. The GVT can be repeatedly struck from any approach angle without harm to those performing the tests or the vehicles being evaluated. Reassembly of the GVT occurs on top of the robotic platform and takes a team of 3 to 5 people approximately 7 to 10 minutes to complete.
- An LPRV platform that supports the GVT and provides for precisely controlled GVT motion. The LPRV contains the batteries, drive motors, GPS receiver, and the control electronics for the system. It has a top speed of 50 mph (80 km/h); a maximum longitudinal acceleration and deceleration of 0.12 g (1.18 m/s^2) and 0.8 g (7.8 m/s^2), respectively; and a maximum lateral acceleration of 0.5 g (4.9 m/s^2). The LPRV is preprogrammed and allows the GVT's movement to be accurately and repeatedly choreographed with the test vehicle and/or other test equipment required by a pre-crash scenario using closed-loop control. The LPRV is designed to be safely driven over by the SV without damage if the GVT is struck by the SV.

The key requirements of the POV element are to:

- Provide an accurate representation of a real vehicle to BSI and BSD sensors, including cameras and radar.
- Be resistant to damage and inflict little or no damage to the SV as a result of repeated SV-to-POV impacts.

The key requirements of the POV delivery system are to:

- Accurately control the nominal POV speed up to 50 mph (80 km/h).
- Accurately control the lateral position of the POV within the travel lane.
- Allow the POV to move away from the SV after an impact occurs.

Operationally, the GVT body is attached to LPRV using Velcro hook and loop fasteners. The GVT and LPRV are designed to separate if the GVT is struck by the SV. The GVT/LPRV system is shown in Figures A6 and A7 in Appendix A and a detailed description can be found in the NHTSA report: “A Test Track Comparison of the Global Vehicle Target (GVT) and NHTSA’s Strikeable Surrogate Vehicle (SSV)”.[3]

D. Throttle Controller

The actual vehicle POV was equipped with a programmable throttle controller, which was used for the False Positive Assessment test scenario to modulate the speed and headway overlap. The throttle controller system consisted of the following components:

- Electronically controlled servo motor, mounted on an aluminum rail system and installed in the vehicle.
- Real time computer (Arduino).

E. Instrumentation

Table 4 lists the sensors, signal conditioning, and data acquisition equipment used for these tests.

[3] Snyder, A.C., Forkenbrock, G.J., Davis, I.J., O’Harra, B.C., and Schnelle, S.C., A Test Track Comparison of the Global Vehicle Target (GVT) and NHTSA’s Strikeable Surrogate Vehicle (SSV), DOT HS 812 698, Vehicle Research and Test Center, National Highway Traffic Safety Administration, Washington, DC, July 2019.

Table 4. Test Instrumentation and Equipment

Type	Output	Range	Accuracy, Other Primary Specs	Mfr, Model	Serial Number	Calibration Dates Last Due
Differential Global Positioning System	Position, Velocity	Latitude: ±90 deg Longitude: ±180 deg Altitude: 0-18 km Velocity: 0-1000 knots	Horizontal Position: ±1 cm Vertical Position: ±2 cm Velocity: 0.05 km/h	Trimble GPS Receiver, 5700 (base station and in-vehicle)	00440100989	N/A
Multi-Axis Inertial Sensing System	Position; Longitudinal, Lateral, and Vertical Accels; Lateral, Longitudinal and Vertical Velocities; Roll, Pitch, Yaw Rates; Roll, Pitch, Yaw Angles	Accels ± 10g, Angular Rate ±100 deg/s, Angle >45 deg, Velocity >200 km/h	Accels .01g, Angular Rate 0.05 deg/s, Angle 0.05 deg, Velocity 0.1 km/h			By: Oxford Technical Solutions
				SV IMU#1 Oxford Inertial +	2258	Date: 5/3/2019 Due: 5/3/2021
				SV IMU#2 Oxford xNAV 550	015386	Date: 8/8/2019 Due: 8/8/2021
				POV IMU Oxford Inertial +	2182	Date: 9/16/2019 Due: 9/16/2021
				LPRV IMU Oxford RT3000 v3	40213	Date: 3/23/2020 Due: 3/23/2022
Real-Time Calculation of Position and Velocity Relative to Lane Markings (LDW) and POV (FCW)	Distance and Velocity to lane markings (LDW) and POV (FCW)	Lateral Lane Dist: ±30 m Lateral Lane Velocity: ±20 m/sec Longitudinal Range to POV: ±200 m Longitudinal Range Rate: ±50 m/sec	Lateral Distance to Lane Marking: ±2 cm Lateral Velocity to Lane Marking: ±0.02m/sec Longitudinal Range: ±3 cm Longitudinal Range Rate: ±0.02 m/sec	Oxford Technical Solutions (OXTS), RT-Range	97	N/A

Type	Output	Range	Accuracy, Other Primary Specs	Mfr, Model	Serial Number	Calibration Dates Last Due
Microphone	Sound (to measure time at alert)	Frequency Response: 80 Hz – 20 kHz	Signal-to-noise: 64 dB, 1 kHz at 1 Pa	Audio-Technica AT899	N/A	N/A
Light Sensor	Light intensity (visual alert)	Spectral Bandwidth: 440 - 800 nm	Rise Time < 10 ms	DRI designed and developed light sensor	N/A	N/A
Accelerometer	Acceleration (to measure time at alert)	±5g	≤ 3% of full range	Silicon Designs, 2210-005	N/A	N/A
Tire Pressure Gauge	Vehicle Tire Pressure	0-100 psi	< 1% error between 20 and 100 psi	Omega DPG8001	18111410000	Date: 5/4/2020 Due: 5/4/2021
Platform Scales	Vehicle Total, Wheel, and Axle Load	2200 lb/platform	0.1% of reading	Intercomp SW wireless	0410MN20001	Date: 4/20/2020 Due: 4/20/2021
Coordinate Measurement Machine	Point x,y,z location	0-8 ft 0-2.4 m	±.0020 in. ±.051 mm (Single point articulation accuracy)	Faro Arm, Fusion	UO8-05-08-06636	Date: 1/6/2020 Due: 1/6/2021

Type	Description	Mfr, Model	Serial Number
Data Acquisition System	Data acquisition is achieved using a dSPACE MicroAutoBox II. Data from the Oxford IMU, including Longitudinal, Lateral, and Vertical Acceleration, Roll, Yaw, and Pitch Rate, Forward and Lateral Velocity, Roll and Pitch Angle are sent over Ethernet to the MicroAutoBox.	dSPACE Micro-Autobox II 1401/1513	
		Base Board	549068
		I/O Board	588523
Steering Controller	Precise controlled steering is accomplished using a steering machine designed and constructed by DRI. DRI has used its Automated Vehicle Controller (AVC) steering machine for many vehicle tests including FMVSS 126 tests. It can provide up to 65 ft-lb torque and rates over 1300 deg/sec. The integrated angle encoder has an unlimited range with a resolution of 0.045 degrees and an accuracy of ±0.045 degrees. The steering motor is controlled by a MicroAutoBox II from dSPACE, which also acts as the data acquisition system.	DRI developed	N/A
Throttle Controller	Arduino based, servo actuated controller for managing POV speed	DRI developed	N/A

APPENDIX A

Photographs

LIST OF FIGURES

Figure A1. Front View of Subject Vehicle

Figure A2. Rear View of Subject Vehicle

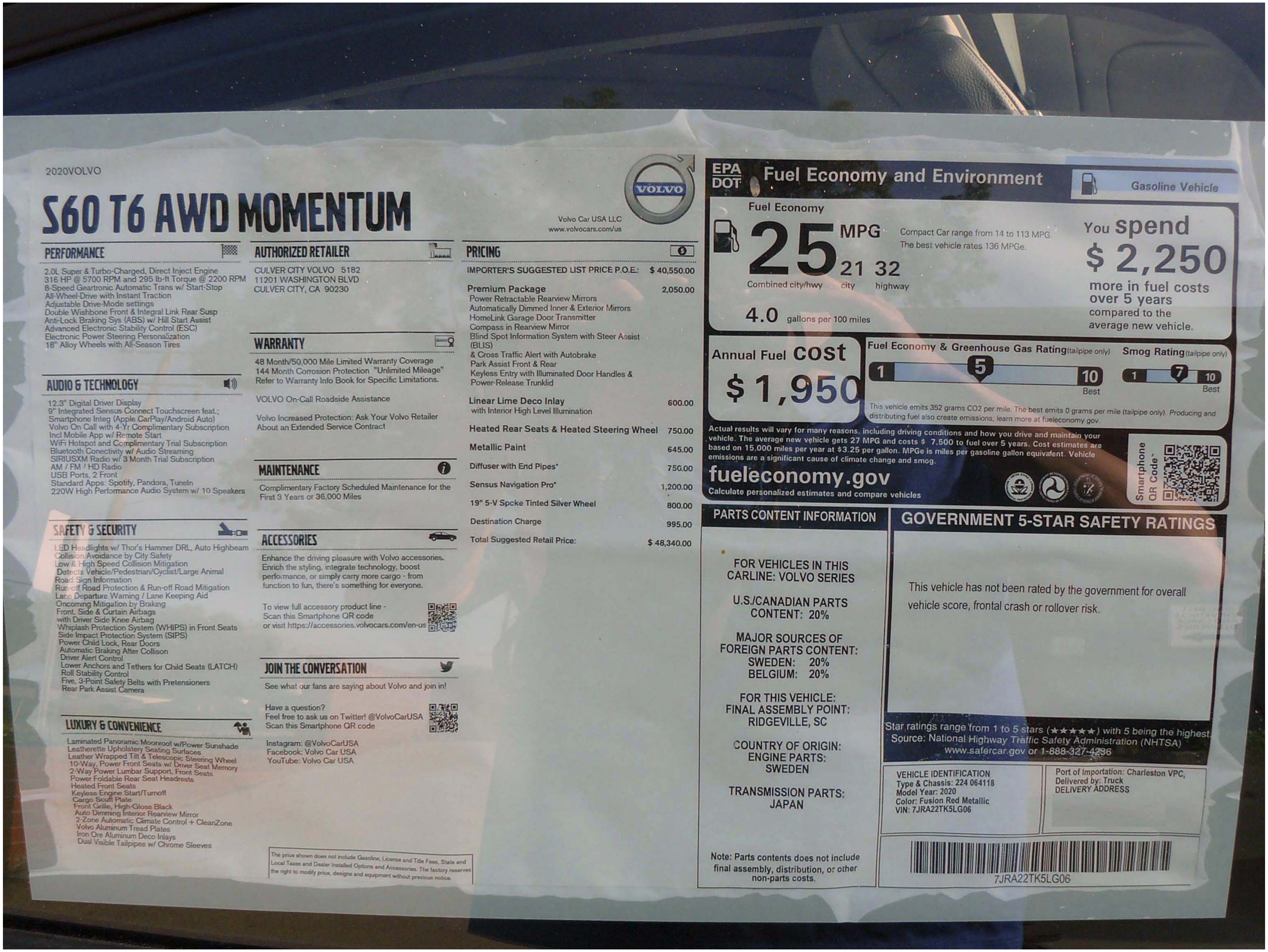


Figure A3. Window Sticker (Monroney Label)

Figure A4. Vehicle Certification Label

Figure A5. Tire Placard

Figure A6. Front View of Principal Other Vehicle - GVT (Tests 1 and 2)

Figure A7. Rear View of Principal Other Vehicle - GVT (Tests 1 and 2)

Figure A8. Front View of Principal Other Vehicle (Test 3)

Figure A9. Rear View of Principal Other Vehicle (Test 3)

Figure A10. Computer and Steering Controller Installed in Subject Vehicle

Figure A11. DGPS, Inertial Measurement Unit, and MicroAutoBox Installed in Subject Vehicle

Figure A12. Sensor for Monitoring Turn Signal On/Off

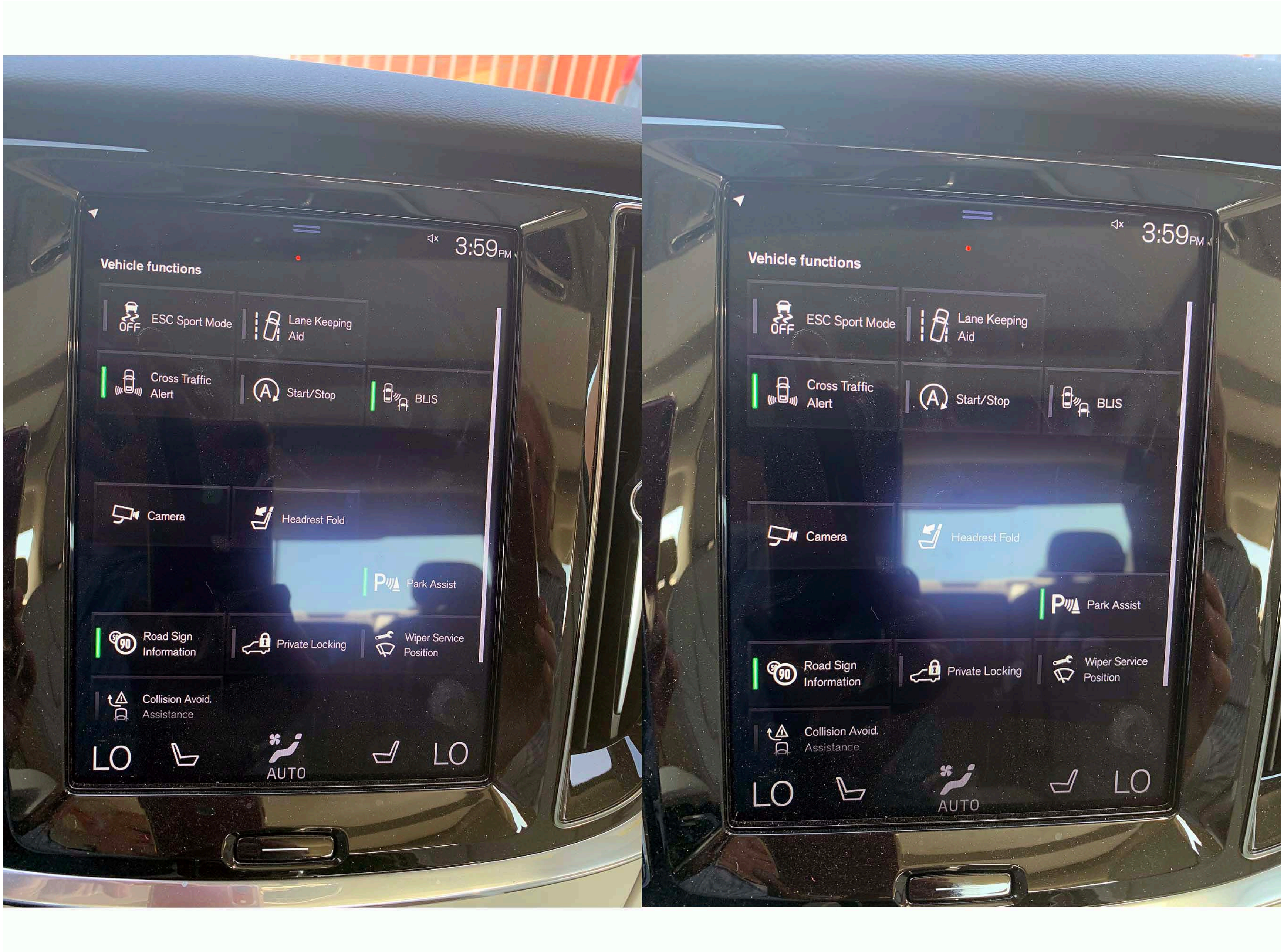


Figure A13. System Setup Menus

Figure A14. Visual Alert

APPENDIX B

Excerpts from Owner's Manual

NOTE

The warning with direction indicators for Rear Collision Warning* is deactivated if the collision warning distance in the City Safety function is set to the lowest level "**Late**".

The seat belt tensioning and braking functions remain active.

NOTE

The function uses the vehicle's camera and radar sensor, which has certain general limitations.

Related information

- Rear Collision Warning* (p. 320)
- Setting a warning distance for City Safety (p. 309)
- Camera/radar sensor limitations (p. 301)

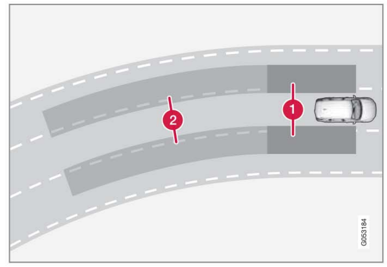
BLIS*

The BLIS[65] function is designed to help provide assistance in heavy traffic with several lanes moving in the same direction by helping the driver to detect the presence of vehicles in the "blind spot" area behind and to the side of the vehicle.

Location of BLIS indicator light.

BLIS is a driver support system designed to alert the driver of:

- vehicles in your "blind spot"
- vehicles approaching rapidly in adjacent lanes.



BLIS overview

1. Blind spot zone
2. Rapidly approaching vehicle zone.

The system is designed to react to:

- vehicles passing your vehicle
- vehicles that are rapidly approaching your vehicle from behind.

When BLIS detects a vehicle in zone 1 or a rapidly approaching vehicle in zone 2, an indicator light will illuminate in the relevant rearview mirror and glow steadily. If the driver then uses the turn signal on the side in which the warning has been given, the indicator light will become brighter and begin flashing.

BLIS is active when your vehicle is traveling at a speed over 10 km/h (6 mph).

65 Blind Spot Information

If a passing vehicle's speed is more than 15 km/h (9 mph) faster than your vehicle, BLIS will not react.

NOTE

The light illuminates on the side of the vehicle where the system has detected the vehicle. If the vehicle is passed on both sides simultaneously, both lights come on.

WARNING

- The function is supplementary driver support intended to facilitate driving and help make it safer – it cannot handle all situations in all traffic, weather and road conditions.
- The driver is advised to read all sections in the Owner's Manual about this function to learn of its limitations, which the driver must be aware of before using the function.
- Driver support functions are not a substitute for the driver's attention and judgment. The driver is always responsible for ensuring the vehicle is driven in a safe manner, at the appropriate speed, with an appropriate distance to other vehicles, and in accordance with current traffic rules and regulations.

Related information

- Driver support systems (p. 260)
- Activating or deactivating BLIS (p. 322)
- BLIS limitations (p. 323)
- BLIS messages (p. 324)

Activating or deactivating BLIS

The BLIS[66] function can be activated or deactivated.

Activate or deactivate the function using this button in the center display's Function view.

- GREEN button indicator light – the function is activated.
- GRAY button indicator light – the function is deactivated.

If BLIS is activated when the engine is started, the indicator lights in the rearview mirrors will flash once.

If BLIS is deactivated when the engine is turned off, it will remain off the next time the engine is started and the indicator lights will not illuminate.

Related information

- BLIS* (p. 321)
- BLIS limitations (p. 323)

66 Blind Spot Information

* Option/accessory.

BLIS limitations

BLIS[67] functionality may be reduced in certain situations.

Keep the marked area clean (on both the left and right sides of the vehicle)[68].

Examples of limitations:

- Dirt, ice and snow covering the sensors may reduce functionality and prevent the system from providing warnings.
- The BLIS function is automatically deactivated if a trailer, bicycle holder or similar is connected to the vehicle's electrical system.
- For BLIS to function effectively, bicycle holders, luggage racks or similar should not be mounted on the vehicle's towbar.

⚠ WARNING

- BLIS does not work in sharp curves.
- BLIS does not work when the vehicle is being reversed.

ⓘ NOTE

The function uses the vehicle's camera and radar sensor, which has certain general limitations.

Related information

- BLIS* (p. 321)
- Camera/radar sensor limitations (p. 301)

67 Blind Spot Information
68 Note: This illustration is general and details may vary depending on model.

BLIS messages

A number of messages related to BLIS[69] may be displayed in the instrument panel. Several examples are provided below.

Message	Meaning
Blind spot sensor **Service required**	The system is not functioning as intended. Contact a workshop[A].
Blind spot system off **Trailer attached**	BLIS and CTA [B] have been deactivated because a trailer has been connected to the vehicle's electrical system.

[A] An authorized Volvo workshop is recommended.
[B] Cross Traffic Alert*

A text message can be erased by briefly pressing the ◯ button in the center of the right-side steering wheel keypad.

If a message cannot be erased, contact a workshop[A].

Related information

- BLIS* (p. 321)
- Cross Traffic Alert* (p. 325)

[69] Blind Spot Information

* Option/accessory.

Steering assistance at risk of collision

The **Collision avoidance assistance** function can help the driver reduce the risk of the vehicle leaving its lane unintentionally and/or colliding with another vehicle or obstacle by actively steering the vehicle back into its lane and/or swerving.

The function consists of these sub-functions:

- Run-Off Mitigation with steering assistance
- Steering assistance during collision risks from oncoming traffic
- Steering assistance during collision risks from behind*

After the system has automatically intervened, this text message will appear in the instrument panel:

Collision avoidance assistance – Automatic intervention

WARNING

- The function is supplementary driver support intended to facilitate driving and help make it safer – it cannot handle all situations in all traffic, weather and road conditions.
- The driver is advised to read all sections in the Owner's Manual about this function to learn of its limitations, which the driver must be aware of before using the function.
- Driver support functions are not a substitute for the driver's attention and judgment. The driver is always responsible for ensuring the vehicle is driven in a safe manner, at the appropriate speed, with an appropriate distance to other vehicles, and in accordance with current traffic rules and regulations.

NOTE

It is always the driver who must decide how much the vehicle should be in control – the vehicle can never take command.

Related information

- Driver support systems (p. 260)
- Activating or deactivating steering assistance during collision risks (p. 344)
- Run-Off Mitigation with steering assistance (p. 344)
- Steering assistance during collision risks from oncoming traffic (p. 345)
- Steering assistance during collision risks from behind* (p. 346)
- Steering assistance during collision risks limitations (p. 347)
- Symbols and messages for steering assistance during collision risks (p. 348)

* Option/accessory.

Activating or deactivating steering assistance during collision risks

The steering assistance function is optional – the driver can choose to have it activated or deactivated.

Activate or deactivate the function using this button in the center display's Function view.

- GREEN button indicator light – the function is activated.
- GRAY button indicator light – the function is deactivated.

The function is automatically activated each time the engine is started[94].

> **NOTE**
>
> When the **Collision avoidance assistance** function is deactivated, all sub-functions of the following are deactivated:
>
> - Steering assistance at risk of run-off
> - Steering assistance at risk of head-on collision
> - Steering assistance during collision risks from behind*
>
> Although it is possible to deactivate the function, the driver is advised to keep it activated since it can help improve driving safety in most cases.

Related information

- Steering assistance at risk of collision (p. 343)
- Steering assistance during collision risks limitations (p. 347)

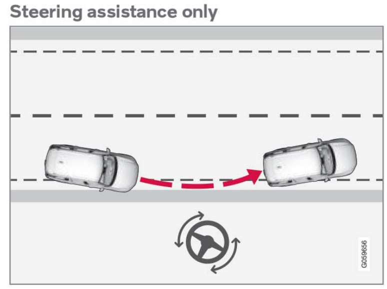
Run-Off Mitigation with steering assistance

Steering assistance has several sub-functions. Run-Off Mitigation with steering assistance can help the driver and reduce the risk of the vehicle inadvertently running off the road by actively steering the vehicle back onto the road.

This function has two activation levels for intervention:

- Steering assistance only
- Steering assistance with braking

Steering assistance only



Intervention with steering assistance.

94 On some markets, the setting that was active when the engine was switched off is reactivated.

* Option/accessory.

APPENDIX C

Run Log

Subject Vehicle: **2020 Volvo S60 T6 AWD Momentum** Date: **8/3/2020**

Test Engineer: **J. Robel**

Notes: For this testing, the steering wheel was released once a certain heading angle was met. For subsequent BSI research testing on other vehicle models, the steering wheel was released within 250 ms of achieving the desired heading and after exiting the curve, thus allowing the point of steering wheel release to be during a more stable portion of the steering for the later tests. Because of these procedural adjustments, the steering wheel release timing for this testing may appear earlier than that recorded for subsequent tests.

Run	Test Type	Valid Run	Minimum Distance to POV (ft)	Minimum Distance to Left Lane Edge (ft)	BSI Activated (Y/N)	Contact (Y/N)	Meets Criteria [4]	Notes
21	SV Lane Change Constant Headway	N						Lane change SV
22		Y	0.00	-2.81	-	Y	N	
23		N						Late turn signal
24		Y	0.00	-3.54	-	Y	N	
25		Y	0.00	-3.52	-	Y	N	
26		Y	0.00	-3.55	-	Y	N	
27		Y	0.00	-3.51	-	Y	N	Ran out of space at end of run (after BSI intervention)
28		Y	0.00	-3.48	-	Y	N	
29		N						POV lateral error
30		Y	0.77	-2.73	-	N	Y	Ran out of space at end of run (after BSI intervention)

[4] The acceptability criteria listed herein are used only as a guide to gauge system performance, and are identical to the Pass/Fail criteria given in NHTSA's most current Test Procedure in docket NHTSA-2019-0102-0001, BLIND SPOT INTERVENTION SYSTEM CONFIRMATION TEST.

Run	Test Type	Valid Run	Minimum Distance to POV (ft)	Minimum Distance to Left Lane Edge (ft)	BSI Activated (Y/N)	Contact (Y/N)	Meets Criteria [4]	Notes
31	SV Lane Change Closing Headway	N						POV Speed
32		N						POV Speed
33		N						POV Speed
34		N						GPS Fix Type
35		Y	0.40	-2.98	-	N	Y	Ran out of space at end of run (after BSI intervention)
36		N						POV path dev, POV speed
37		N						POV path dev, POV speed
38		N						POV path dev
39		N						POV speed, POV path dev
40		N						POV Speed
41		Y	0.00	-2.97	-	Y	N	
42		Y	0.00	-3.28	-	Y	N	
43		Y	0.00	-3.67	-	Y	N	
44		Y	0.00	-2.89	-	Y	N	
45		N						POV path dev
46		Y	0.00	-3.19	-	Y	N	
47		Y	0.00	-3.46	-	Y	N	
1	SV Lane Change Constant Headway False Positive Baseline	N						Ran out of space
2		Y						
3		Y						
4		Y						

Run	Test Type	Valid Run	Minimum Distance to POV (ft)	Minimum Distance to Left Lane Edge (ft)	BSI Activated (Y/N)	Contact (Y/N)	Meets Criteria [4]	Notes
5	**SV Lane Change Constant Headway False Positive Baseline**	Y						
6		Y						
7		Y						
8		Y						
9	**SV Lane Change Constant Headway False Positive Assessment**	N						Matlab error (channels empty)
10		N						POV lateral error
11		Y				N	Y	Check avg yaw rate
12		Y				N	Y	
13		Y				N	Y	
14		N						POV lateral error
15		Y				N	Y	
16		Y				N	Y	
17		N						POV lateral error
18		N						POV lateral error
19		Y				N	Y	
20		Y				N	Y	

Appendix D

TIME HISTORY PLOTS

LIST OF FIGURES

Description of Time History Plots

A set of time history plots is provided for each valid run in the test series. Each set of plots comprises time varying data from both the Subject Vehicle (SV) and Principal Other Vehicle (POV), as well as pass/fail envelopes and thresholds. Plots shown herein are grouped by test type and are presented sequentially within a given test type. The following is a description of data types shown in the time history plots, as well as a description of the color code indicating to which vehicle the data pertain.

Each time history plot consists of data relevant to the test type under consideration, and therefore the data channels plotted vary according to test type. The test types (shown in the plot titles) include:

- SV Lane Change with Constant Headway
- SV Lane Change with Closing Headway
- SV Lane Change with Constant Headway, False Positive Assessment – Baseline
- SV Lane Change with Constant Headway, False Positive Assessment – Evaluation

Time history figures include the following sub-plots:

- SV Turn Signal – Displays the cycling of the SV turn signal indicator. The bold vertical line indicates the time at which the turn signal is activated.

- Headway (ft) – Longitudinal separation between the rear of the SV and the front of the POV. A negative value for headway indicates that the front-most point of the POV is forward relative to the rear-most point of the SV.

- SV/POV Speed (mph) – Indicates the speed of the SV and POV.

- SV Ax (g) (Vehicles for which the BSI system operates using a brake intervention.) – Displays the SV lateral acceleration. A vertical bold line marked "BSI Onset" indicates the time at which BSI intervention first occurred.

- SV SWA (deg) (Vehicles for which the BSI system operates using a steering intervention.) – Displays the SV steer wheel angle as measured by a steer wheel encoder. A vertical bold line marked "BSI Onset" indicates the time at which the BSI intervention first occurred.

- Yaw Rate (deg/sec) – Yaw rate of the SV. A vertical bold line marked “SW Release” indicates the point at which the control of the steering wheel by the robotic controller is released allowing for free response of the vehicle. If the BSI system operates using a steering wheel input, a vertical bold line marked “BSI Onset” indicates the time at which BSI intervention first occurred.

- Lateral Velocity (ft/s) – Lateral velocity of the SV. For the False Positive scenario, the average lateral velocity calculated from half a second before the lane line crossing to half a second after the lane line crossing is noted. For the other scenarios, the lateral velocity at the time of steering wheel release is noted.

- Distance to Lane Line (ft) – For both the SV and POV, the distance from the outer-most (not including side mirrors) part of the vehicle to the edge of the lane line. The minimum distance from the left side of the SV to the adjacent left side lane is shown. A negative value indicates that the SV has crossed over the left side lane line.

- Minimum Distance (ft) – Distance between the outer-most (not including side mirrors) parts of the SV and POV. The minimum distance between the SV and POV is shown on the right of the plot. Note that this is not shown for False Positive Baseline cases.

- SV Path Deviation (ft) – The SV deviation from its intended path.

Envelopes and Thresholds

Some of the time history plot figures contain either green or yellow envelopes and/or black threshold lines. These envelopes and thresholds are used to programmatically and visually determine the validity of a given test run. Envelope and threshold exceedances are indicated with either red shading or red asterisks, and red text is placed to the right side of the plot indicating the type of exceedance. Such exceedances indicate either that the test was invalid or that the requirements of the test were not met (i.e., failure of the BSI system).

For plots with green envelopes, in order for the test to be valid, the time-varying data must not exceed the envelope boundaries at any time within the envelope. Exceedances of a green envelope are indicated by red shading in the area between the measured time-varying data and the envelope boundaries.

For plots with yellow envelopes, the yellow envelope is used to signify an area of interest over which the data is being averaged. The data may exceed the envelope at any point during this envelope with no impact on the test validity.

For SV Lane Change with Constant Headway, False Positive – Evaluation tests only, a dashed boundary line is shown on the yaw rate plot. This dashed boundary line indicates the allowable yaw rate threshold used to determine the presence of a BSI intervention as defined in the test procedure. Exceedances of this boundary will display red text to the right of the plot.

Color Codes

Color codes have been adopted to easily identify which data correspond to which vehicle, as well as to indicate the types of envelopes and thresholds used in the plots.

Color codes can be broken into four categories:

1. Time-varying data
2. Validation envelopes and thresholds
3. Individual data points
4. Text

1. Time-varying data color codes:
   - Blue = Subject Vehicle data
   - Magenta = Principal Other Vehicle data
   - Brown = Relative data between SV and POV (i.e., TTC, lateral distance and headway distance)

2. Validation envelope and threshold color codes:
   - Green envelope = time varying data must be within the envelope at all times in order to be valid
   - Black threshold (Solid) = define points of interest during the run (i.e., steering wheel release, BSI onset, etc.)

3. Individual data point color codes:
   - Green circle = passing or valid value at a given moment in time
   - Red asterisk = failing or invalid value at a given moment in time

4. Text color codes:
   - Green = passing or valid value
   - Red = failing or invalid value

Other Notations

- NG – Indicates that the value for that variable was outside of bounds and therefore “No Good”.
- POV – Indicates that the value for the Principal Other Vehicle was out of bounds.
- SV – Indicates that the value for the Subject Vehicle was out of bounds.
- Lane Early – Indicates that the lane change was initiated too early relative to the timing criteria listed for the scenario.
- Lane Late – Indicates that the lane change was initiated too late relative to the timing criteria listed for the scenario.
- Collision – Indicates that the SV and POV collided.

The minimum (worst) GPS fix type is displayed in the lower right corner of each page. The only valid fix type is RTK fixed (displayed in green). If the fix type during any portion of the test was anything other than RTK fixed, then “RTK Fixed OR LESS!!” is displayed in red.

Examples of time history plots for each test type (including passing, failing, and invalid runs) are shown in Figures D1 through D3. Time history data plots for the tests of the vehicle under consideration herein are provided beginning with Figure D4.

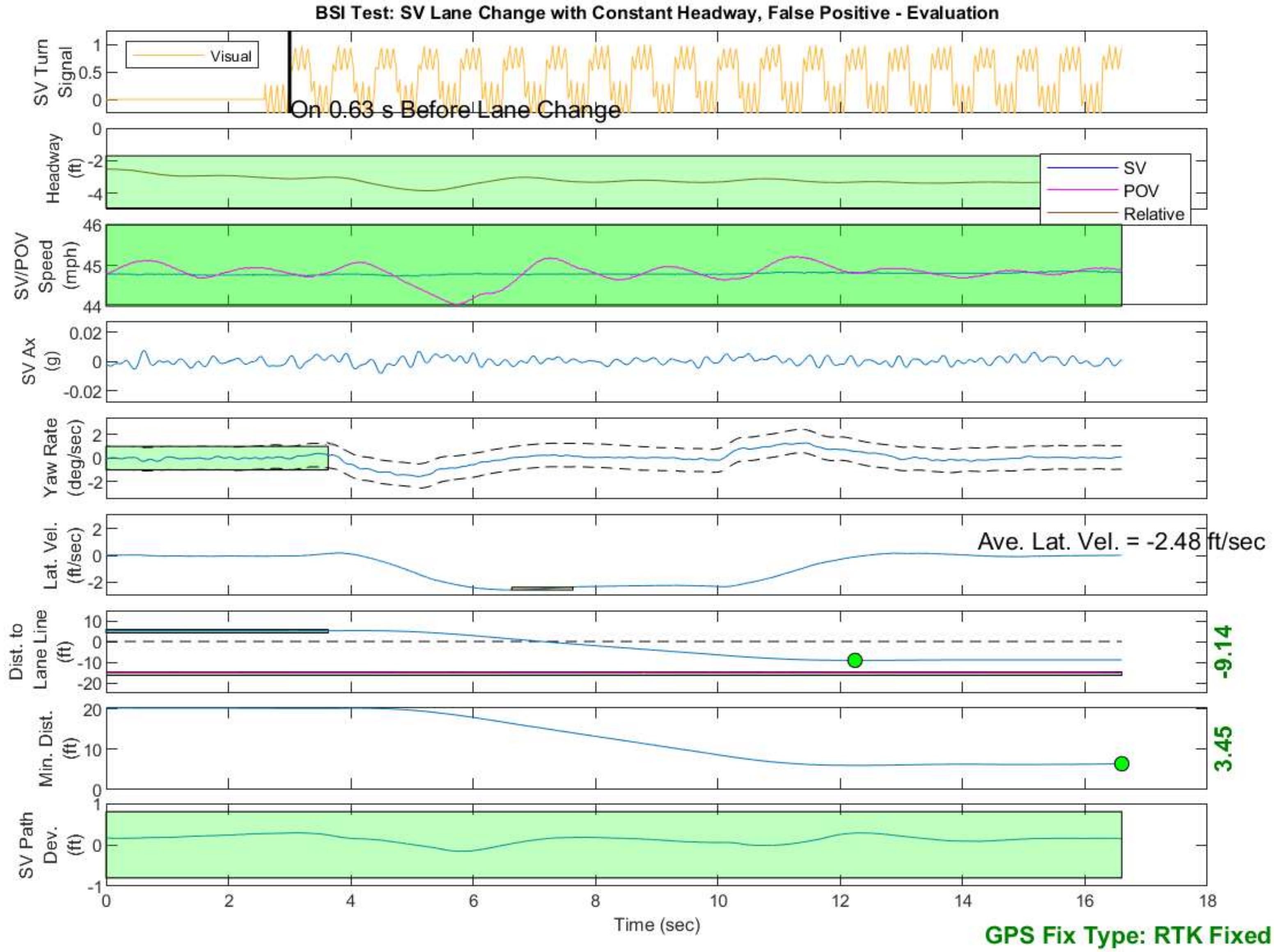


Figure D1. Example Time History for False Positive Evaluation, Passing

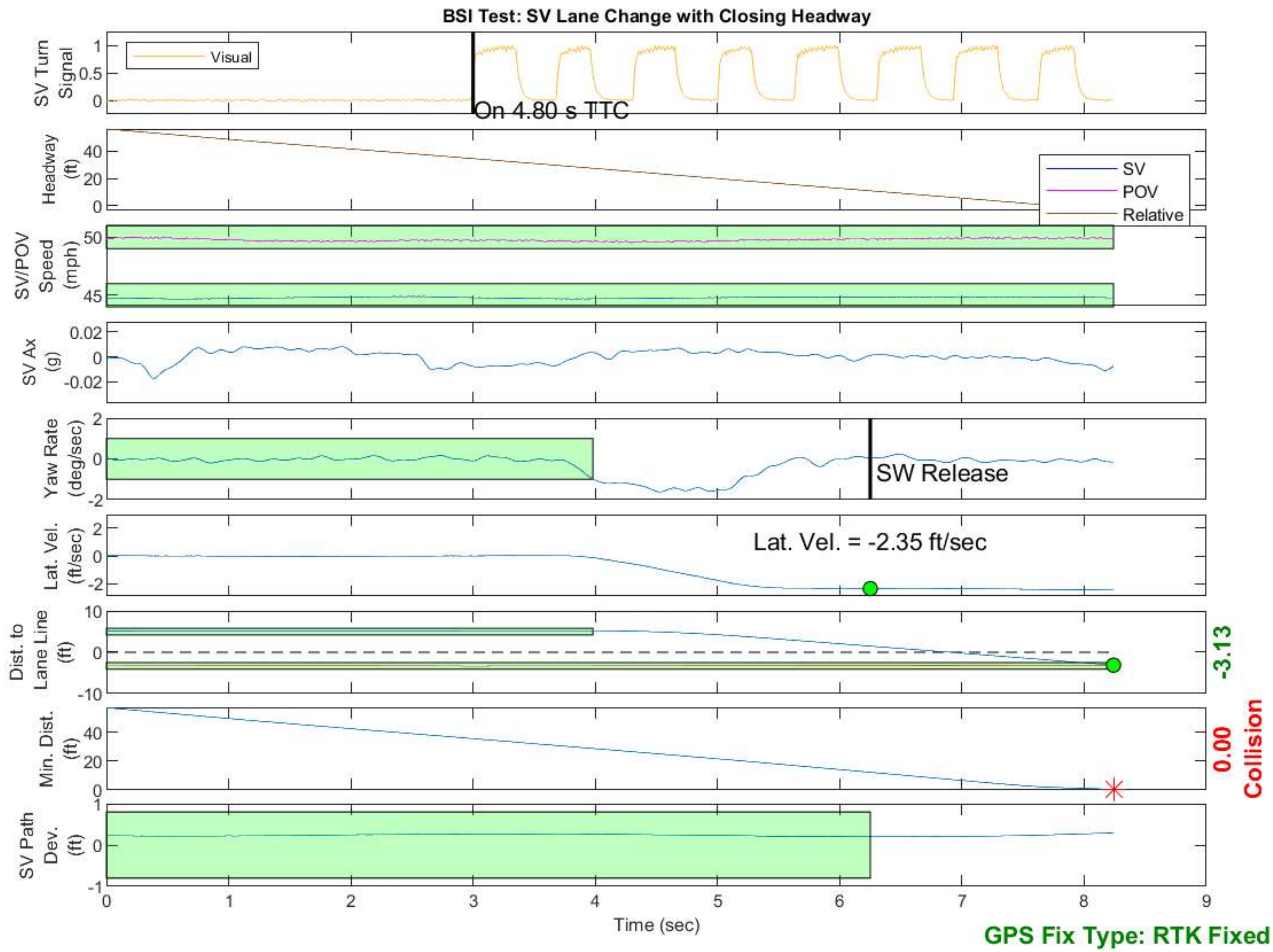


Figure D2. Example Time History for Subject Vehicle with Closing Headway Test, Failing

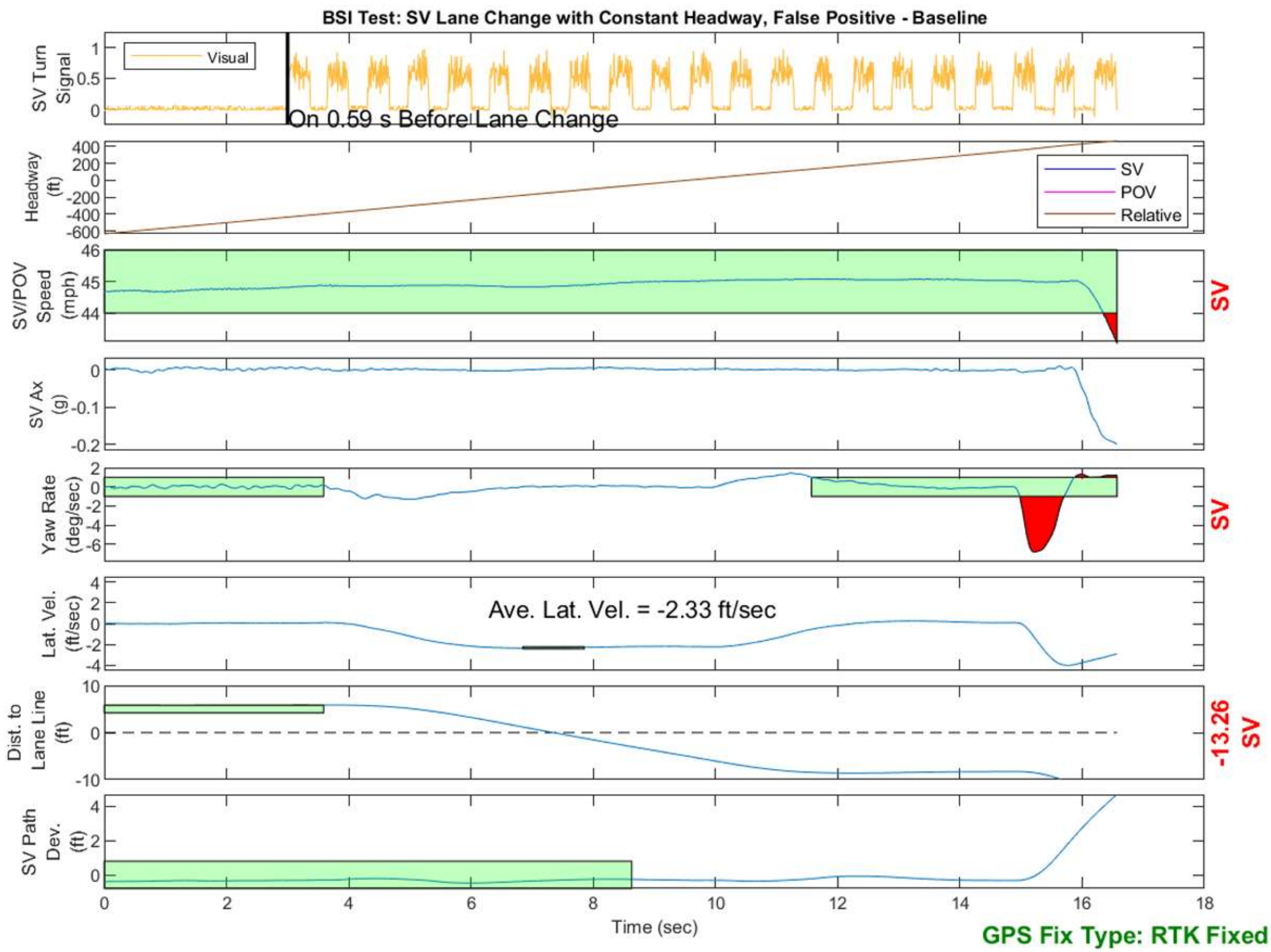


Figure D3. Example Time History for Subject Vehicle with Constant Headway Test, Invalid POV Speed Criteria

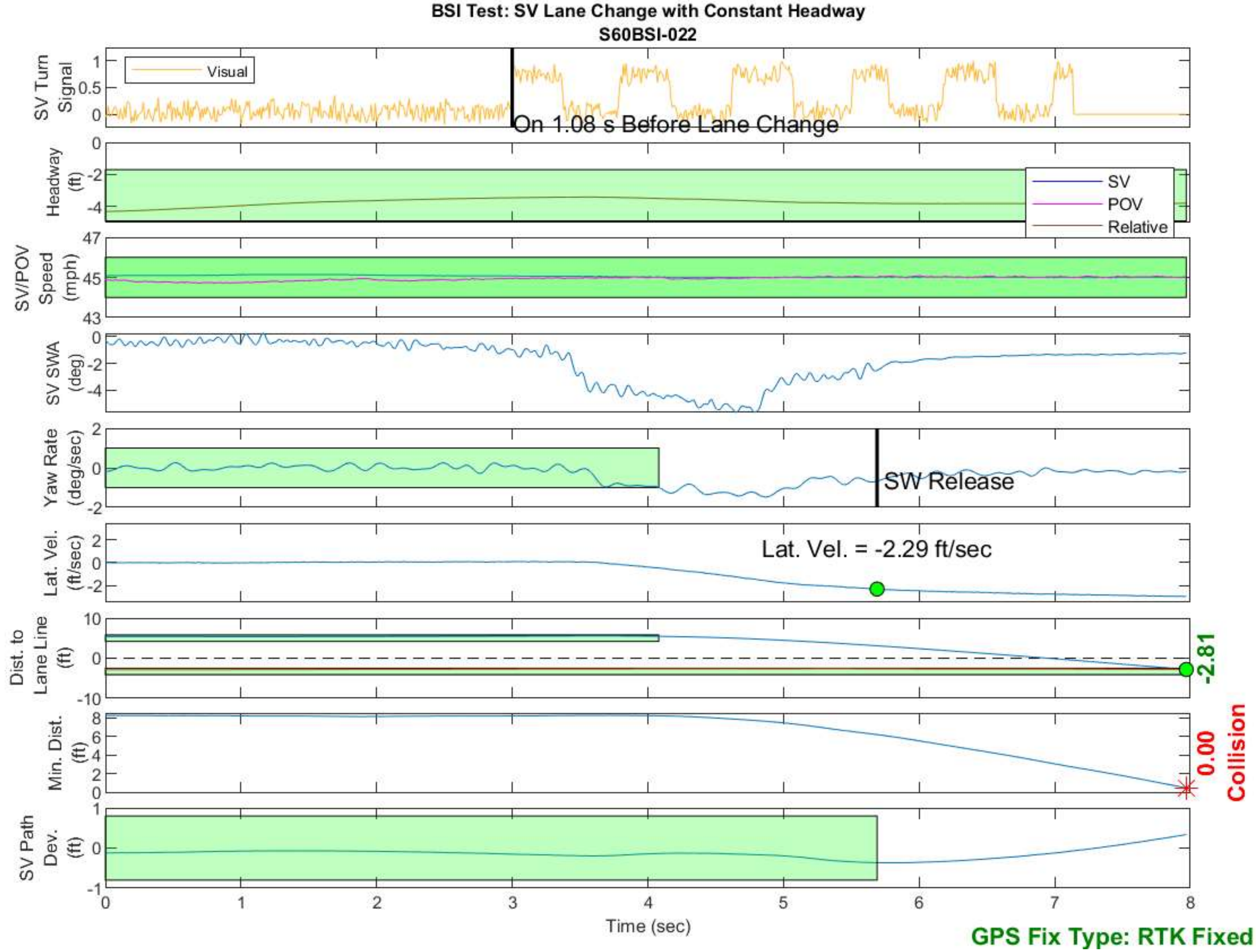


Figure D4. BSI Run 22, Subject Vehicle Lane Change with Constant Headway

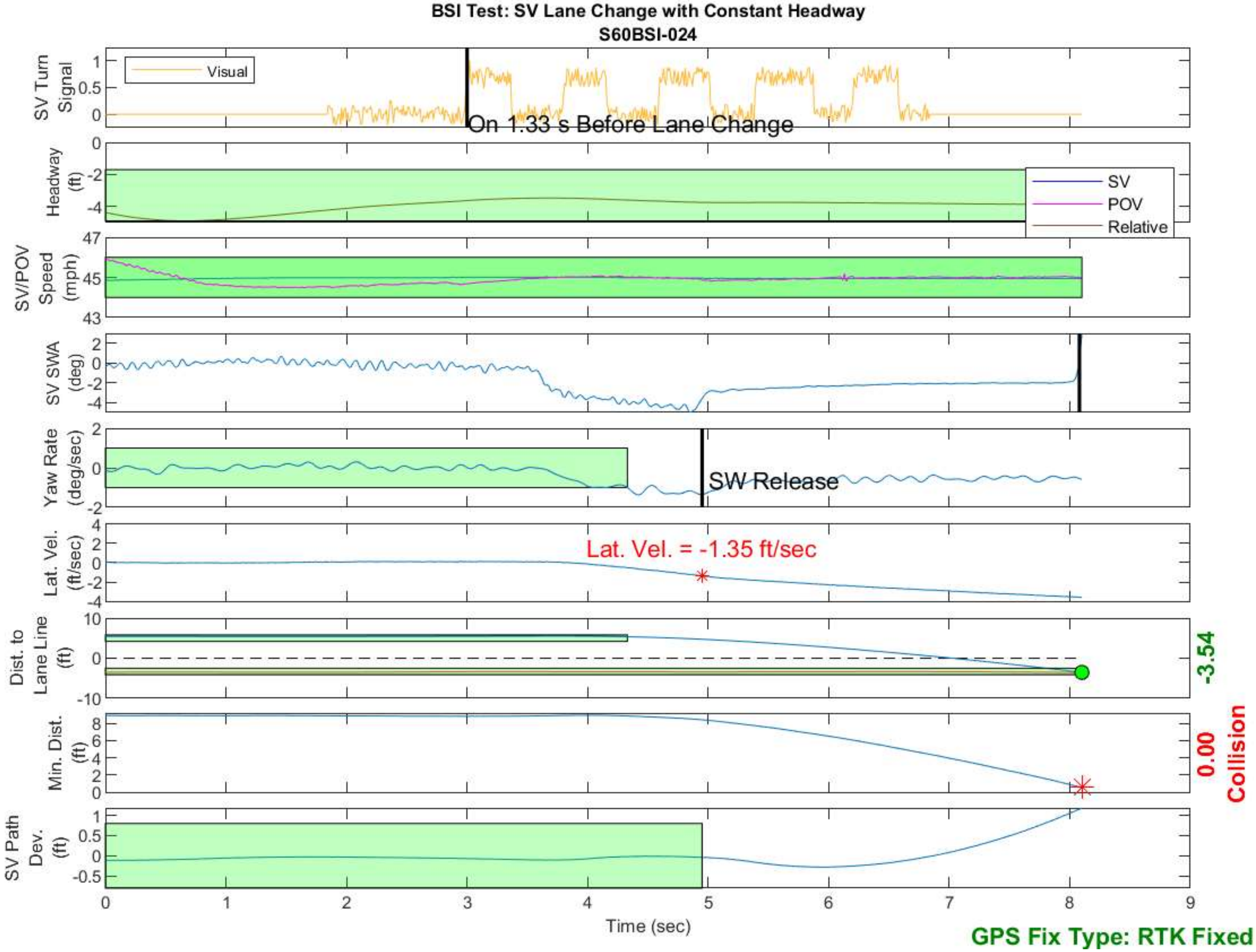


Figure D5. BSI Run 24, Subject Vehicle Lane Change with Constant Headway

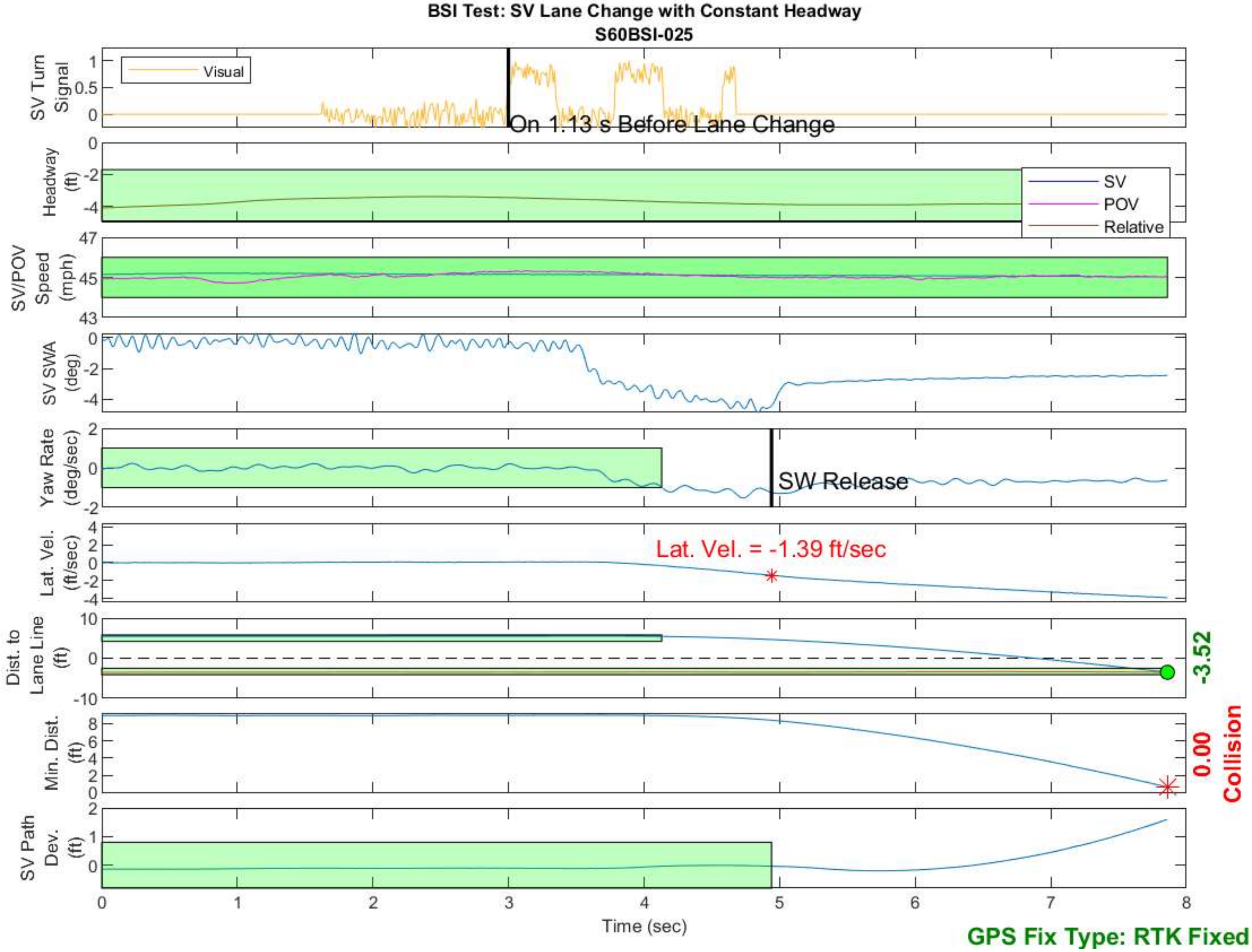


Figure D6. BSI Run 25, Subject Vehicle Lane Change with Constant Headway

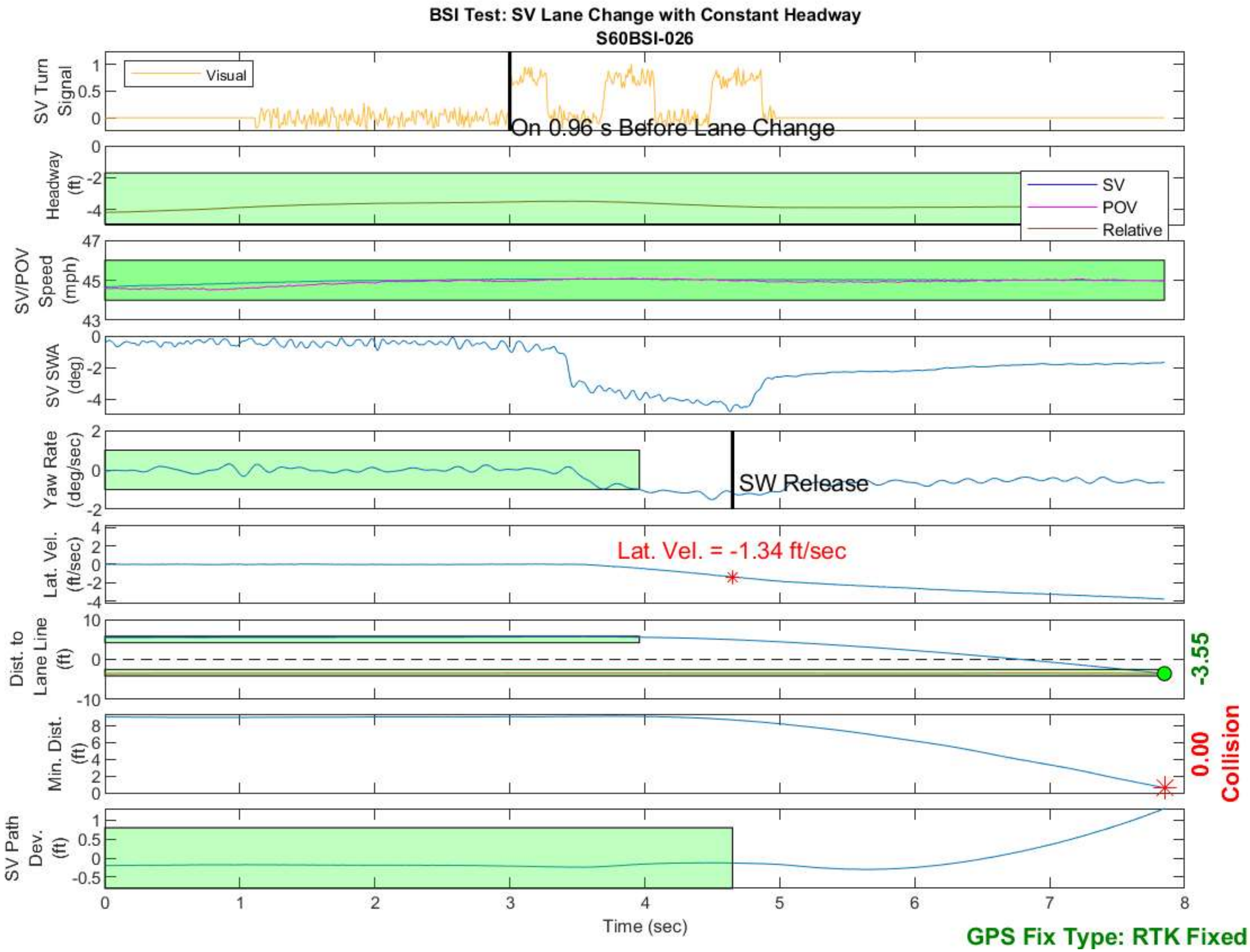


Figure D7. BSI Run 26, Subject Vehicle Lane Change with Constant Headway

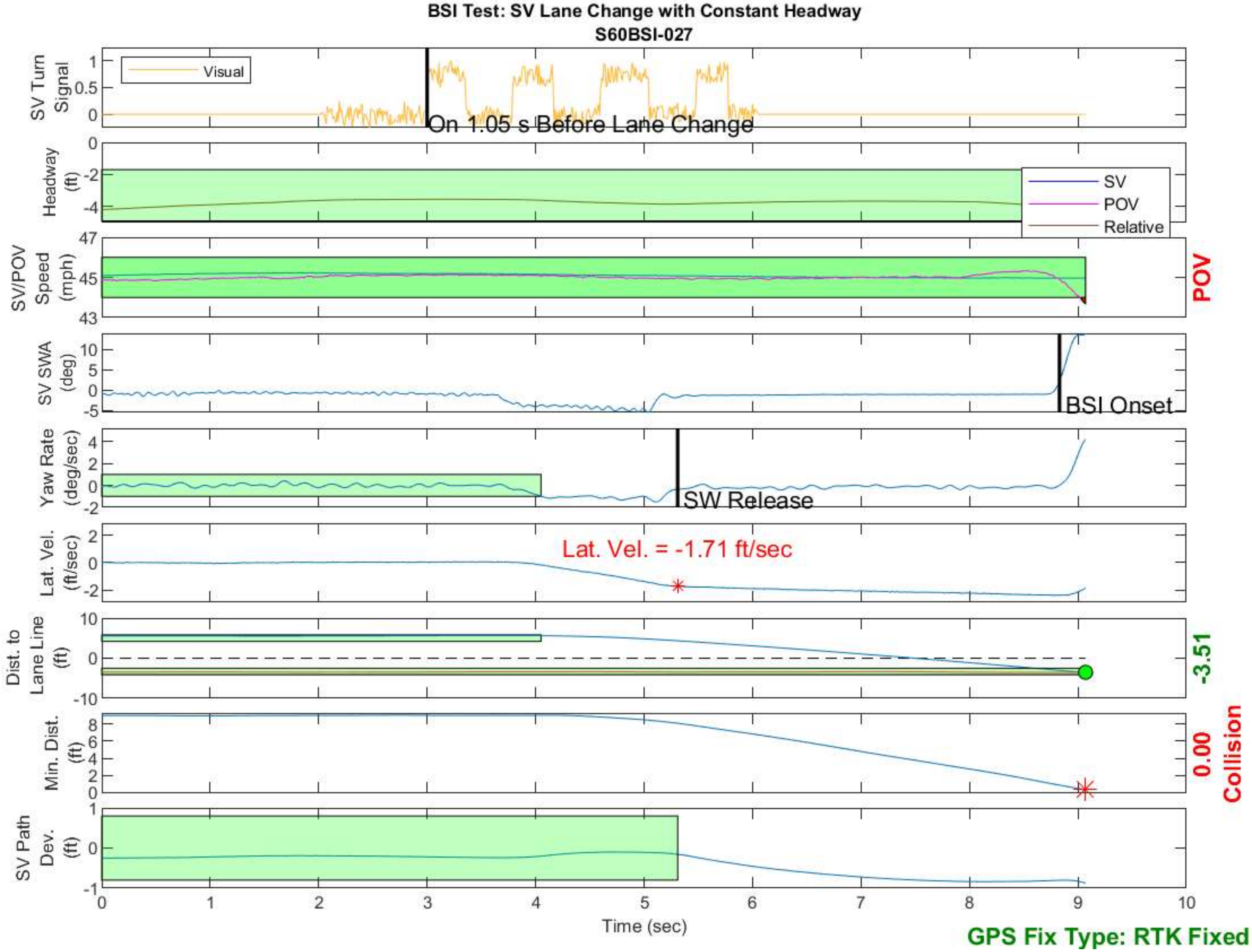


Figure D8. BSI Run 27, Subject Vehicle Lane Change with Constant Headway

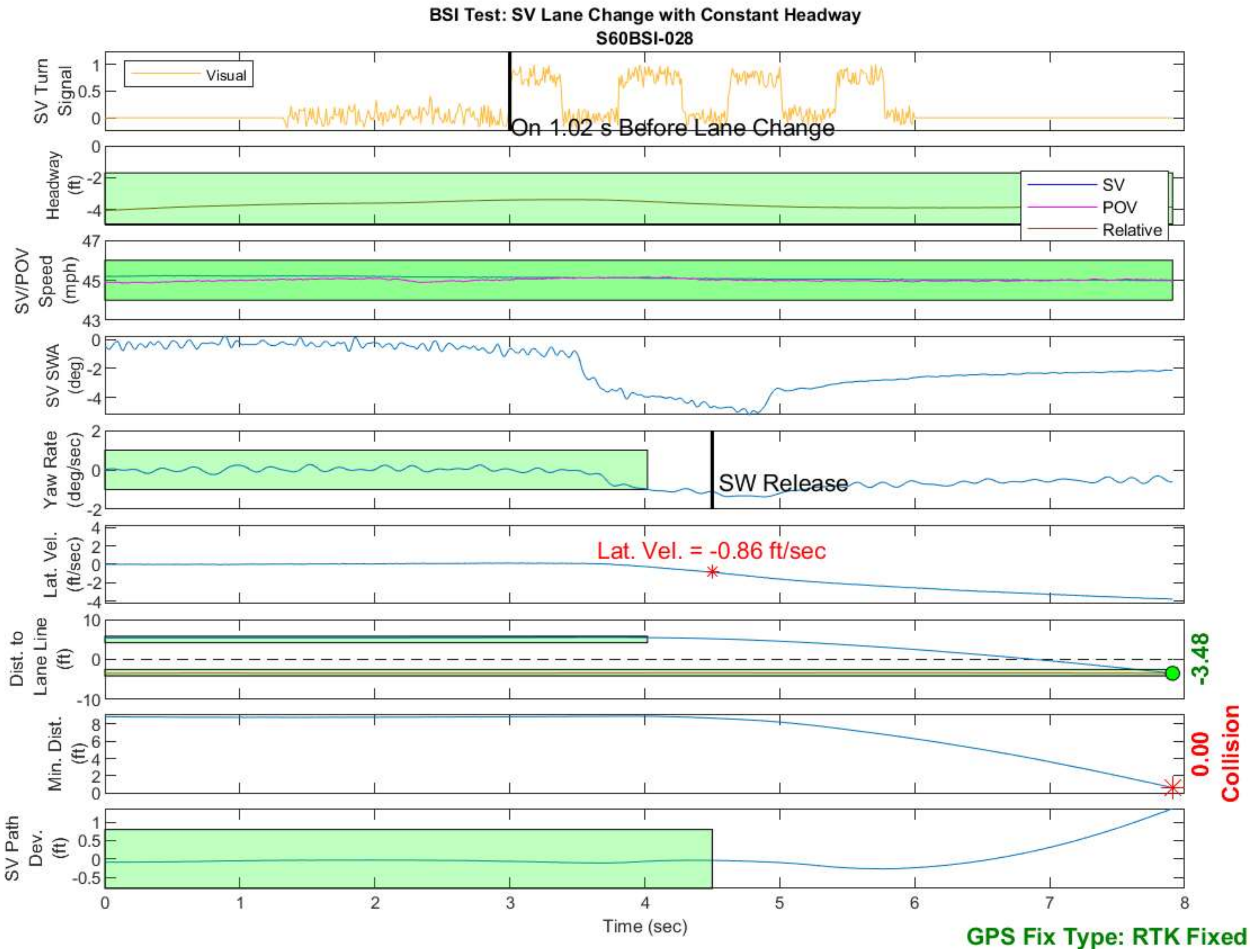


Figure D9. BSI Run 28, Subject Vehicle Lane Change with Constant Headway

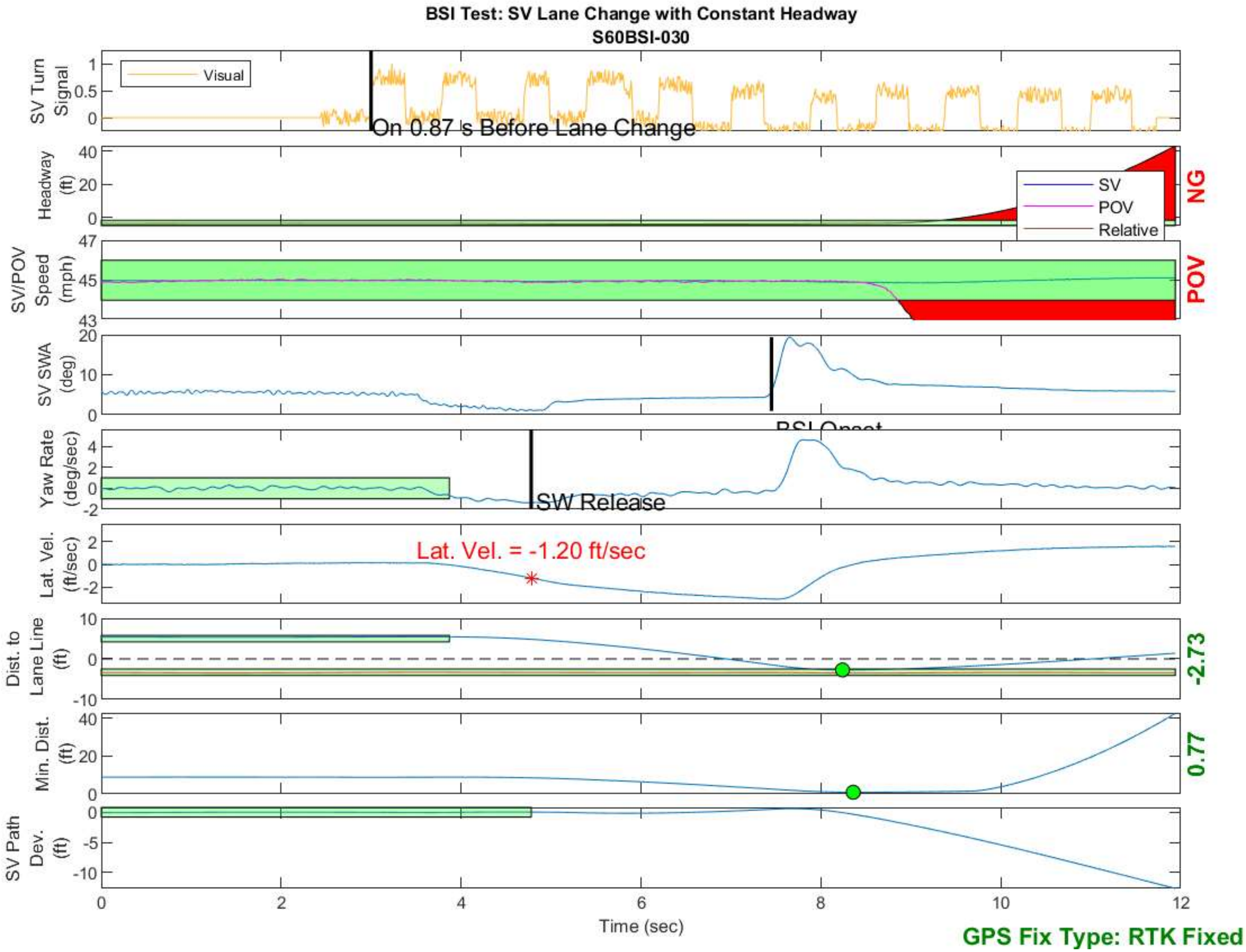


Figure D10. BSI Run 30, Subject Vehicle Lane Change with Constant Headway

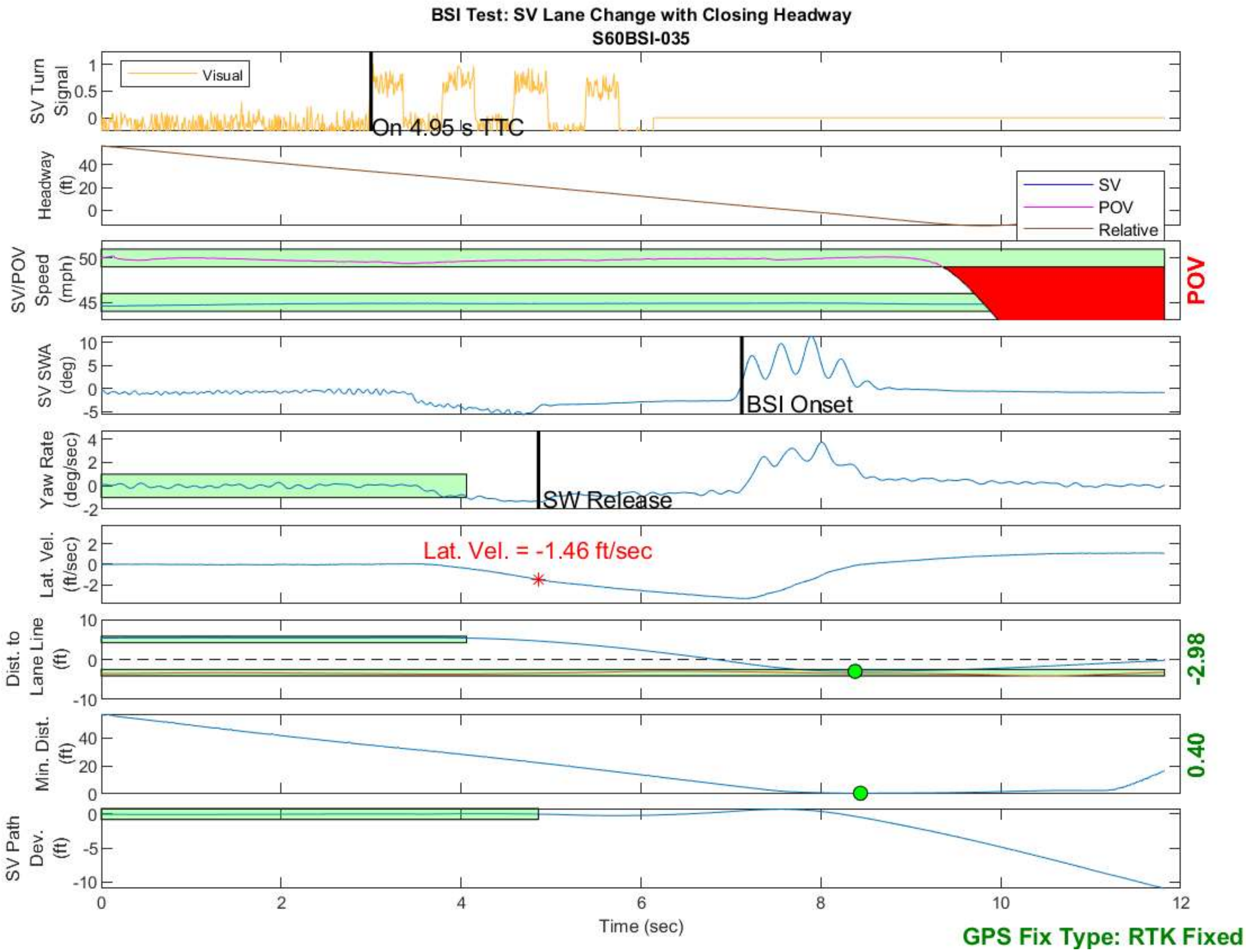


Figure D11. BSI Run 35, Subject Vehicle Lane Change with Closing Headway

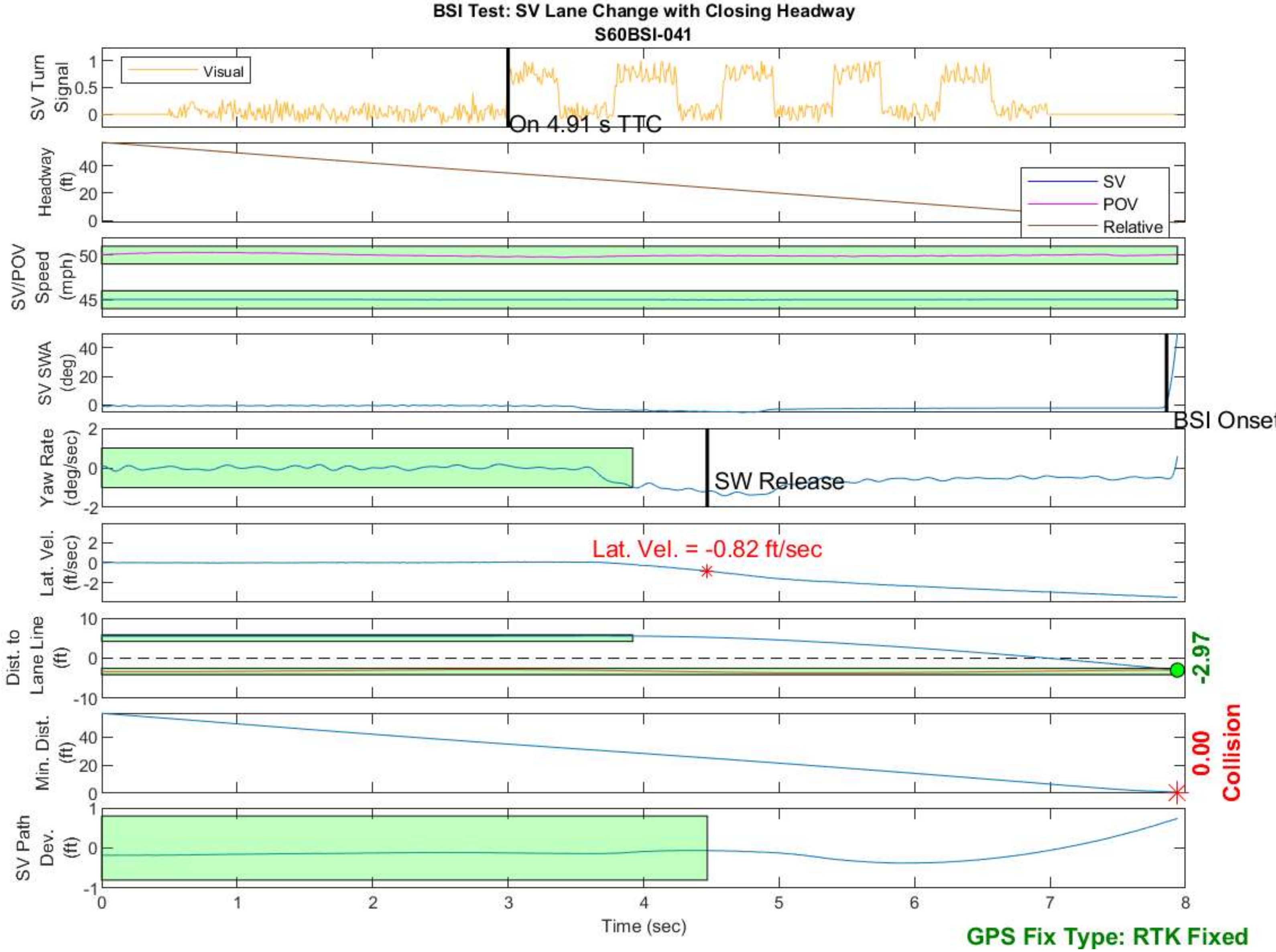


Figure D12. BSI Run 41, Subject Vehicle Lane Change with Closing Headway

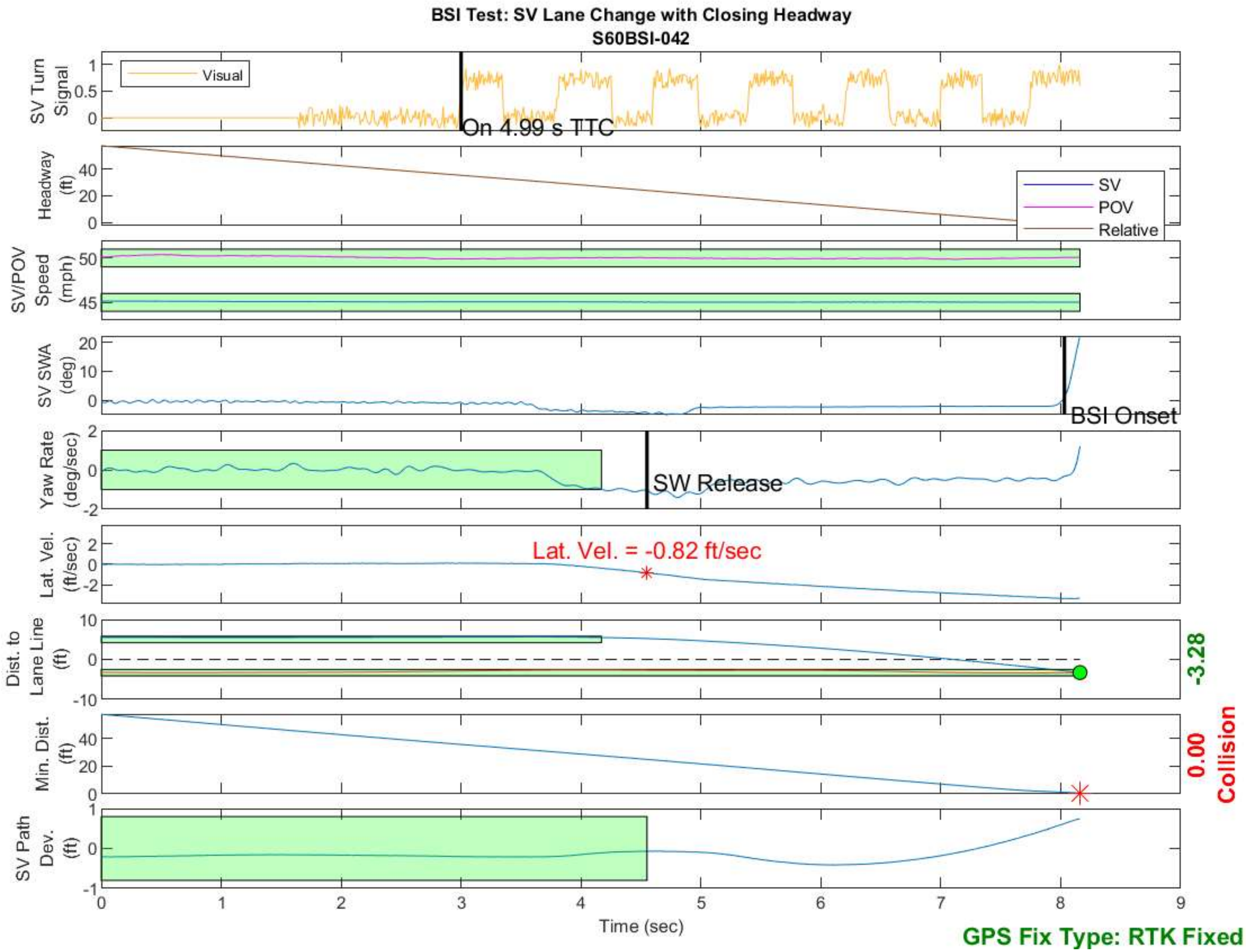


Figure D13. BSI Run 42, Subject Vehicle Lane Change with Closing Headway

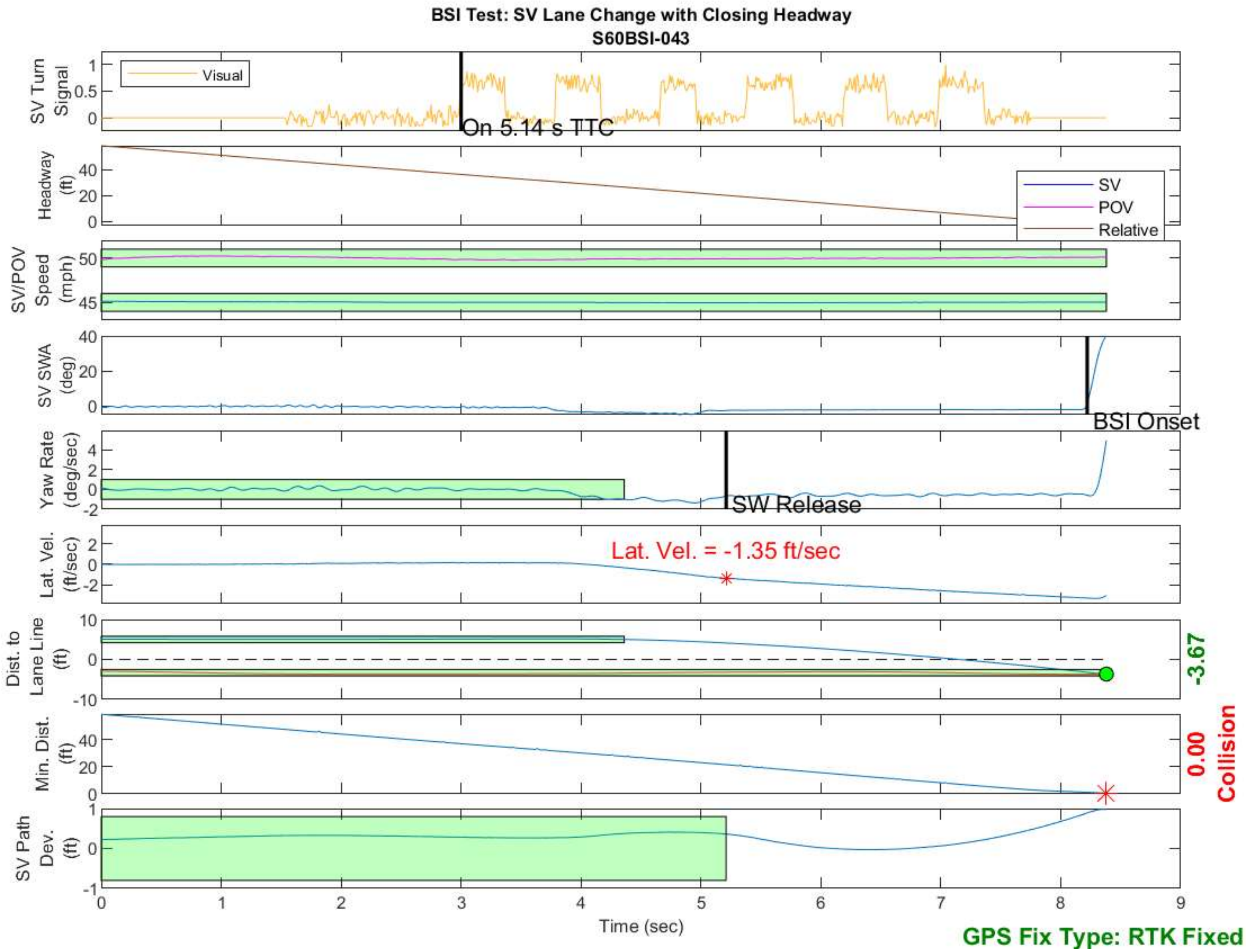


Figure D14. BSI Run 43, Subject Vehicle Lane Change with Closing Headway

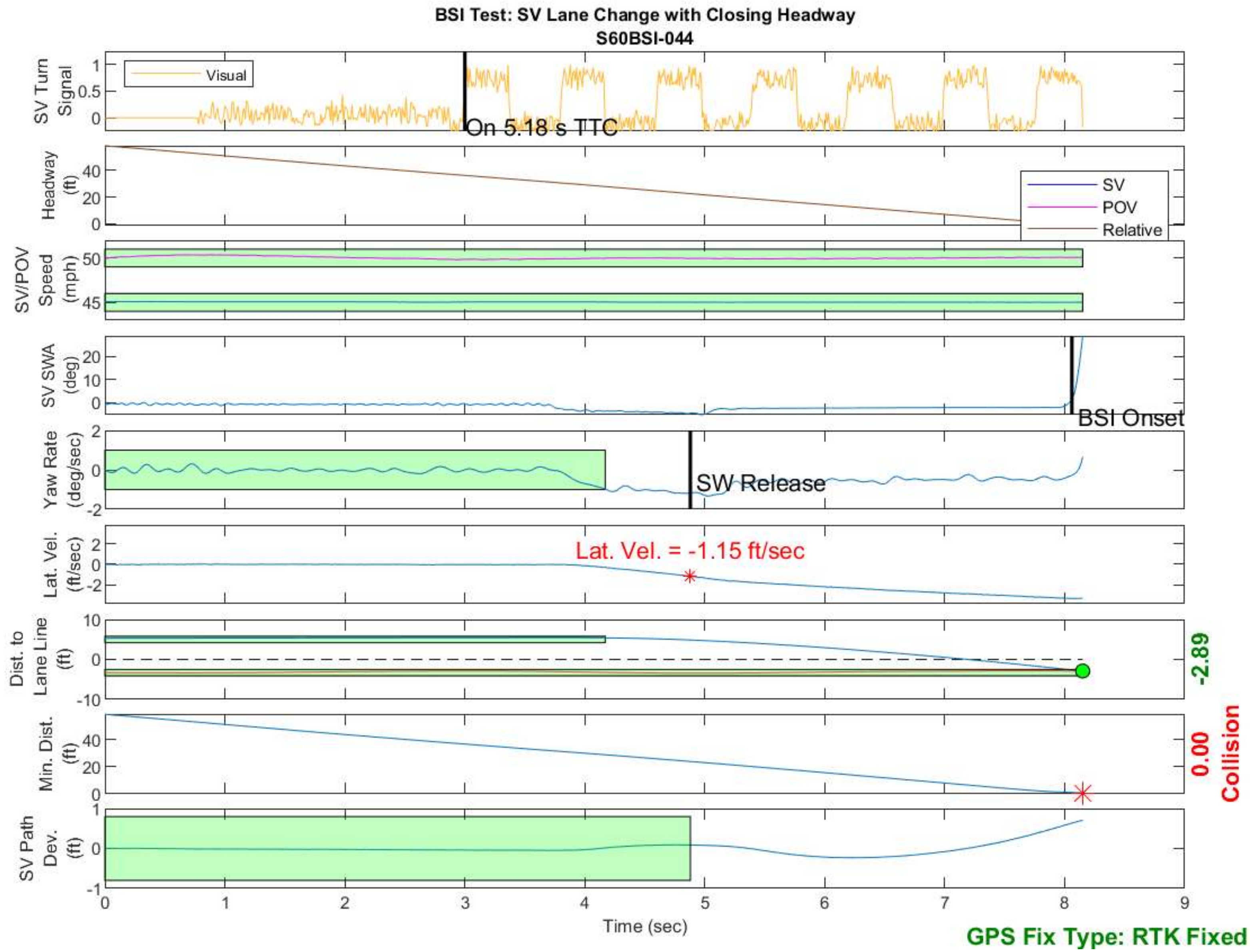


Figure D15. BSI Run 44, Subject Vehicle Lane Change with Closing Headway

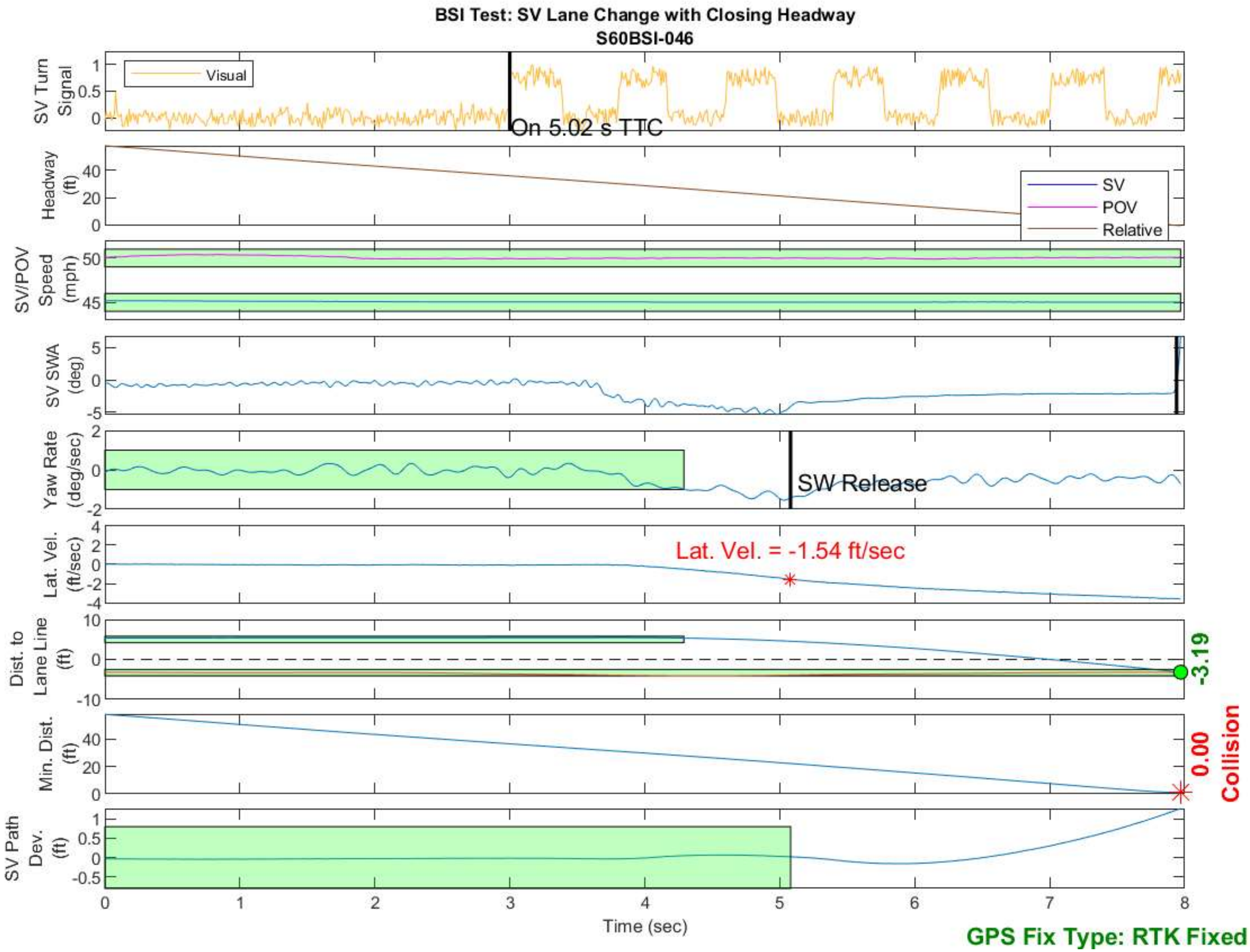


Figure D16. BSI Run 46, Subject Vehicle Lane Change with Closing Headway

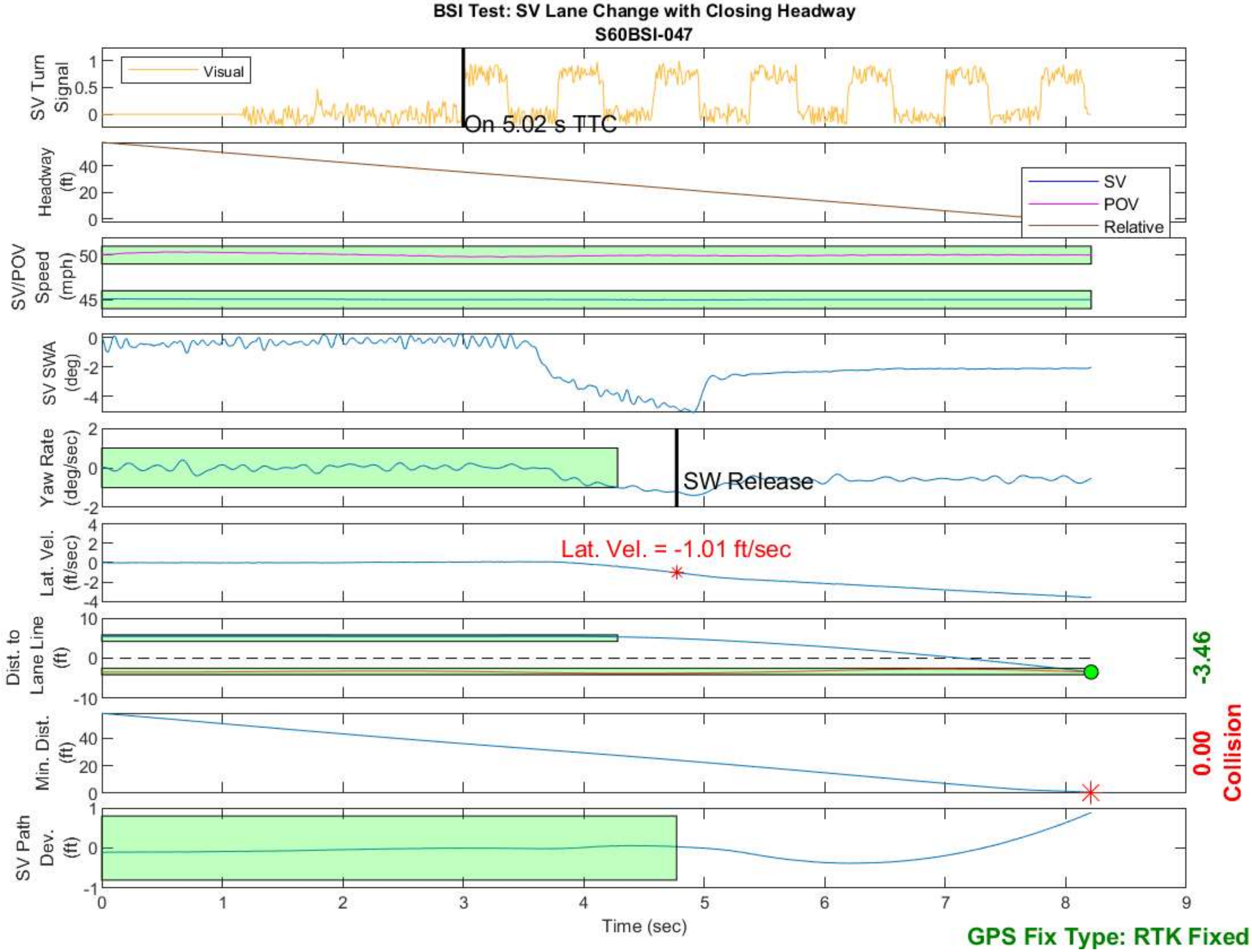


Figure D17. BSI Run 47, Subject Vehicle Lane Change with Closing Headway

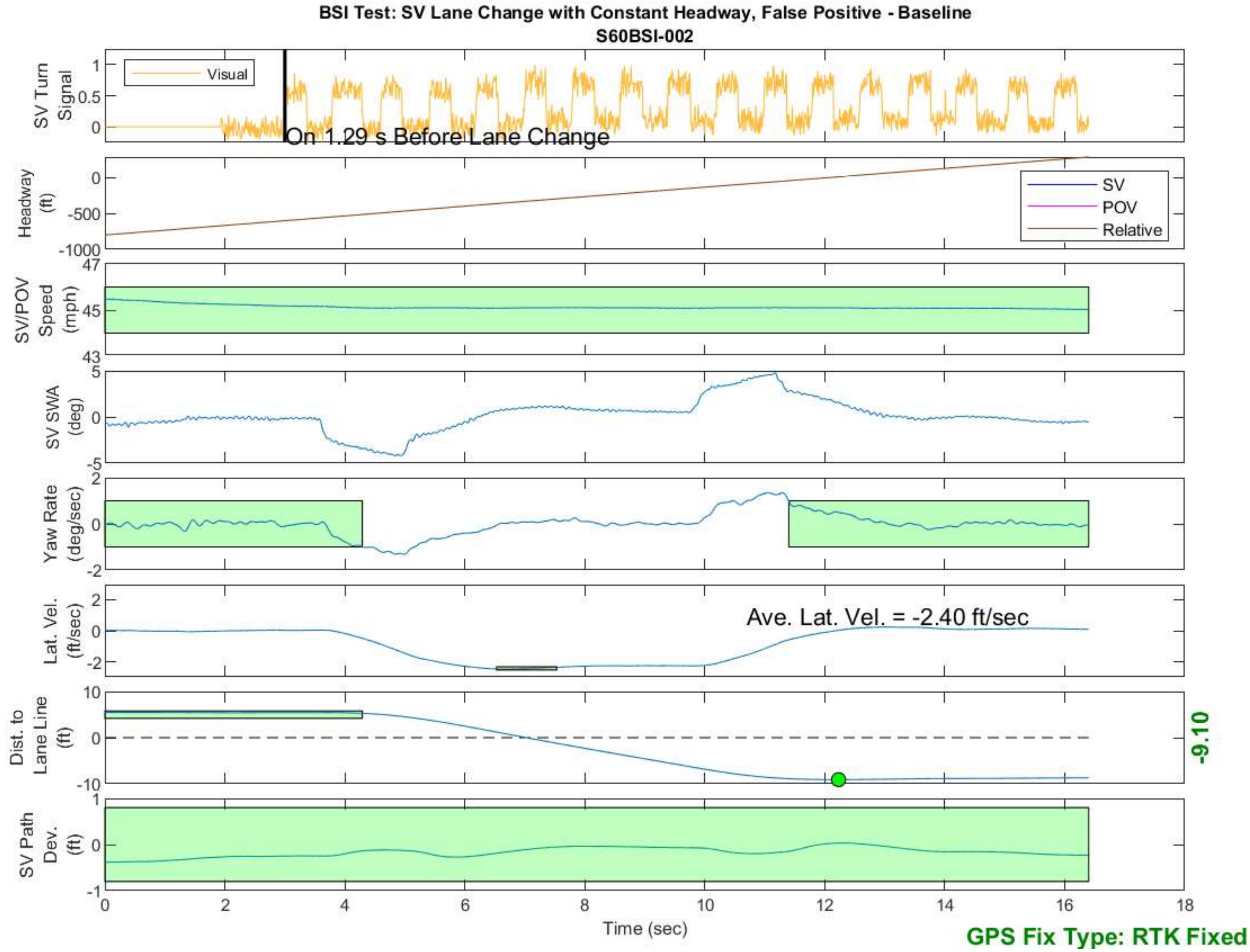


Figure D18. BSI Run 2, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Baseline

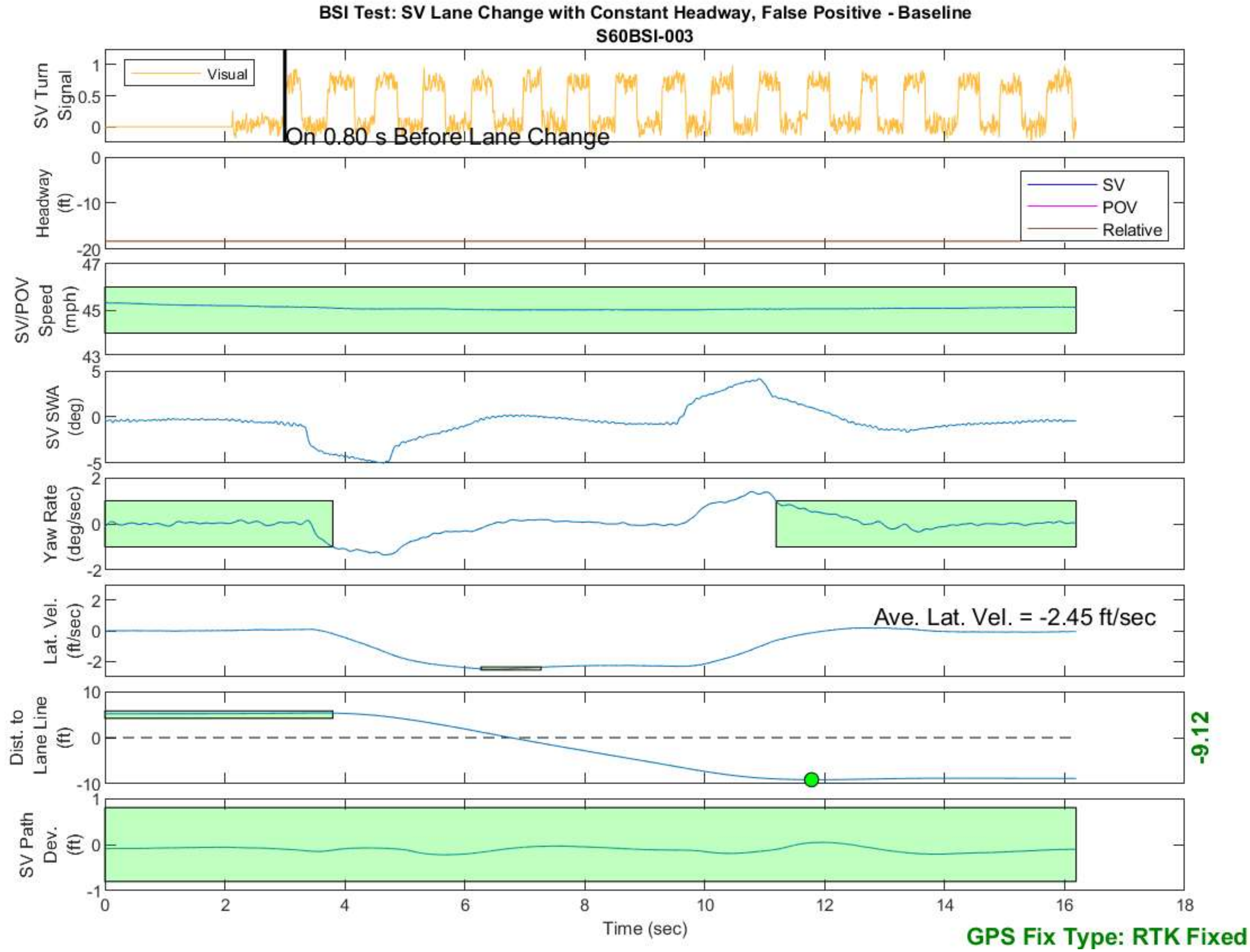


Figure D19. BSI Run 3, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Baseline

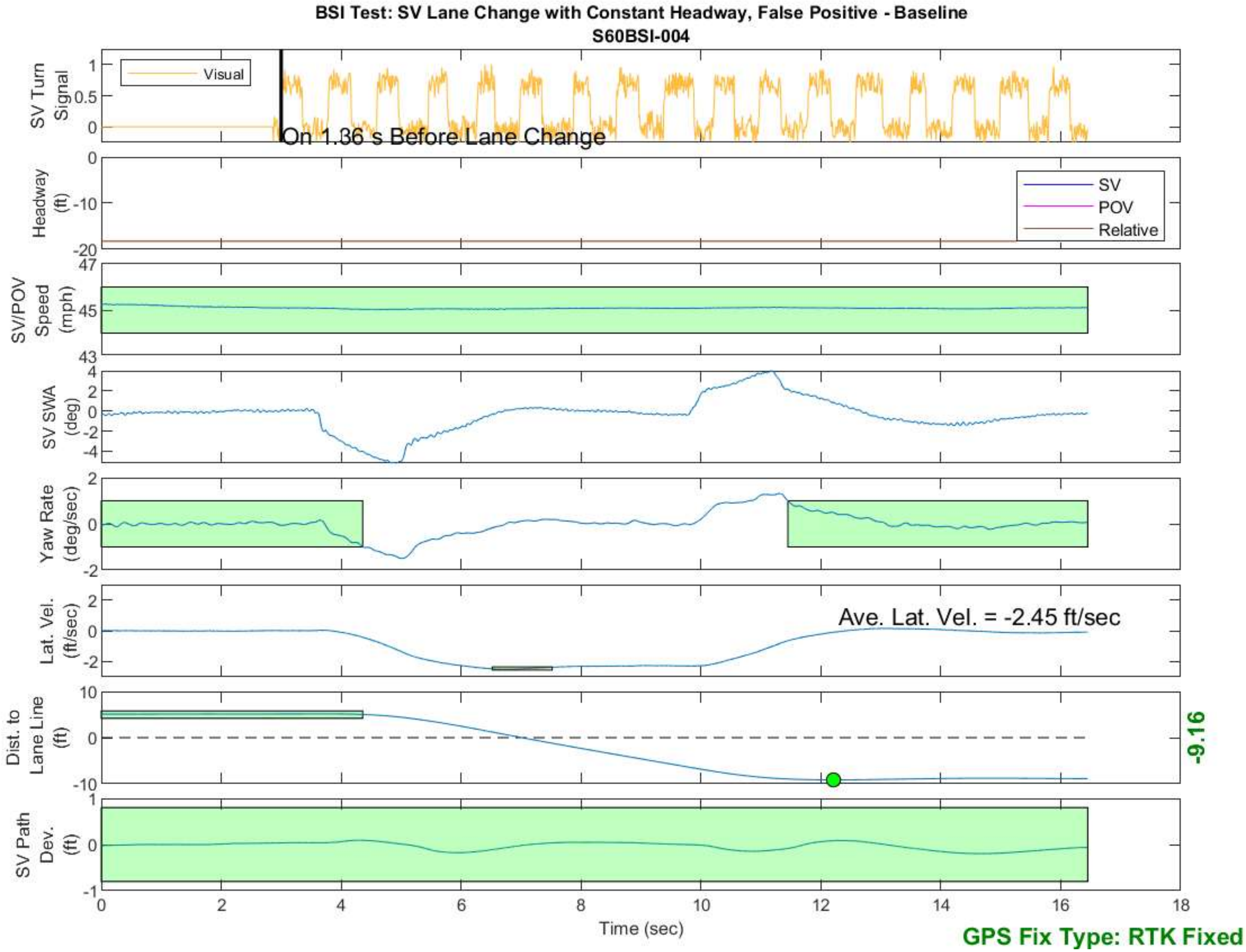


Figure D20. BSI Run 4, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Baseline

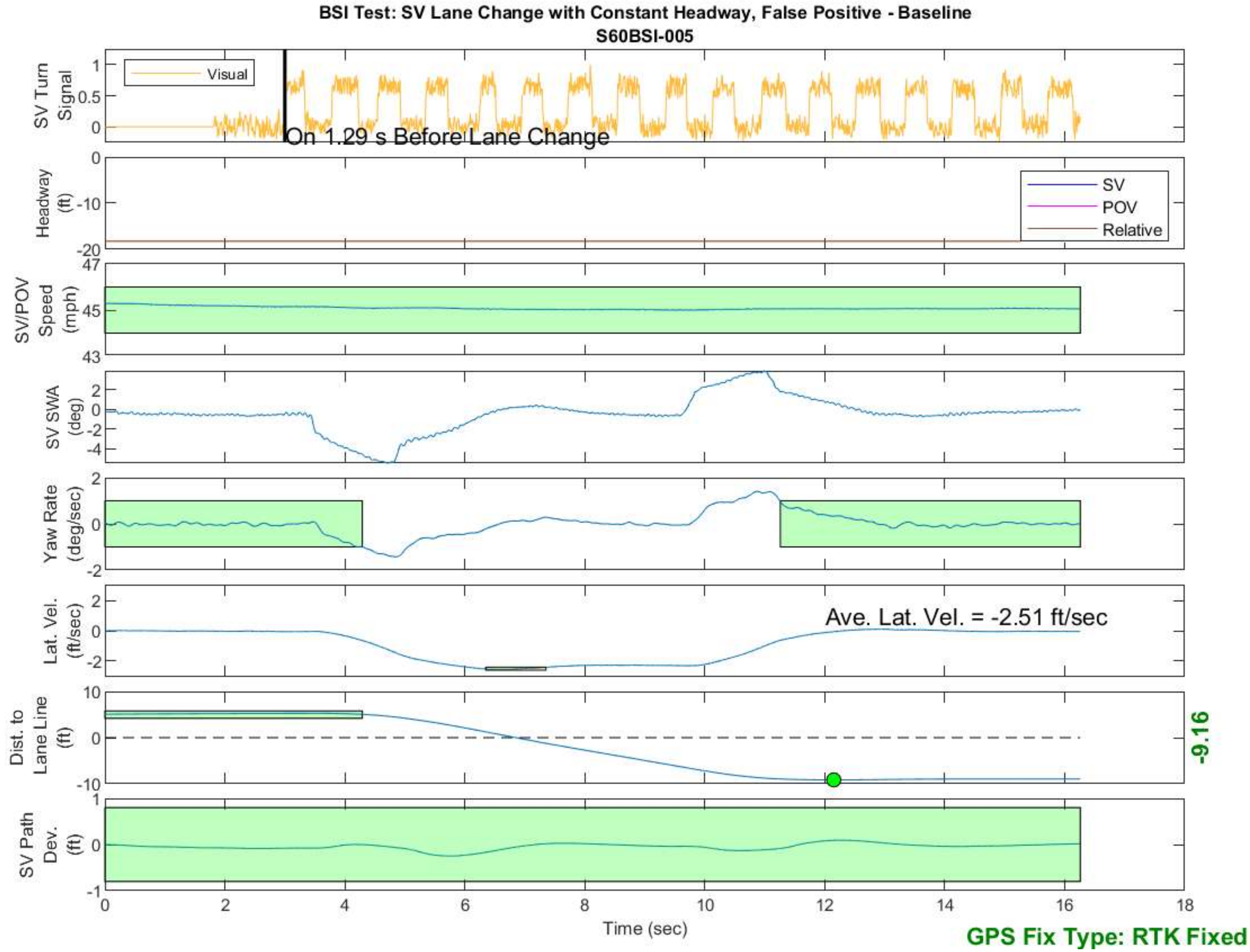


Figure D21. BSI Run 5, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Baseline

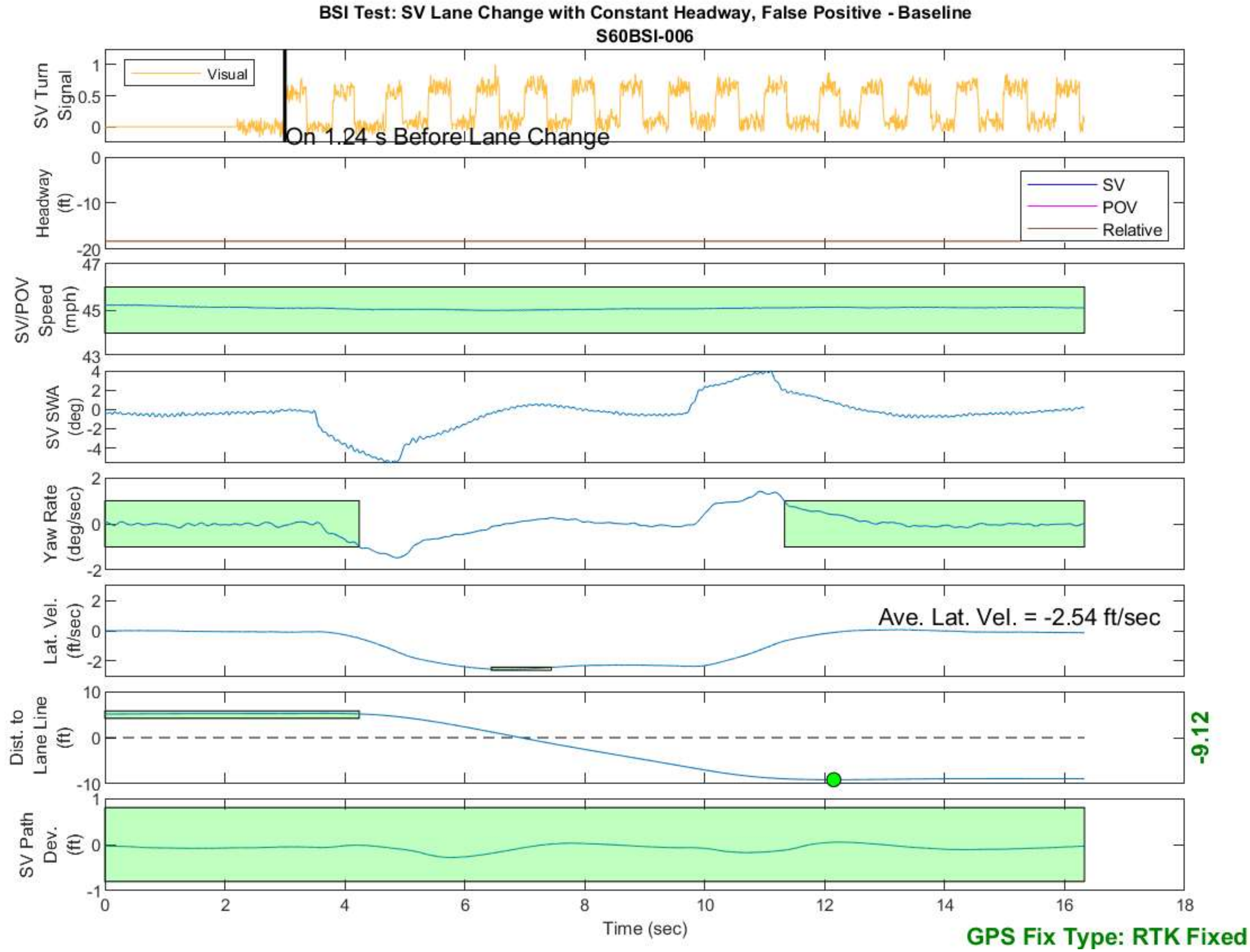


Figure D22. BSI Run 6, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Baseline

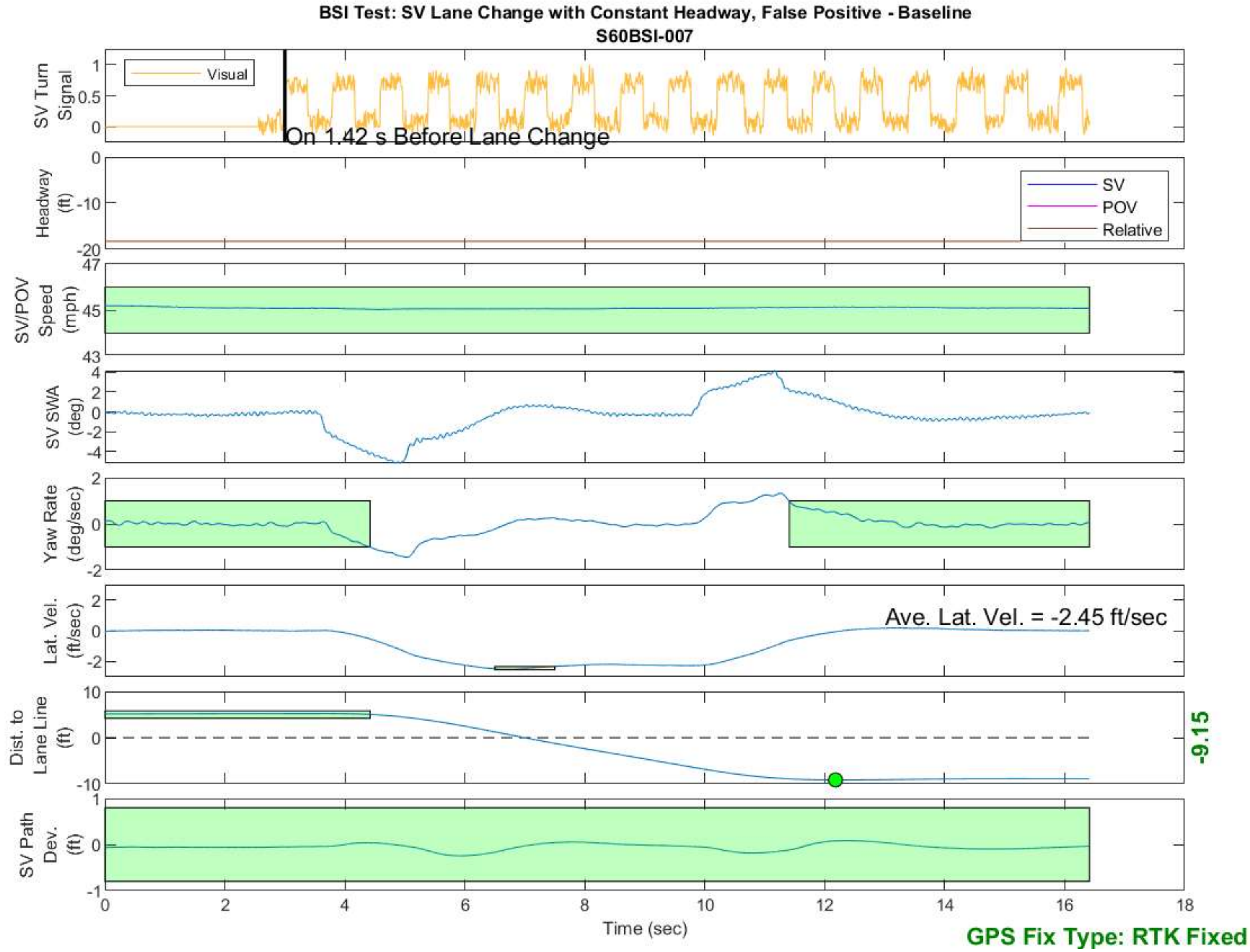


Figure D23. BSI Run 7, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Baseline

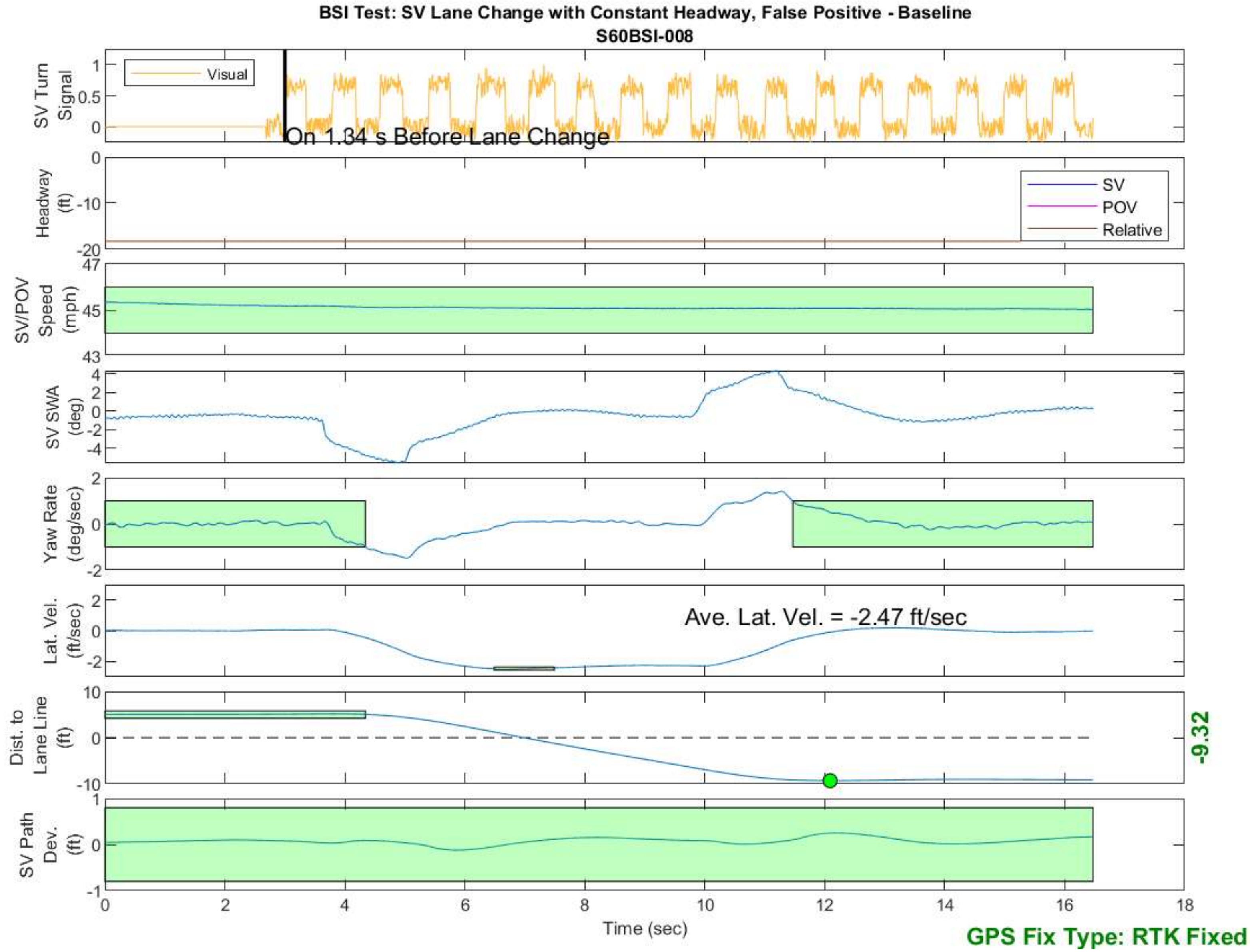


Figure D24. BSI Run 8, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Baseline

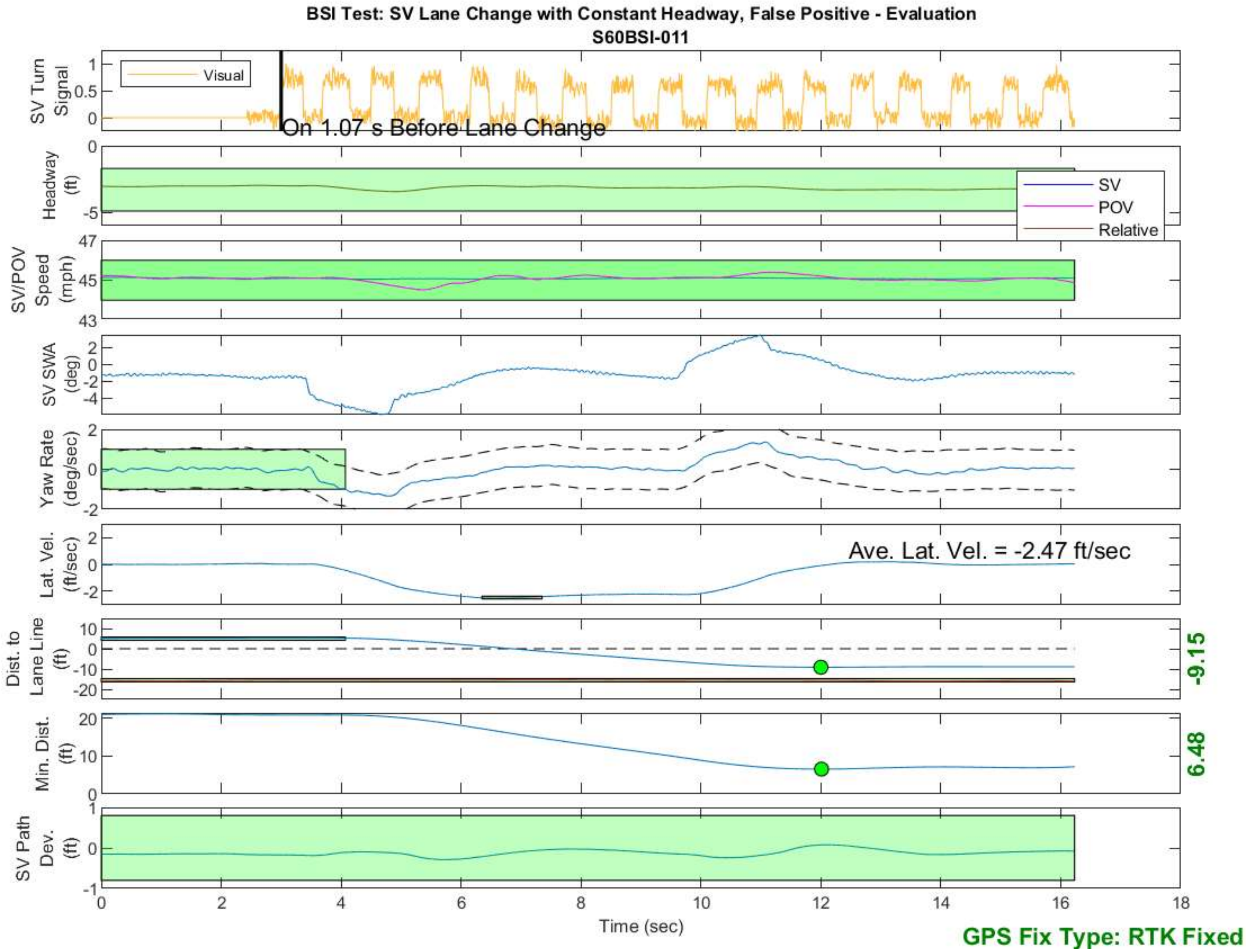


Figure D25. BSI Run 11, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Evaluation

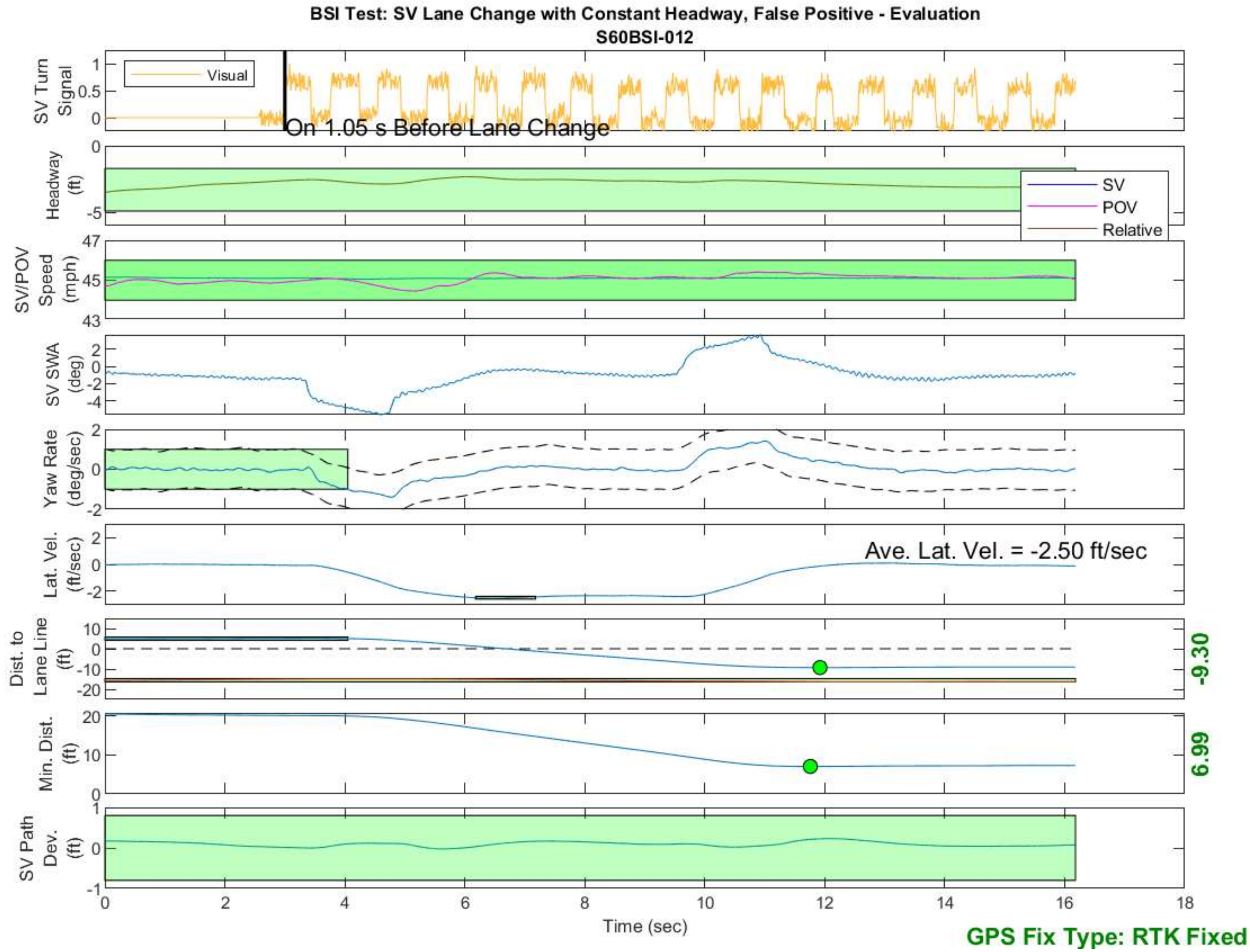


Figure D26. BSI Run 12, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Evaluation

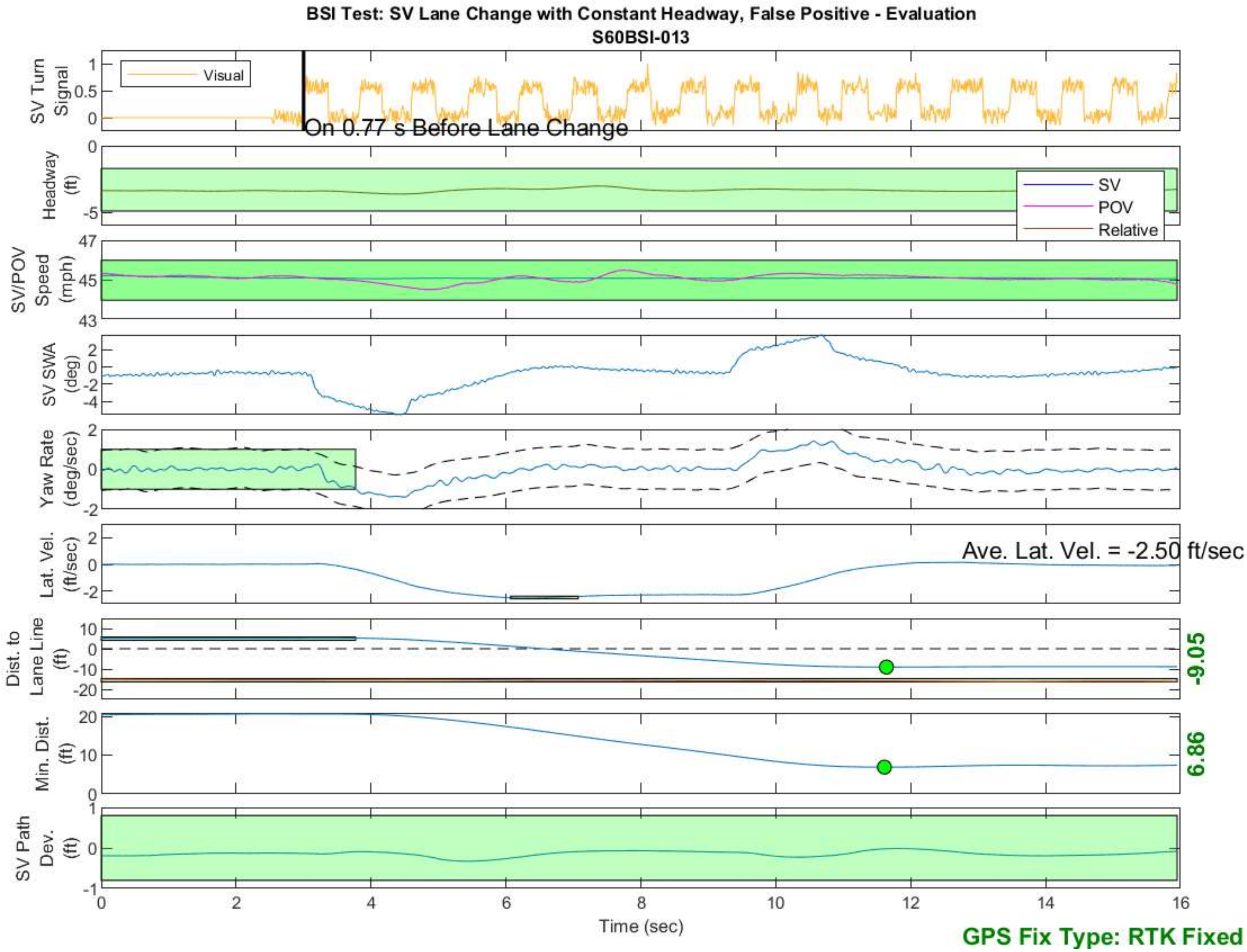


Figure D27. BSI Run 13, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Evaluation

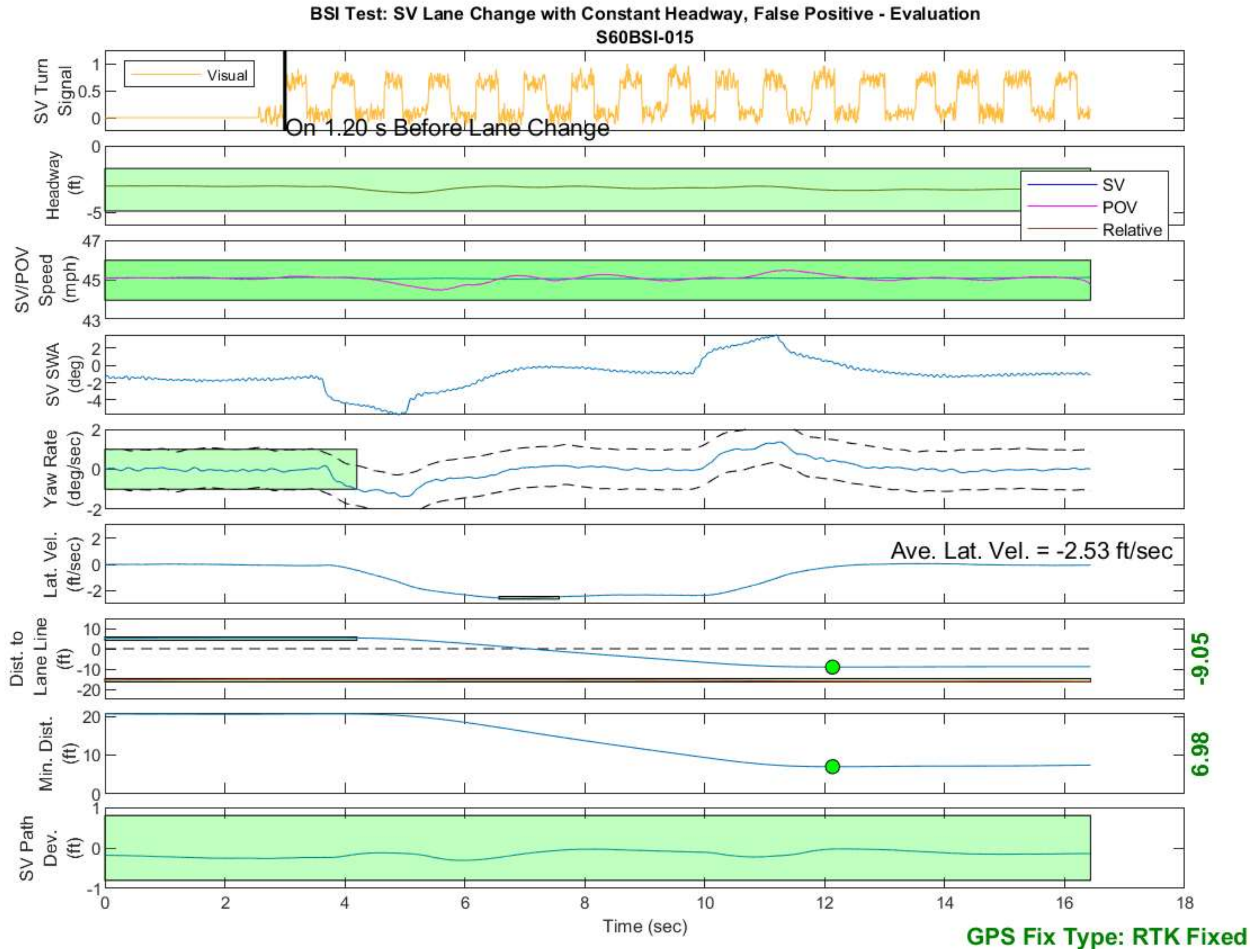


Figure D28. BSI Run 15, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Evaluation

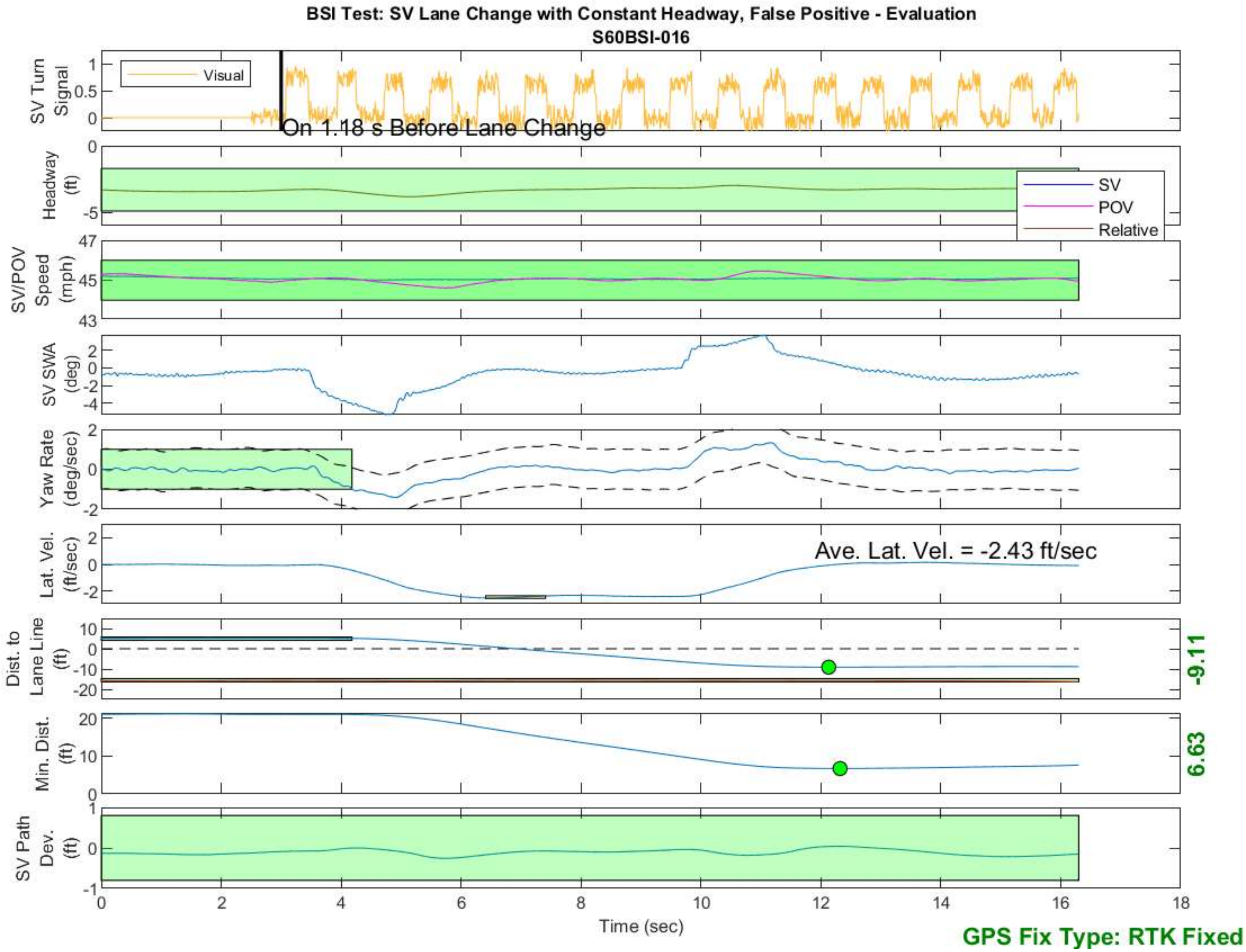


Figure D29. BSI Run 16, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Evaluation

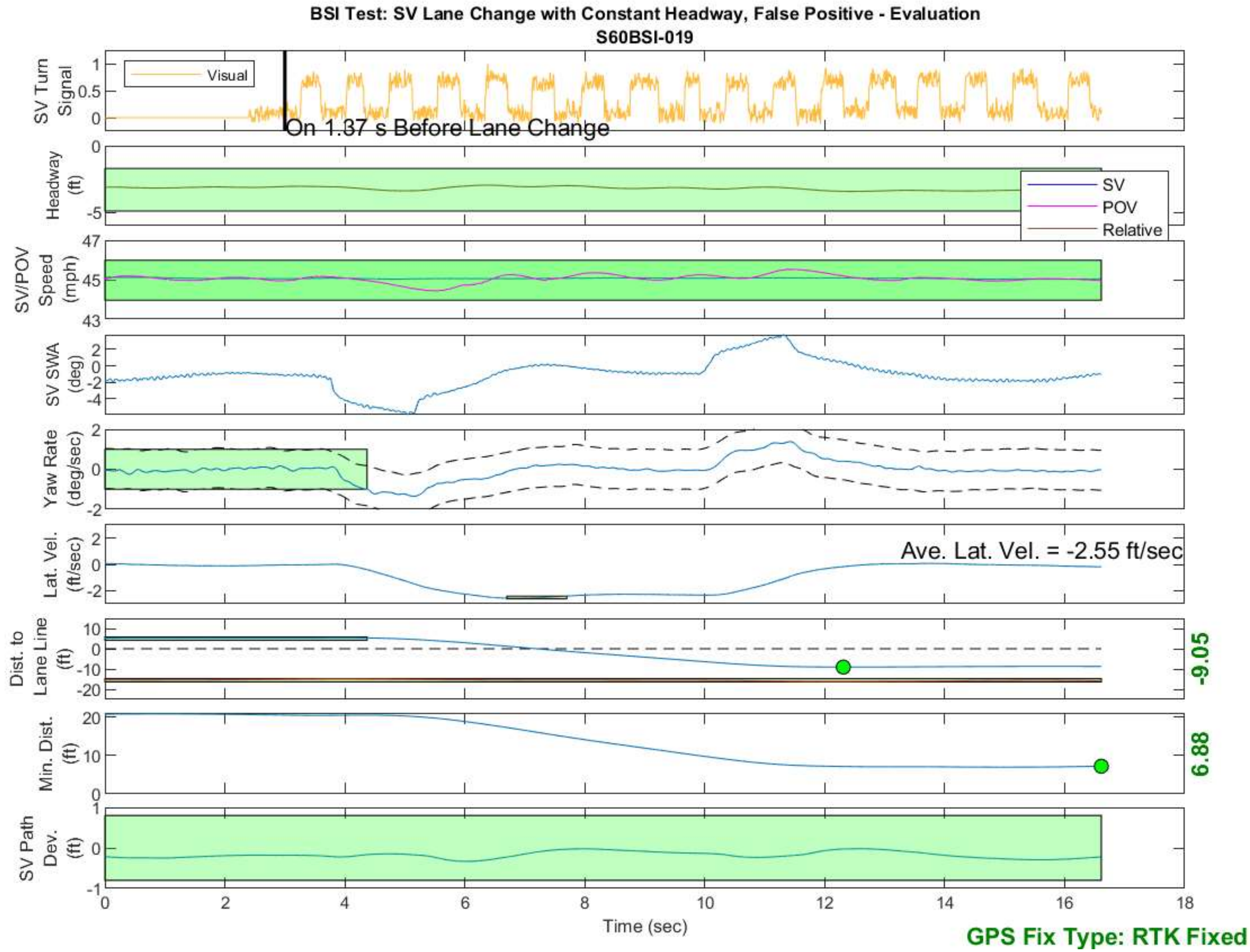


Figure D30. BSI Run 19, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Evaluation

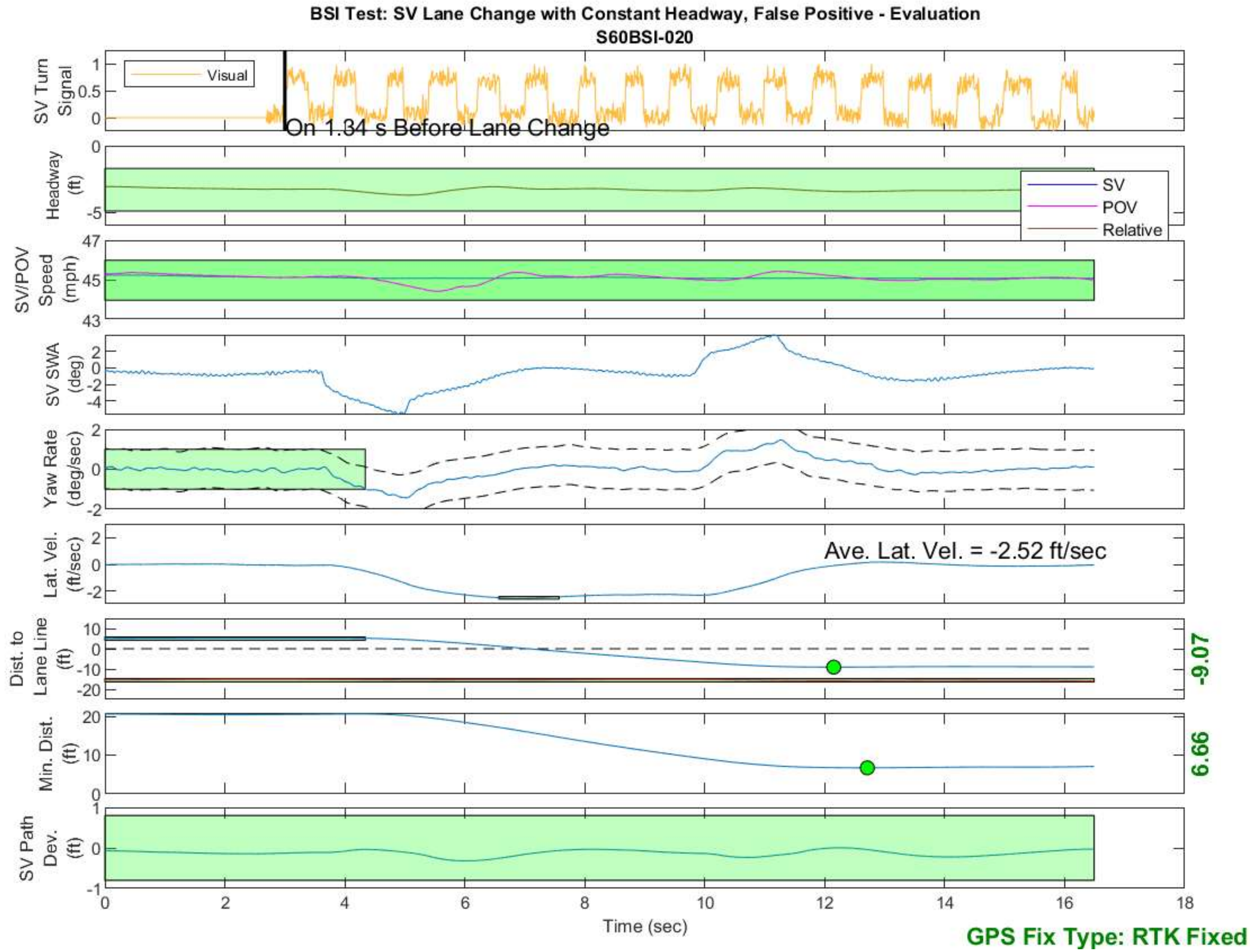


Figure D31. BSI Run 20, Subject Vehicle Lane Change with Constant Headway, False Positive Assessment - Evaluation