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TNO report

| 2.1

MOVE User Manual

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Contents

1 Introduction

The TNO MOVE box can be used to safely take over control of a Toyota Prius 3rd generation. The MOVE box acts as a gateway between the application platform and the vehicle ECUs. MOVE responds to higher level commands received via CAN from an application platform (e.g. dSpace Autobox) and translates these into lower level commands specifically for a Toyota Prius. Consequently, application developers are not required to understand in detail the functionality and interfaces of Toyota ECUs. Furthermore, safety and redundancy measures of the Toyota Prius itself are used in accordance with additional safety measures in the MOVE box. More specifically, if MOVE is disabled the vehicle wiring is electrically identical to an original vehicle and completely safe to be used on public roads. This makes MOVE an ideal prototype environment to safely test different control algorithms on a vehicle level.

Figure 1 High level overview

This document provides a description of the MOVE system, its capabilities and its interfaces. The document is organized as follows: Section 2 describes the features of the MOVE system, Section 3 discusses the system overview and the integration within the vehicle. Section 4 describes how to use MOVE to control the vehicle actuators and Human Machine Interface (HMI). Section 5 describes problems that can be experienced, and common causes of these problems. Lastly, Section 6 describes a quick start procedure where MOVE can be controlled through dSpace and ControlDesk.

2 Features

MOVE interfaces with the vehicle in a safe way enabling the user to read sensor data and take control of specific vehicle components (e.g. longitudinal, lateral, and hmi). MOVE checks requests from external platforms and disables controllers if safety limits are exceeded, for instance if the requested steering angle exceeds the safety range. Furthermore, if the external platform stops functioning, or the communication between the external platform and MOVE is stopped, the control of the vehicle is returned to the user. In addition to these safety measures the driver can always override MOVE by pushing the emergency button, physically disconnecting MOVE from the vehicle CAN bus.

The following list describes sensor data that can be provided by MOVE followed by the control capabilities.

Sensor data:

- Steering angle
- Yawrate
- Longitudinal acceleration
- Lateral acceleration
- Velocity
- Four independent wheel speeds
- Drive force
- Gear indicator
- Brake pressed
- Throttle percentage
- User requested steering torque
- Radar object data (x, y, range rate) for 8 objects

HMI:

- Steering wheel buttons and lever
- HMI display icons (e.g. warning, Adaptive Cruise Control interface, Lane Keeping Assist interface)

Vehicle control:

- Controlling throttle and brake
  - Controllers: force, acceleration, velocity
- Controlling steering wheel angle
  - Controllers: steering angle, yawrate
- Steering control mode:
  - Safe by limited torque (suitable for lane keeping)
  - High Performance (suitable for a large range of velocities)
- Brake control modes:
  - Without hydraulic brakes (can be overridden by driver)
  - With hydraulic brakes (can be overridden by driver)
  - With hydraulic brakes in pre-collision mode (cannot be overridden by driver)

2.1 Limitations

The following limitations are imposed by MOVE or original Toyota ECUs:

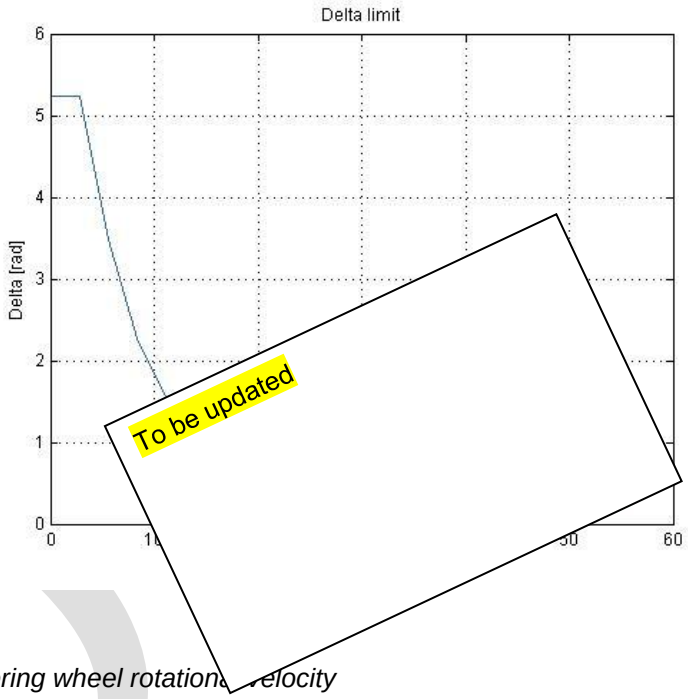
- Maximum deceleration: -6m/s
- Maximum duration in pre-collision modes: 2 seconds
- Steering control : torque is limited to 1.5Nm (LKA)
- High performance lateral control: +/- 540 degrees, only with additional hardware.
- Longitudinal vehicle control is only allowed when in D.

2.2 Safety limits for lateral control

The controllers used for automated steering are limited to ensure safe operation.

2.2.1 Delta limit

The maximum steering angle for the high performance lateral controllers is limited, with respect to the vehicle's velocity by the following limits.



2.2.2 Steering wheel rotation velocity

The rotational velocity is by default limited to 200 degrees/second. Note that this rate limit is applicable for all velocities.

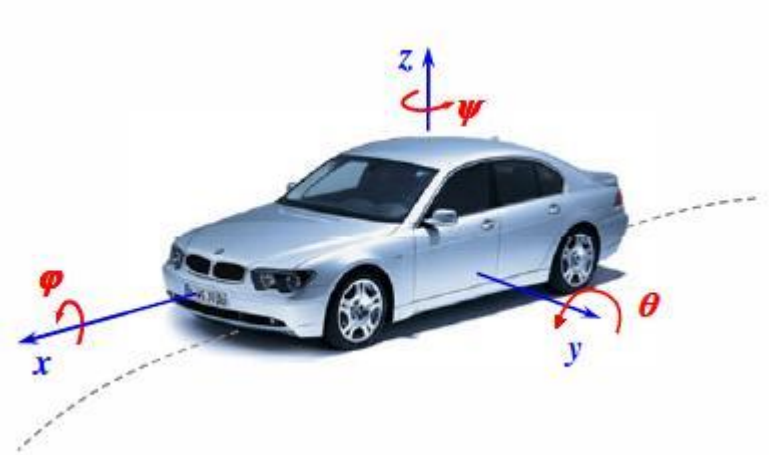
3 System overview

MOVE is installed in a Toyota Prius 3rd Generation with Adaptive Cruise Control. MOVE acts as a gateway between an application platform and the low-level vehicle systems. MOVE contains a series of safety mechanisms and abstractions from the vehicle hardware, enabling the user to concentrate on the higher-level controllers instead of interacting with vehicle-specific systems directly.

MOVE interacts with the low-level vehicle systems via several CAN busses and analog and digital input/output. An external application platform can interface with MOVE via a single CAN bus.

The recommended vehicle instrumentation places MOVE in the glovebox, and replaces the standard navigation unit with a USB touchscreen and several status LEDs. Additional hardware, e.g. the application platform, should be installed in the trunk, where a CAN connection with MOVE can be made available.

3.1 Coordinate frame



The axis orientation used in MOVE, unless specified otherwise, is according to ISO 8855. The axis orientation for ISO 8855 has X forward, Z up, and Y pointing to the left-hand side of the vehicle.

3.2 Interfacing

An external platform, e.g. a dSpace Autobox or a vehicle computer can interface with MOVE via CAN. The CAN baudrate is 500kbit/s and with a terminating resistor on the external platform side.

MOVE starts transmission of CAN messages after receiving message External_Platform_State. This message needs to be transmitted at 25Hz, and MOVE will monitor reception of this message and if communication is lost a timeout is detected. This timeout causes an error which forces MOVE to switch to a safe state, see Section 5 for possible causes and solutions to common problems.

3.3 Input / Output specification

The CAN message specification is provided in xls and dbc format. The xls format gives a clear overview of all messages, the encoding/decoding scheme and a brief explanation of the possible values.

The dbc format contains identical information and can easily be used in Simulink/dSpace models. In RTI CAN blocks in Simulink a reference to a dbc file can be given to specify the encoding/decoding scheme of CAN frames.

4 Controlling the vehicle

MOVE is capable of taking control of the vehicle, after safety checks have been performed and MOVE is enabled. The following sections describe the procedures to enable/disable MOVE and activate specific controllers.

The text in the following sections will refer to the figures below.

Figure 2 Prius display with status LEDs and emergency button

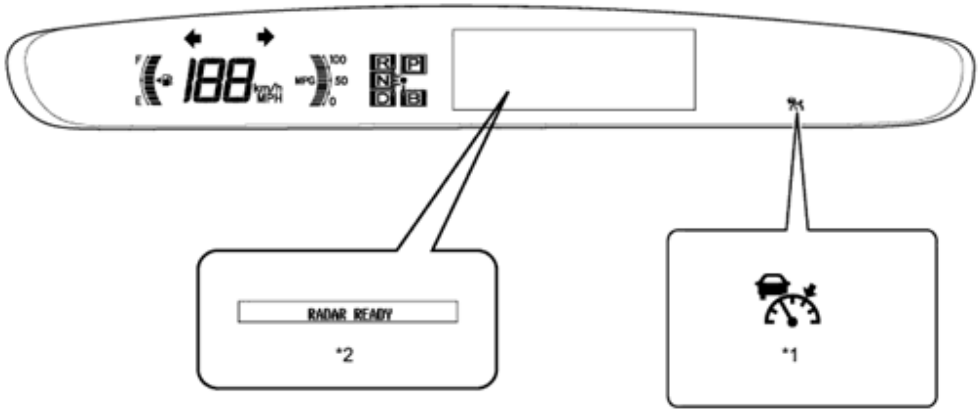


Figure 3 Toyota Prius Display

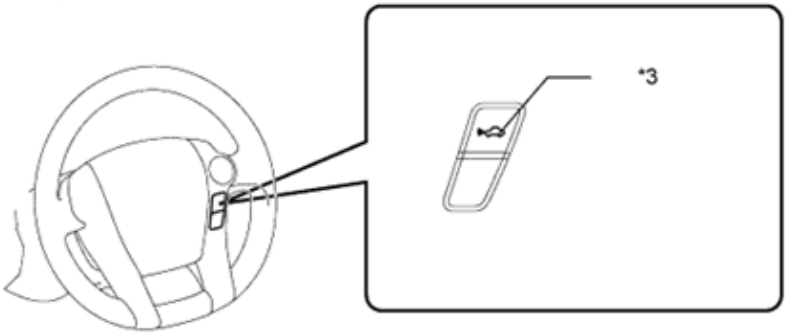


Figure 4 Time headway button

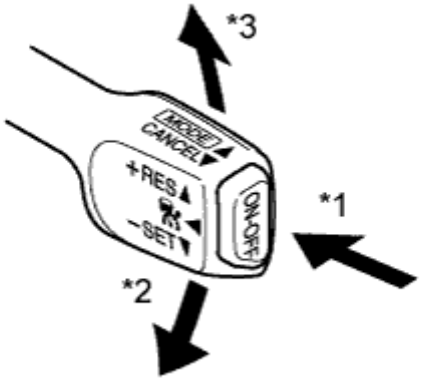


Figure 5 ACC lever

4.1 LED Status

In a standard MOVE system three LEDs (green, orange, red) are used to interact with the driver. If the lateral MOVE hardware is installed a fourth LED (green) is added. The Green LEDs follow the same logic, but work independently of each other.

Status	Green LED lateral	Green LED longitudinal	Orange LED	Red LED
Safe state	X	Flashing	Flashing	Flashing
Not enabled	X	X	On	X
Enabled / Control Allowed	On	On	X	X
Enabled / Control NOT Allowed	Off	Off	X	X
Enabled / all controllers OFF	Off	Off	Flashing fast	X
Active	Flashing	Flashing	X	X
Overrule	Flashing fast	Flashing fast	X	X
Error	X	X	Flashing	On

4.2 Lateral MOVE additional hardware

If the lateral MOVE hardware is installed, a fourth LED (green) and a pushbutton switch are installed. The LED is used to inform the driver about the lateral controller state as specified in Section 4.1. The pushbutton, named *lateral control enable switch*, must be pressed by the driver if lateral control functionality is desired. This additional step ensures that the driver is aware that lateral control can be activated.

4.3 Enabling MOVE

MOVE can be enabled if the vehicle is running and the emergency button is released.

Enabling MOVE must be done according to the following procedure:

1. Make sure the factory ACC is switched off. If 'Radar Ready' (Figure 3) is visible, press the On/Off button on the ACC lever (Figure 5) to switch off the ACC.
2. Make sure the vehicle velocity is smaller than 25 km/h.
3. Simultaneously press the time headway button on the steering wheel (Figure 4) and SET (Figure 5) by moving the ACC lever down to activate MOVE.
4. If the vehicle is in D (Drive) and the application platform is transmitting message External_Platform_State with a valid status then MOVE is allowed to take longitudinal control of the vehicle. This is presented to the driver with only the green longitudinal status LED being lit (yellow and red LEDs are not lit).
5. If the *lateral control enable switch* has been pressed, the lateral green LED switches on, in any gear. Lateral control is allowed in any gear.

4.4 Disabling MOVE

MOVE can be disabled while driving, guaranteeing the application platform cannot take control of the vehicle anymore. The following procedure disables MOVE:

1. Simultaneously press the time headway button (Figure 4) and RES (Figure 5) by moving the ACC level up to deactivate MOVE.
2. The green LEDs switch off, the orange LED will be lit.

4.5 Error handling

If an error is detected MOVE will directly be switched off, giving control to the driver. As a consequence, the red LED will be lit and a buzzer will sound.

The orange LED will blink, and the number of times it blinks provides information about the error, see Section 5 for possible errors and common solutions.

Once the problem is solved the system can be reset with RES (Figure 5) by moving the ACC lever up. If the error is really solved the red LED will switch off and the orange LED will be continuously lit. The system can be activated again according to the procedure described in Section 4.1.

4.6 Safe start

MOVE can be started in a safe state, in which it is not possible to accidentally activate MOVE. In this state all relays in MOVE are switched to their default position, leaving all CAN connections in the vehicle in their original configuration.

The procedure to enable this safe state is as follows:

- Make sure the vehicle is switched off
- Make sure the emergency button is pressed (Figure 2)
- Simultaneously press the time headway button (Figure 4) and CANCEL by pulling the ACC lever (Figure 5) towards you
- Start the vehicle by pressing the brake pedal and push start
- All status LEDs are flashing
- Leaving the safe start state is possible by switching off the vehicle

4.7 Initiating CAN communication

The external platform is required to transmit message 0x200 External Platform State at a rate of 25Hz. This message contains the external platform status, which must be equal to 1 to enable MOVE. Optionally the time out setting can be (temporarily) changed. MOVE checks whether communication with the external platform is still available, based on the reception of message 0x200. The time out value defines what the maximum duration between two messages is allowed to be. The default value of 0.2s is recommended.

4.8 Longitudinal

Longitudinal controllers can be activated if MOVE is enabled (only green LED should be lit). MOVE supports the following longitudinal controllers:

- Force control (set point driving force)
- Acceleration control (set point desired acceleration)

MOVE will communicate the controller status to the external platform in message 0x103 MOVE longitudinal state.

A controller follows the following state diagram. In each state the status of the green LED is given.

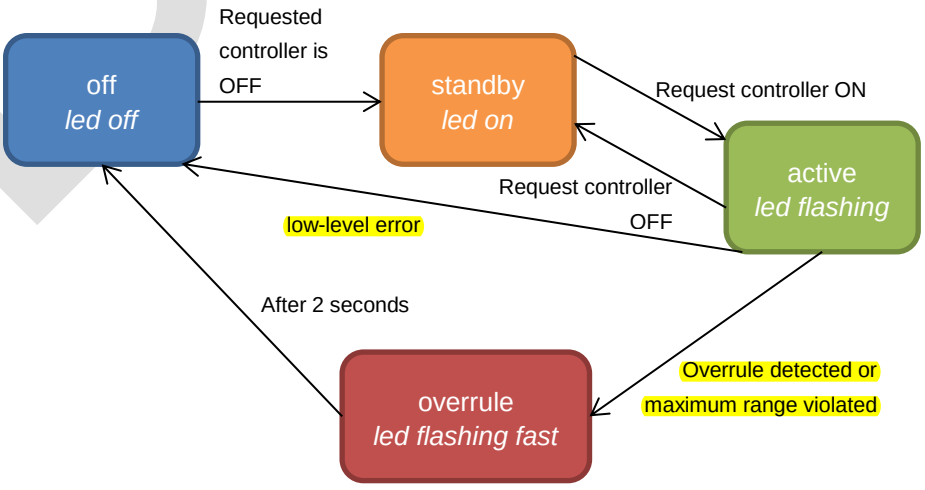


Figure 6 Controller state machine

By default the controller is OFF, and the external platform should not request a controller. As soon as the longitudinal controller switches to standby, meaning system status is ok, the external platform may request a specific controller type, e.g. acceleration control. The desired set point and the controller type must be communicated, and if accepted by MOVE the controller status will switch to *active*, and remain active unless requested to switch OFF, an overrule is triggered, or an error is detected. MOVE contains safety mechanisms to ensure safety limits are not exceeded, and to ensure the driver can always take manual control. For longitudinal control an overrule monitor detects if the driver presses the brake pedal, consequently disabling the controller.

In addition the controller type the actuator mode (brake mode) can be selected. The following modes exist:

- Cruise Control: acceleration is allowed; deceleration by lifting the throttle, not hydraulic brakes. Can be overruled by driver (by accelerating or braking). Braking deactivates the controller, accelerating temporarily overrides the controller output, but the controller remains active.
- Adaptive Cruise Control: acceleration is allowed, deceleration by lifting the throttle, or hydraulic brakes (depending on set point; vehicle responds to small decelerations by lifting the throttle or engine braking). Can be overruled by driver (by accelerating or braking). Braking deactivates the controller, accelerating temporarily overrides the controller output, but the controller remains active.
- Pre-Collision Braking: acceleration is not allowed; deceleration maximum of 6m/s2 and for a maximum of 2 consecutive seconds. Cannot be overruled by driver! MOVE reads brake pedal pressure and throttle position to de-active the controller (e.g. when throttle position exceeds 80%).

4.9 Lateral

MOVE, extended by the lateral MOVE hardware enables the operator to enable limited, low torque lateral control and high performance lateral control.

By default, if the vehicle is started all lateral control is disabled. Only after pressing the *lateral enable switch* (switch 1) while driving slower than 25kph, lateral control can be activated. The green lateral LED will be lit if controller can be activated.

This mode can be left by pressing the emergency button, and re-enabling MOVE, or by switching off the vehicle.

MOVE contains the following lateral controllers:

- Steering Wheel Angle
- Yawrate (currently limited to TNO users only)

In addition to the controller type the actuator mode (SteeringMode) can be selected. The following modes exist:

- Safe control by limited torque
- High performance

Activation of lateral controllers follows the same state diagram as longitudinal controllers (Figure 6). MOVE will communicate the controller status to the external platform in message 0x106 MOVE lateral state.

It is recommended to activate lateral control at low velocities with the steering wheel close the center position (zero degrees). Furthermore, sometimes the high performance lateral controller cannot be activated, which is caused by the original Toyota ECUs. In this case the control modes switch from active (2) to off (0). The higher level controller must consequently re-activate the controller.

4.10 HMI

If MOVE is enabled an external platform can take control of the vehicle HMI by transmitting message Vehicle_HMI_outputs. Furthermore, the buttons and the lever on the steering wheel can be read.

4.10.1 Adaptive Cruise Control

The Toyota Prius display can be controlled by MOVE through message 0x230 Vehicle HMI outputs. First, the display state must be set, selecting between *off, adaptive cruise control,* and *cruise control.* The default state is off. If adaptive cruise control standby is selected the display in Figure 3 is visible. Furthermore, cruise speed (Figure 7), time headway (Figure 9) and detected object (Figure 10) can be set.

If cruise control is selected the time headway and object will not be visible, but the cruise speed can be set.

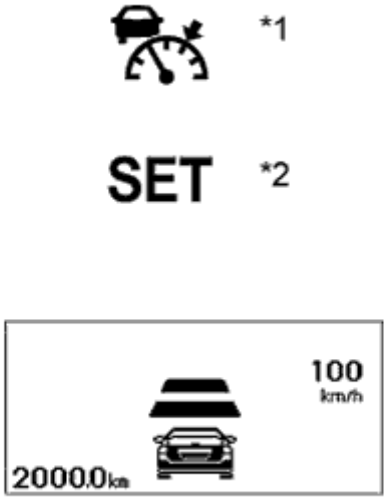


Figure 7 ACC active

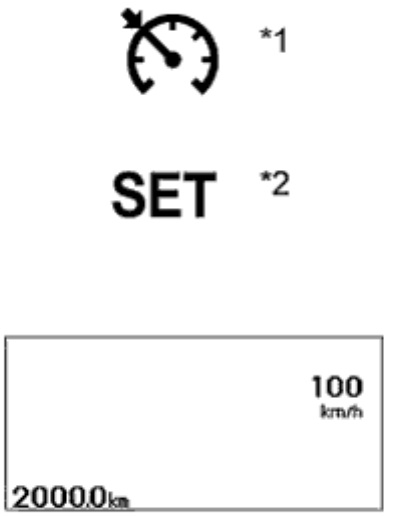


Figure 8 Cruise Control active

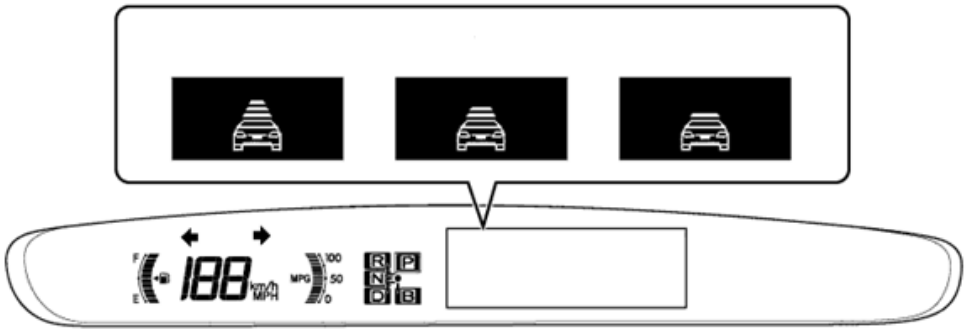


Figure 9 Time headway modes

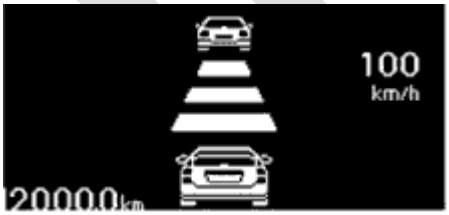


Figure 10 Object detected

4.10.2 Pre Collision

A Pre Collision warning (BRAKE) can be shown in both the combination meter display and the HUD visible to the driver (if installed).

The *brake warning* has the highest priority, and is shown to the driver by setting the signal PCSWarning to on (1).

4.10.3 Seatbelt tensioner

The Toyota Prius is fitted with seatbelt tensioners for the front seats. These can be activated via MOVE. The seatbelts will be tensioned if activated, and will keep this tension unless deactivated. Original Toyota ECUs ensure that only the seatbelts for occupied seats are activated.
Please note:

- Seatbelts must be worn when activating the seatbelt tensioner
- Activating the tensioner often in a short time span, or for a long duration may result in a PCS warning shown in the Toyota display. This error message disappears when re-starting the vehicle.

4.10.4 Lane Keeping

In addition to the adaptive cruise controller interface the lane keeping assist interface, as shown in Figure 11, can be activated.

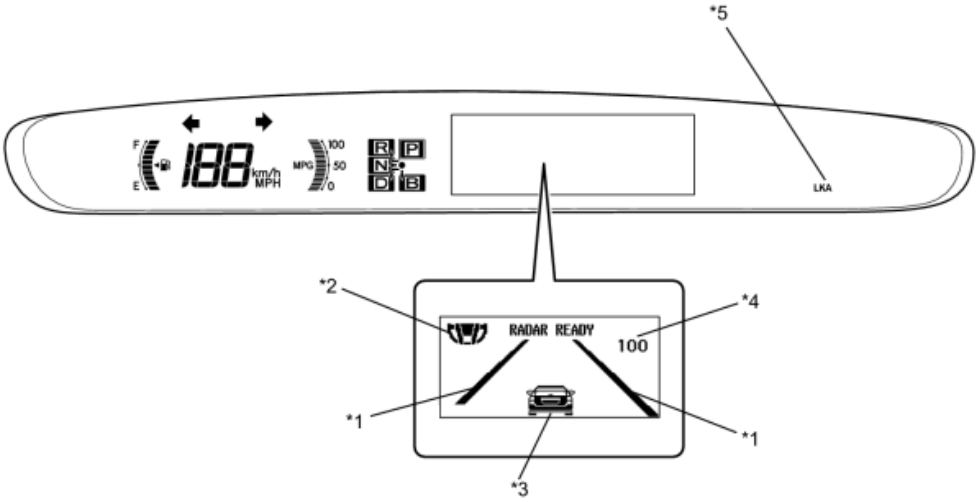


Figure 11 Lane Keeping Assist interface

The LKA icon is visible if LKA is switched on.
The steering wheel and lines can independently be enabled.
The steering wheel icon can be in any of the following states:

- Off
- Visible
- Flashing

The lines can be in any of the following states:

- Off
- Thin
- Solid
- Flashing

The car (*3) is visible as soon as ACC is active, or LKA is on. The cruise speed (*4) can be set to any integer value in the range [1-255].

4.10.5 Buzzer

MOVE can activate a buzzer in the vehicle, and can generate the following sounds:

- Beep twice: a quiet beep original Toyota
- ~~Toyota Warning Beep: deprecated do not use~~

- Warning Beep: loud beep generated by MOVE buzzer. This sound has 200ms period, 50% duty cycle.

4.10.6 Steering wheel buttons and lever

The button on the steering wheel (Time Headway) (Figure 4), and the ACC lever (Figure 5) can be read by MOVE. The status of these buttons (0 if released, 1 if pressed) are available through message 0x130 Vehicle HMI inputs.

5 Fault diagnosis

If an error is detected the red led will be lit, and the orange led informs the driver on the specific error cause.

If the orange LED is continuously on, multiple errors are detected.

If the orange led blinks (# times):

1. Emergency button
2. Battery error
3. Driving Support ECU time-out
4. PMC ECU time-out
5. HCTRL error
6. LCTRL error
7. Radar time-out
8. Application platform time-out
9. Not used
10. Lateral MOVE time-out
11. Lateral MOVE internal error

Error 1 can be resolved by releasing the emergency button.
Error 2-7 can be resolved by switching off the car and restarting.
Error 8 means that the connection with the external application platform has been lost. This often means that the communication is not at the correct rate, which should be 25Hz. If the error is persistent, check the cabling.
Error 10 means that the connection between the MOVE system and the lateral system has been lost. Error 11 notifies the driver that the lateral MOVE system has an internal error, this could be due to a time-out. If the error persists after resetting or restarting the vehicle, the cabling must be checked.

An error message can be reset by moving the ACC lever upwards (+ res). If the error has been resolved, MOVE will switch into standby mode and can be re-activated.

6 Quick start using dSpace

The Simulink model MOVE_Interface.mdl contains the CAN I/O required to interact with MOVE. By default CAN4 is used. The CAN format is specified in the dbc file which is stored in the same folder.

The ControlDesk experiment MOVE_Interface.cdx can be used to interact with MOVE. The different layouts are categorized according to the functionality provided (e.g. longitudinal control, lateral control, HMI).