UNDERSTANDING THE BYWIRE XGV VEHICLE MODE

The ByWire XGV™ ("XGV") has many different levels of vehicle mode, and acquiring an understanding of how these modes are calculated, controlled, and what they affect is critical for safe and efficient use of the XGV.

This application note explains the vehicle modes in a step-by-step process. After reading this application note, you should have a better understanding of the XGV.

WARNING: This application note alone does not contain sufficient information to operate the ByWire XGV. Read the entire XGV User Manual before operating.

Getting Started

In this section, we'll explain a couple important topics before beginning to define the different vehicle modes.

System Activation

If the XGV system is not active, the XGV will respond exactly as a stock Ford Hybrid Escape. For information on how to activate the system, see the XGV User Manual.

Basic Control Schemas

When the XGV system is active, the XGV can be operated in three distinct modes:

1. Manual control: In this mode, all the systems remain under complete manual control, allowing a user to drive the vehicle manually and collect data.
2. Open-Loop drive-by-wire control allows user software to command throttle (percent), brake (percent), steering, transmission gear (R,N,D,L), engine on/off, and a variety of auxiliary controls.
3. Closed-Loop drive-by-wire control allows user software to command a desired speed (m/s) with maximum acceleration to achieve the speed, and desired curvature (1/m) with desired rate of change of curvature to achieve the curvature. In this mode, the XGV's internal speed controller and curvature controller generates the throttle, braking, transmission and steering commands to track the user-set speed and curvature.

How are the control schemas achieved?

The ByWire XGV is JAUS-interoperable. JAUS, the Joint Architecture for Unmanned Systems, is a service-oriented, logical interoperability standard for unmanned systems. JAUS defines messages, then assembles collections of messages and protocol together to build "services" that provide a particular capability. A "service" is simply a collection of messages and the associated protocol for

using those messages. Examples of services are a Local Pose Sensor, a Primitive Manipulator, or a Waypoint Driver.

JAUS also defines "components", the smallest addressable software entities within JAUS; when a JAUS system is assembled, each component is given a 32-bit ID, referred to as its "JAUS ID", or "JAUS address". Components are the entities that exchanges JAUS messages with each other, and can be thought of as "containers for services". In JAUS version 3.x (the XGV is JAUS version 3.3), a component usually provides only the core message service and one additional service.

There are six (6) JAUS components on the XGV Controller. In the scope of this application note, we will refer to only two of them. The Primitive Driver is responsible for accepting the messages related to open-loop control, while the Motion Profile Driver is responsible for accepting the messages related to closed loop control. To operate the vehicle in drive-by-wire mode, user software sends messages to either the Primitive Driver (if open-loop control is desired), or to the Motion Profile Driver (if closed-loop control is desired). Additional components support messages to command the headlights and turn signals, or to obtain sensor information such as the vehicle's current speed.

Enough about JAUS…. How are the control schemas achieved?

To operate the XGV in open-loop mode, user software activates the Primitive Driver (PD) JAUS component within the XGV. This amounts to sending a message to the PD to "request control" of the PD. Once the user software has obtained control of the PD (activated it), the PD will accept messages to command throttle, brakes, steering, transmission gear, etc. The JAUS message for throttle, braking, and steering is called "Set Wrench Effort".

To operate the XGV in closed-loop mode, user software activates the Motion Profile Driver (MPD) JAUS component within the XGV. This amounts to sending a message to the MPD to "request control" of the MPD. Once the user software has obtained control of the MPD (activated it), the MPD will accept messages to command speed and curvature. The TORC experimental JAUS message used to command curvature and speed is called "Set Motion Profile".

Safety Devices

To allow for safe drive-by-wire operation, the XGV provides a number of safety overrides. First, a wireless emergency stop system (the TORC SafeStop™) can command a "pause" or "stop" to the vehicle; "pause" brings the vehicle to a stop using a constant (user set) acceleration, and "stop" applies 100% brake and returns all other systems to manual control. The SafeStop facilitates unmanned operation.

Second, a manual override can be engaged at any time, to instantly return all systems to manual control. Engaging the manual override causes the vehicle to respond as a stock Ford Hybrid Escape.

In addition to the SafeStop and manual override, a number of additional safety devices and internal health monitoring is in place.

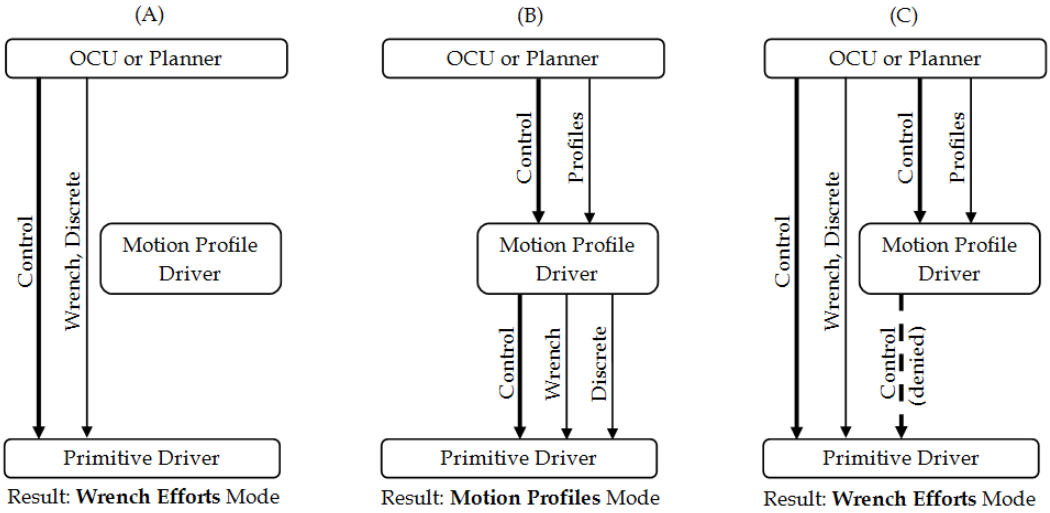
The Three Vehicle Modes

There are three (3) different aspects of the vehicle mode. The **control mode** refers to the type of messages the XGV should execute: open-loop Set Wrench Effort commands, or closed-loop Set Motion Profile commands. The **ready mode** can be thought of as a software-controlled pause that user software can command. Finally, the **safety mode** refers to the current operational state of the vehicle (drive-by-wire, e-stop pause, manual override, etc) as determined by the SafeStop, the manual override, and other safety devices. A fourth, pseudo-mode – the **partial mode** – determines which axes (steering and/or speed), the computer will control in drive-by-wire, allowing a safety rider to, for example, steer manually while the computer operates the throttle and brakes.

We will now discuss each mode in detail.

Control Mode

The control mode (possible values: "wrench efforts", motion profiles", or "software pause") determines what type of command messages the XGV should execute – Set Motion Profile commands (speed and curvature), or Set Wrench Effort and Set Discrete Devices commands (throttle, brake, steer, transmission gear, engine on/off). It is based on the current controlling entities of the Primitive Driver and Motion Profile Driver components. User software sets the control mode by sending JAUS commands to request or release control of the Primitive Driver and/or Motion Profile Driver.



Three possible configurations are shown above. In all other configurations, the control mode defaults to "Software Pause" and the XGV will not execute incoming Set Motion Profile or incoming Set Wrench Effort commands. Note that when the Motion Profile Driver is activated (controlled), it tries to request control of the Primitive Driver, in order to send Wrench Effort commands to the Primitive Driver.

Ready Mode

The ready mode (possible values: "software pause" or "ready") is a software pause that can be commanded by user software. It is based on the component status of the Primitive Driver and Motion Profile Driver. Recall that each JAUS component maintains a component status, which can take on the values "initialize", "standby", "ready", "emergency", "shutdown", and "failure". User software sets the ready mode by sending JAUS commands to set the component status of the Primitive Driver and Motion Profile Driver.

The ready mode is dependent upon the control mode. If the control mode is "wrench efforts", the ready mode is "ready" only if the component status of the Primitive Driver is "ready". If the control mode is "motion profiles", the ready mode is "ready" only if the component statuses of the Primitive Driver and Motion Profile Driver are both "ready". In all other cases, the ready mode is "software pause".

Safety Mode

The safety mode determines the final operating state of the XGV. It is calculated from safety devices on the vehicle, such as the SafeStop, the hardwired E-Stop button(s), the emergency manual override button (factory option), and the manual override selector. Additionally, internal errors detected by the XGV will cause a software pause. The user sets the safety mode by (a) physically manipulating the safety devices such as the manual override and emergency stop, and (b) operating the XGV such that no internal errors are caused.

The possible values for the safety mode are, in increasing order of precedence:

1. Drive-By-Wire – In drive-by-wire mode, the vehicle is fully operable by the computer. This state is entered if errors are clear from all systems, there are no "pause" or "disable" commands from the SafeStop, the manual override is not engaged, and the control mode and ready mode are not "software pause".

   Whether the XGV executes open-loop Set Wrench Effort messages or closed loop Set Motion Profile messages depends on the control mode.

2. Software Pause – This mode is entered when the XGV controller determines that vehicle movement would be unsafe, for instance, when a door is open. In this mode, the brakes will apply to bring the vehicle to a stop. Once the vehicle is stopped the brakes will continue to apply 50% braking effort. The throttle will not respond; it will apply 0% effort. The steering will continue to execute JAUS commands, ensuring that the vehicle will remain on its desired path until it has stopped. All commands to the vehicle that do not result in movement will continue to be allowed. The engine on/off, horn, lights, signals, and hazards will continue to respond to JAUS commands.

3. E-Stop Pause – The E-stop pause state is commanded from the toggle switch on the SafeStop transmitter. In all other respects, this state is identical to the Software Pause state.

4. Manual Override – The XGV system is capable of being manually overridden at any time. When the manual override is engaged, the vehicle will not respond to computer input, and all systems will be under manual control. However, whenever the XGV system is active, even if the manual override is engaged, the emergency stop system can still transition the vehicle to E-Stop Disable.

5. Emergency Manual Override – This mode is functionally equivalent to Manual Override, except that it is accomplished via hardware, with no software in the loop.

6. E-Stop Disable – E-Stop Disable can be commanded from either the "stop" button on the SafeStop transmitter or from the hard-mounted emergency stop button(s). In this mode, the XGV will apply 100% braking effort to stop the vehicle. It will also shut off the engine (if configured to do so) and return throttle, shifting, and steering commands back to manual control. This mode takes precedence over all other modes.

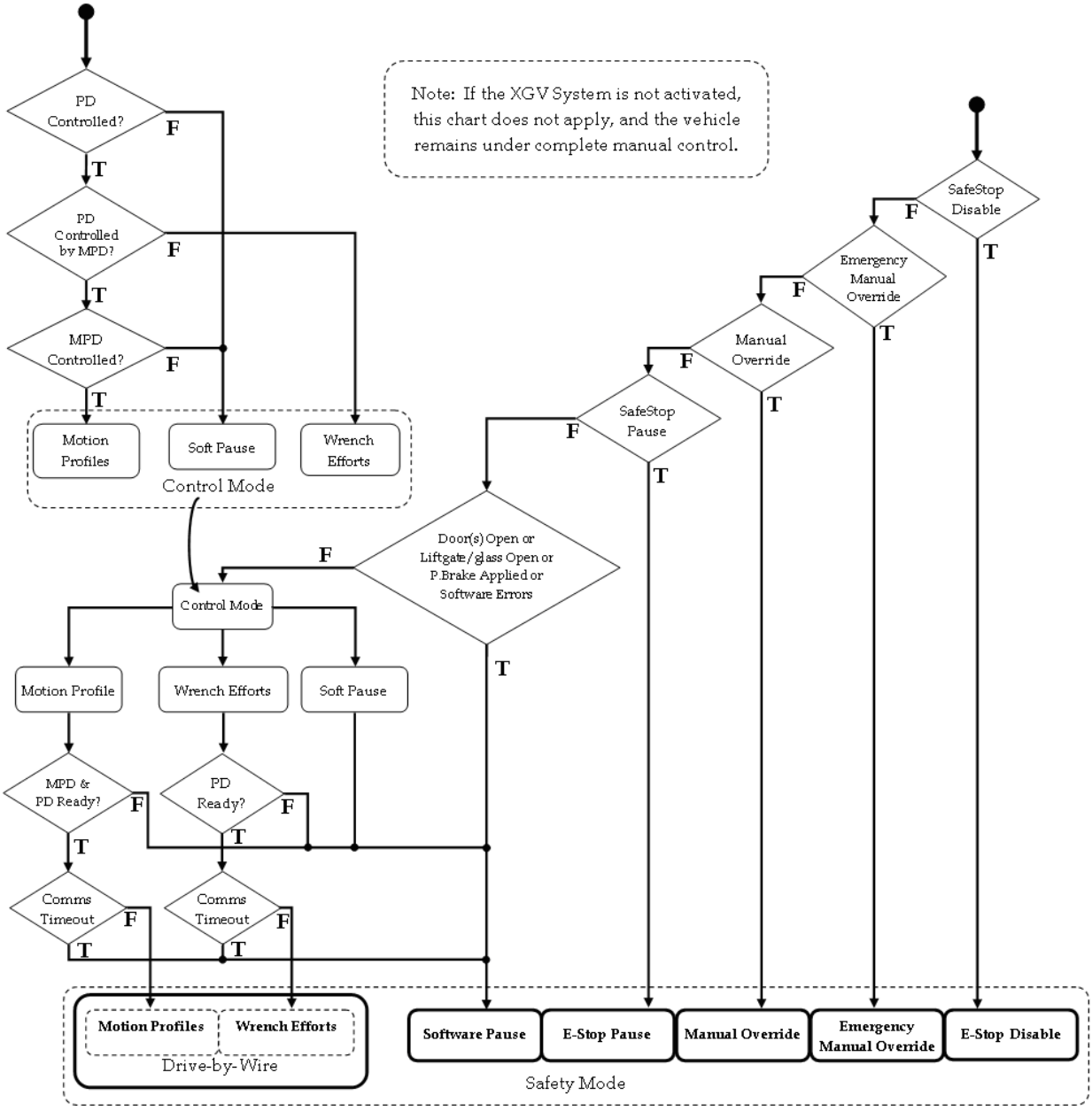
7. Inactive – Finally, if the XGV system is not active, the XGV controller is not booted, none of the three modes discussed above are calculated, and the vehicle remains under complete manual control.

Advanced Partial Mode

The partial mode (possible values: "full drive-by-wire", "manual steering", and "manual speed") determines which axes (steering and/or throttle/brake) the computer will take control of when the safety mode is "drive-by-wire", "software pause", or "e-stop pause". For other values of the safety mode, the partial mode is ignored. A user sets the partial mode via the "advanced modes" submenu of the user interface LCD.

How does the XGV Calculate the Vehicle Modes?

The logic used to calculate the control mode, ready mode, and safety mode is shown below. Not shown in this figure is the partial mode. The partial mode simply determines which axes (steering and/or throttle/brake) the computer will take control of when the safety mode is "drive-by-wire", "software pause", or "e-stop pause". For other values of the safety mode, the partial mode is ignored.



How Can User Software Obtain the Vehicle Mode?

User software can obtain the vehicle mode either via several standard JAUS messages, or via a single experimental message. To obtain the mode using only standard JAUS messages, user software should establish service connections for the Report Component Status and Report Component Control messages from the Primitive Driver and Motion Profile Driver, and implement the above flowchart.

Alternately, the experimental Report Vehicle Mode message (described below) contains the control mode, the ready mode, the safety mode, the partial mode overrides, and the status of the individual safety devices used to calculate the safety mode. User software can establish a service connection for this message. The Node Manager component on the XGV supports this message.

Report Vehicle Mode (code 0xE456, experimental)

This message reports the current vehicle mode. In the following discussion, the Primitive Driver and Motion Profile Driver JAUS components are referred to by the abbreviations PD and MPD, respectively.

This message is not supported in version 1.0 and 1.1 of the XGV controller firmware.

Field 2 (Control Mode) indicates whether the XGV will execute Set Motion Profile commands, or Set Wrench Effort commands. It is based on the current controlling entities of the PD and MPD components. User software sets the control mode by sending JAUS commands to request or release control of the PD and/or MPD.

Field 3 (Ready Mode) is a software pause that can be commanded by user software. It is based on the component status of the PD and MPD components. Recall that each JAUS component maintains a component status, which can take on the values “initialize”, “standby”, “ready”, “emergency”, “shutdown”, and “failure”. User software sets the ready mode by sending JAUS commands to set the component status of the PD and MPD.

Field 4 (Safety Mode) indicates the final operating state of the XGV. It is calculated from the safety devices on the vehicle, such as the SafeStop, the hardwired E-Stop button(s), emergency manual override button (factory option), and the manual override selector. Additionally, internal errors detected by the XGV will cause a software pause. The user sets the safety mode by (a) physically manipulating the safety devices such as the manual override and emergency stop, and (b) operating the XGV such that no internal errors are caused.

Field 5 (Partial Mode Overrides) indicates which axes (steering, and/or throttle/brake) the computer will control when the safety mode is “drive-by-wire”, “software pause”, or “e-stop pause”. The user sets these via the “advanced modes” submenu of the user interface LCD.

Finally, field 6 (Safety Devices) reports the status of the devices that are used to calculate the Safety Mode.

Field	Name	Type	Units	Interpretation
1	Version	U8 (Byte)	n/a	TORC experimental message version. Currently set to 0 (zero).
2	Control Mode	U8 (Byte)	n/a	Enumeration: 0: unknown/reserved 1: software pause 2: wrench efforts 3: motion profiles 4-255: reserved
3	Ready Mode	U8 (Byte)	n/a	Enumeration: 0: unknown/reserved 1: software pause 2: ready

				3-255: reserved
4	Safety Mode	U8 (Byte)	n/a	Enumeration: 0: unknown/reserved 1: drive-by-wire 2-7: software pause 8: e-stop pause 9: manual override 10: emergency manual override 11: e-stop stop (e-stop disable) 12-255: reserved
5	Partial Mode Overrides	U8 (Byte)	n/a	bit 0: partial mode override: steering - 0: computer control - 1: manual control bit 1: partial mode override: speed - 0: computer control - 1: manual control bits 2-7: reserved
6	Safety Devices	U16 (Unsigned Short Integer)	n/a	bit 0: manual override - 0: disengaged - 1: engaged bit 1: SafeStop pause relay - 0: run - 1: pause bit 2: SafeStop stop relay - 0: run - 1: stop bits 3-4: SafeStop link status - 0: no link - 1: bypass - 2: link good - 3: reserved bit 5: external estop button - 0: run - 1: stop bit 6: door/liftgate pause - 0: run - 1: pause bit 7: errors detected - 0: no errors - 1: paused due to errors bit 8: emergency manual override - 0: disengaged - 1: engaged bit 9: steering requires initialization - 0: initialized - 1: uninitialized bit 10: steering init awaiting user input - 0: initialized - 1: user must manually init steering or press OK bits 11-15: reserved