Appendix D. Summary of Test Scenarios

Technical Support to the National Highway Traffic Safety Administration (NHTSA) on the Reported Toyota Motor Corporation (TMC) Unintended Acceleration (UA) Investigation

January 18, 2011
This Appendix documents the test scenarios completed by NASA for the National Highway Traffic Safety Administration (NHTSA) Toyota Sudden Acceleration Study.

Figure D-1 illustrates the flow the NESC followed in assessing potential design and implementation vulnerabilities in the TMC ETCS-i system that could possibly cause a UA. Exploratory analysis and testing looked at interactions of operational sequences and events along with one or multiple failure conditions. A significant amount of testing was completed to understand how the ETCS-i operates and what fail-safes exist. Once this “testing for understanding” was completed, more formal testing of test scenarios of operational sequences, and failure conditions was completed. For the purposes of this study, functional failures such as open circuit signal lines, short to ground, high resistance, shorts between signals and short to source voltage as well as potential design vulnerabilities in fault detection and mitigation were the primary focus. Monitoring of actual responses inside the ECM hardware was not possible; however, the software model and ASIC block diagrams did give a level of insight into system function. Model responses were compared to the hardware external responses. Likewise, potential faults related to timing margins were beyond the scope of this effort. Test scenarios were run on a range of vehicles to encompass major changes such as the potentiometer versus Hall Effect sensor changes and ECM evolution.

Test scenarios were developed based on analysis of software and hardware documentation. Table D-1 is a list of test scenarios, multiple individual tests grouped into
themes, performed in the course of this study. Multiple tests were run for each Scenario with different failure conditions and on either a simulator or vehicle(s). Vehicle tests were performed at PARK or in idle, at speed or at both conditions. As noted earlier, testing was both for understanding and confirmation and the table indicates which were done for each scenario. Test for confirmation were more formal tests and included more thorough documentation than the tests for understanding.
### Table D-1. List of Test Scenarios and Conditions

<table>
<thead>
<tr>
<th>Function</th>
<th>Scenario Title</th>
<th>Objective</th>
<th>Type of Test (Understanding or Confirmation)</th>
<th>Failure Condition</th>
<th>Test System/Condition (Simulator or Vehicle - PARK or at Speed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throttle</td>
<td>Map the ECU response to throttle sensor inputs</td>
<td>Map ECU DTC response to throttle sensor signal range failures. Determine if there are dead zones and if they can be exploited as to force unintended acceleration</td>
<td>Understanding</td>
<td>Mapping</td>
<td>Simulator Vehicle - PARK/Idle</td>
</tr>
<tr>
<td>Throttle</td>
<td>Evaluate computer response to failures in the throttle sensors</td>
<td>Determine if series resistance in throttle sensor power, signal line (e.g. high resistance connector contact), or both together can result in erroneous throttle signals that cause the computer to open the throttle. Address the theory proposed by Rajkumar that a valid voltage bias on the throttle sensor signals might trick the feedback loop into opening the throttle further. Also, test for learning effects of sensor signal failures on the Idle Speed Control (ISC) system.</td>
<td>Understanding &amp; Confirmation</td>
<td>Insert series resistance and noisy or failing resistance in the Vc (+5 V) supply line, sensor ground (5 Volt return) line, sensor output</td>
<td>Simulator Vehicle - PARK/Idle, at Speed</td>
</tr>
<tr>
<td>Throttle</td>
<td>Evaluate throttle response to noise (AC, spikes, and DC variation) on the ECU power supply input (+12 volts) and/or output (+5 volts)</td>
<td>Determine if the ECU power supply is susceptible to noise.</td>
<td>Understanding</td>
<td>Conducted Susceptibility (CS) testing</td>
<td>Vehicle - PARK/Idle, at Speed</td>
</tr>
<tr>
<td>Throttle</td>
<td>Evaluate throttle response to AC noise into the throttle sensor signal feedback loop on the PID controller</td>
<td>Determine if PID controller signal loop is sensitive to AC noise</td>
<td>Understanding</td>
<td>Phase/gain test set to produce Bode plot for the throttle control loop. AC sinusoidal variation to the VTA1 signal only. VTA2 signal only and VTA1 &amp; VTA2 together and VPA1 signal only, VPA2 signal only, VPA2 signal only, and VPA1 &amp; VPA2 signal together.</td>
<td>Simulator</td>
</tr>
<tr>
<td>Throttle</td>
<td>Evaluate motor/bridge failure detection logic (includes the motor, H-Bridge or Motor ASIC)</td>
<td>Test the effect of anomalous throttle motor drive on the electronic throttle system. Also investigate possibilities of throttle motor latch-up.</td>
<td>Understanding &amp; Confirmation</td>
<td>Force the vehicle throttle to open using the simulator and the power (M+) line</td>
<td>Simulator Vehicle - PARK/Idle</td>
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<tr>
<td>Throttle</td>
<td>Evaluate effects of throttle angle on vehicle acceleration?</td>
<td>Collect data to measure the effect that throttle opening has on acceleration</td>
<td>Understanding</td>
<td>Release brake at throttle 3, 5, 10, &amp; 18% opening conditions &amp; step throttle to 3, 5, 10, &amp; 18% throttle opening at 30 mph</td>
<td>Vehicle - Idle &amp; 30 mph</td>
</tr>
<tr>
<td>Throttle</td>
<td>Throttle angle air flow test</td>
<td>Understand air flow from different engine conditions</td>
<td>Understanding</td>
<td>Measure mass airflow at different engine conditions</td>
<td>Vehicle - Park and from 0 to ~60mph</td>
</tr>
<tr>
<td>Pedal</td>
<td>Map the ECU response to the pedal sensor inputs</td>
<td>Map engine ECU DTC response to pedal sensor signal range failures. Verify dead zones where faults may not be detected per software model results</td>
<td>Understanding</td>
<td>Mapping</td>
<td>Simulator - Vehicle - PARK/Idle</td>
</tr>
<tr>
<td>Pedal</td>
<td>Evaluate throttle response to failures in the pedal sensors</td>
<td>Determine if anomalies in pedal sensor power, signal line or both together can result in erroneous pedal signals that cause the computer to open the throttle more than desired and test for learning effects of sensor signal failures on the Idle Speed Control (ISC) system.</td>
<td>Understanding &amp; Confirmation</td>
<td>Step VPA1 signal from 0 to 5 volts in increments while the VPA2 signal is normal idle VPA1 &amp; VPA2 signal fail open circuit, short to (with resistance) +12 Volts, and short to ground Partially paired VPA1 and VPA2 signal with resistance and with added resistance &amp; opens to the individual pedal signals</td>
<td>Simulator - Vehicle - PARK/Idle, at Speed</td>
</tr>
<tr>
<td>Pedal</td>
<td>Evaluate the pedal to throttle control loop stability and transient response</td>
<td>Test to characterize the pedal to throttle control loop phase and gain margin and transient response.</td>
<td>Understanding</td>
<td>Use phase/gain test set to inject signal across the 100 ohm resistor and produce Bode plot for the pedal to throttle control loop. Also characterize step response.</td>
<td>Simulator</td>
</tr>
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<tr>
<td>Pedal</td>
<td>Characterization of defective pedal</td>
<td>Characterize a defective pedal mechanically, electrically and its ’s performance</td>
<td>Understanding</td>
<td>Examine the defective pedal to determine its failure mode, cause, and effects on the vehicle under different conditions</td>
<td>Simulator Vehicle - PARK/idle, at Speed</td>
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<td>Idle Speed Control</td>
<td>Evaluate throttle response to failures in electrical load sensors</td>
<td>Test effect of electrical load switch signal failures on the electronic throttle system.</td>
<td>Understanding</td>
<td>Fail the sensing signals from the Air Conditioning, Headlamp, and Radiator Fan electrical load on/off signals</td>
<td>Vehicle - PARK/idle</td>
</tr>
<tr>
<td>Idle Speed Control</td>
<td>Evaluate throttle response to failures in mechanically load sensors</td>
<td>Test effect of mechanical load switch signal failures on the electronic throttle system.</td>
<td>Understanding &amp; Confirmation</td>
<td>Fail the sensing signals from the engine coolant temperature, temperature of air flow, timing, Crankshaft and camshaft signals (timing, crankshaft &amp; camshaft to noise also)</td>
<td>Vehicle - PARK/idle, at Speed</td>
</tr>
<tr>
<td>Cruise Control Vehicle</td>
<td>Evaluate cruise control switch failures for increased acceleration</td>
<td>Test warning signs that switches may get stuck on and/or be susceptible to noise inducing unintended set speed</td>
<td>Understanding &amp; Confirmation</td>
<td>Fail the signal by short to +12 Volts, short to Ground, and resistive shorts to Ground.</td>
<td>Vehicle at Speed</td>
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<tr>
<td>Cruise Control Vehicle</td>
<td>Evaluate cruise control switch failures for increased acceleration</td>
<td>Test warning signs that switches may get stuck on and/or be susceptible to noise inducing unintended set speed</td>
<td>Understanding &amp; Confirmation</td>
<td>Fail the switch to set state and accelerate, attempt to “CANCEL” or “OFF” using the Cruise Control switch</td>
<td>Vehicle at Speed</td>
</tr>
<tr>
<td>Cruise Control Vehicle</td>
<td>Evaluate the effects of noise introduced into the cruise control line on unintended increased throttle angle</td>
<td>Determine if the Cruise Control system is susceptible to noise inducing unintended set speed.</td>
<td>Understanding &amp; Confirmation</td>
<td>Conducted Susceptibility testing</td>
<td>Vehicle at Speed</td>
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<td>Cruise Control Vehicle</td>
<td>Evaluate brake switch failures effects on preventing the cancelling of cruise control</td>
<td>Test effect of failed brake switch and its effect on cruise control enable/cancel and determine if DTC is set</td>
<td>Understanding &amp; Confirmation</td>
<td>Fail the normally open &amp; closed signal, and apply brakes when engaged and engaging enable/cancel switch. Enable Cruise control and restrain the brake plunger and verify vehicle maintains speed when brake is pressed. Press the brake as if to cancel the cruise control.</td>
<td>Vehicle at Speed</td>
</tr>
<tr>
<td>Trans-mission Shifting</td>
<td>Evaluate torque converter lock up on speed increase</td>
<td>Test to determine whether the vehicle reaches a steady state under load with a given accelerator position and if it continues to demand an increase in throttle</td>
<td>Understanding &amp; Confirmation</td>
<td>Dynamometer - 150 ft-lb. load - increase speed past torque converter lock-up of ~34 mph</td>
<td>Vehicle at Speed</td>
</tr>
<tr>
<td>Fuel Cutoff</td>
<td>Fuel cutoff test</td>
<td>Evaluate conditions for Fuel Cutoff</td>
<td>Understanding &amp; Confirmation</td>
<td>Record conditions that cause each of the Fuel Cutoff modes to engage and disengage</td>
<td>Vehicle - PARK/idle, at Speed</td>
</tr>
<tr>
<td>Inspection and evaluation of complaint cars</td>
<td>Inspection and evaluation of complaint cars</td>
<td>Characterize available suspect vehicles in an attempt to replicate the initial complaint, including possible fault traces.</td>
<td>Understanding</td>
<td>Measure voltages, resistances, DTC's and inspect for anomalies</td>
<td>Vehicle - PARK/idle, at Speed</td>
</tr>
</tbody>
</table>

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