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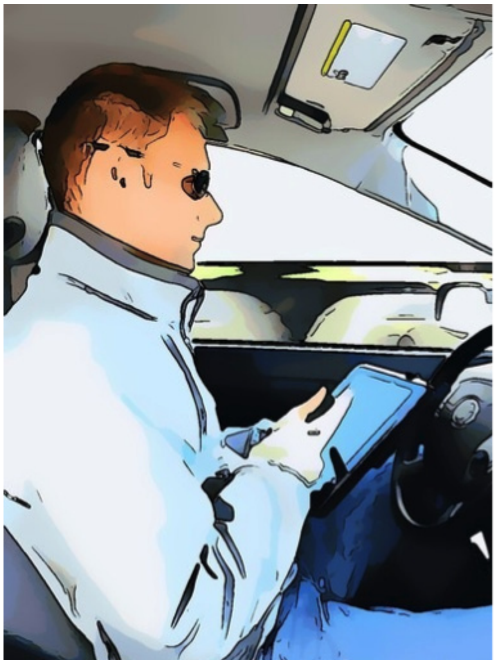
Human Factors Evaluation of Level 2 And Level 3 Automated Driving Concepts

Concepts of Operation



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16. Abstract

The Concepts of Operation document evaluates the functional framework of operations for Level 2 and Level 3 automated vehicle systems. This is done by defining the varying levels of automation, the operator vehicle interactions, and system components; and further, by assessing the automation relevant parameters from a scenario-based analysis stand-point. Specific to the "Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts" research effort, scenarios and literature are used to identify the range of near- to mid-term production-intent systems such that follow-on research topics with highest impact potential can be identified through commonalities in operational concepts.

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Chapter 1 Introduction

This document defines the automated passenger vehicle functional domain of operations for the purposes of this project. The document addresses system functionality in terms of the vehicle's interaction with the driver, environment, and surrounding traffic. System operation, processes, and interactions are described on a basic level. The document is based on team expertise and available literature.

The document is limited to Level 2 (L2) and Level 3 (L3) automated vehicle operations for passenger cars. The focus includes transitions between levels.

The typical Concept of Operations (ConOps) document focuses on a specific system implementation to enable a developer organization to describe the capabilities and limitations in detail and to assess system impacts, costs, and long-term requirements (maintenance, etc.). From this the developer would define functional requirements based on the ConOps, followed by technical requirements and system design.

This document is not focused on system design and development; it instead proceeds from a different basis. It supports a process to understand the broad functional domain of operations for automated vehicles and, from that universe, select several representative system configurations for L2 and L3 automation. Therefore, a full set of parameters is described that refers to the operating environment and the system function. These parameters are then assessed in terms of relevance to potential future systems as envisioned by the broader industry. From this, several concepts are formed, and scenarios are developed to create a likely depiction of first-generation L2 and L3 vehicle automation. This document, therefore, establishes a context in which to pose an array of questions related to automation from which research questions will be chosen to guide the experimental portion of the project.

This document is designed to provide a definition of the system considered to ensure that all stakeholders have a baseline from which to consider all proposed research efforts. Additionally, this document generally follows the format of an IEEE 1362-1998 standard ConOps document. However, modifications have been made based on the research nature of this system. Among the most important aspects of this document are the operational definitions. These definitions offer a common understanding necessary for continued discussion, research, and reporting. Primary among them, for this effort, are the definitions of the National Highway Traffic Safety Administration (NHTSA) taxonomy for automation:

Level 0 (L0; No Automation): The driver is in complete and sole control of the primary vehicle controls (brake, steering, throttle, and motive power) at all times, and is solely responsible for monitoring the roadway and for safe operation of all vehicle controls. Vehicles that have certain driver support/convenience systems but do not have control authority over steering, braking, or throttle would still be considered "L0" vehicles. Examples include systems that provide only warnings (e.g., forward collision warning (FCW), lane departure warning (LDWS), blind spot monitoring) as well as systems providing automated secondary controls such as wipers, headlights, turn signals, hazard lights, etc. Although a vehicle with vehicle-to-vehicle (V2V) warning technology alone would be at this level, that technology could significantly augment, and could be necessary to fully implement, many of the technologies described below, and is capable of providing warnings in several scenarios where sensors and cameras cannot (e.g., vehicles approaching each other at intersections).

Level 1 (L1; Function-specific Automation): Automation at this level involves one or more specific control functions; if multiple functions are automated, they operate independently from each other. The driver has overall control, and is solely responsible for safe operation, but can choose to cede limited authority over a primary control (as in adaptive cruise control), the vehicle can automatically assume limited authority over a primary control (as in electronic stability control), or the automated system can provide added control to aid the driver in certain normal driving or crash-imminent situations (e.g., dynamic brake support in emergencies). The vehicle may have multiple capabilities combining individual driver support and crash avoidance technologies, but does not replace driver vigilance and does not assume driving responsibility from the driver. The vehicle's automated system may assist or augment the driver in operating one of the primary controls – either steering or braking/throttle controls (but not both). As a result, there is no combination of vehicle control systems working in unison that enables the driver to be disengaged from physically operating the vehicle by having his or her hands off the steering wheel AND feet off the pedals at the same time. Examples of function-specific automation systems include: cruise control, automatic braking, and lane keeping.

Level 2 (L2; Combined Function Automation): This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. Vehicles at this level of automation can utilize shared authority when the driver cedes active primary control in certain limited driving situations. The driver is still responsible for monitoring the roadway and safe operation and is expected to be available for control at all times and on short notice. The system can relinquish control with no advance warning and the driver must be ready to control the vehicle safely. An example of combined functions enabling an L2 system is adaptive cruise control in combination with lane centering. The major distinction between L1 and L2 is that, at L2 in the specific operating conditions for which the system is designed, an automated operating mode is enabled such that the driver is disengaged from physically operating the vehicle by having his or her hands off the steering wheel AND foot off pedal at the same time.

Level 3 (L3; Limited Self-Driving Automation): Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The vehicle is designed to ensure safe operation during the automated driving mode. An example would be an automated or self-driving car that can determine when the system is no longer able to support automation, such as from an oncoming construction area, and then signals to the driver to reengage in the driving task, providing the driver with an appropriate amount of transition time to safely regain manual control. The major distinction between L2 and L3 is that at L3, the vehicle is designed so that the driver is not expected to constantly monitor the roadway while driving.

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Level 4 (L4; Full Self-Driving Automation): The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver[*] will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles. By design, safe operation rests solely on the automated vehicle system.

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[*] Several State automated vehicle laws consider the person who activates the automated vehicle system to be the “driver” of the vehicle even if that person is not physically present in the vehicle. NHTSA, however, is not aware of any prototype automated vehicle systems that are capable of operating on public roads without the presence of a driver in the driver’s seat who is ready to control the vehicle.

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Chapter 3 Definition of the Current System

The baseline definition of the current system provides a reference point from which a discussion of change can occur, including the specifics of that change. This section provides that baseline definition for all stakeholders.

Operator-vehicle Interaction System Operational Definition

A ConOps document traditionally presents a framework documenting a system. The ConOps also provides a method to systematically define each important attribute of the system to an audience that might operate the system. For the present study, this ConOps document follows the framework of a traditional ConOps document but is intended to capture operations of a research/experimental system rather than a production system. For the purposes of scoping future research—and based on existing systems—this ConOps document provides an overview of the conceptual L2 and L3 systems with sufficient detail to avoid confusion while allowing enough variability that future technological advances may still apply.

This ConOps document covers automated vehicles that fall within NHTSA L2 and L3 definitions and is intended to provide an assessment of the details specific to these two levels of automated vehicles. For context, some L4 systems are briefly referenced as well. To ensure a common understanding of the automated vehicles specific to this research effort, there is a need to provide an operational definition of current motor vehicles and their automation technology. As subsequent research and development of L2 and L3 automation technology has the potential to dramatically change motor vehicles in combination with the legacy vehicles that will remain in-service, the definition should focus on the broad concepts of the operator-vehicle system. What is proposed is a general model and definitions that should apply to all motor vehicle operations in regards to the operator-vehicle interaction (OVI). This model and the definitions only examine the interaction level; they are not concerned with the operation of the dependent components. Instead, this model provides a succinct overview of the OVI system. It is important to note that there is a hierarchical taxonomy for this ConOps document in regards to system nomenclature. Within the system there can be multiple subsystems; each subsystem comprises components that are grouped together for categorical reasons. Within subsystems, there are components that individually exist to serve a specific purpose. Each process or function defined and discussed in this document represents a component which, when grouped by subsystem and collectively considered, represents the greater system. This structured hierarchy is necessary to ensure clear understanding of the relationships between the various parts (subsystems, components, etc.) of the system.

Operator-vehicle Interaction Subsystems

The OVI system consists of three subsystems: the operator, the vehicle, and the environment in which the OVI exists. Within these subsystems, the operator comprises three major components, and the vehicle comprises three major components. Beyond recognizing the environment as responsible for many possible inputs to the system, further breakdown of the environment subsystem is considered outside the bounds of the OVI system.

Within the operator subsystem there are Operator Input, Cognition Process, and Operator Output components. All external stimuli affecting the operator begin in the Operator Input component. Information is then passed to the Cognition Process, where the information processed by the operator and any needed responses are formulated. When a decision to act occurs, the directive for action is passed to the Operator Output component, and the action is implemented.

Within the vehicle subsystem, the components include Vehicle-Control Manipulation (VCM), Computational or Operational Process (COP), and Feedback or Display. The VCM component handles all inputs to the vehicle subsystem. Information is then passed to the COP component, where the input is processed for type, capability, and action. The actions are then passed to two locations: the Feedback or Display component, where acknowledgement of the subsystem input and subsequent action are communicated to the operator, and to other systems performing work. For the purposes of the operational definition of the OVI system, these systems (grouped here as non-OVI work systems) are considered external to the OVI. It is sufficient to understand that these actions are performed by the vehicle and can generate environmental feedback that re-enters the bounds of the OVI system through the environment subsystem. Figure 3-1 provides a model of this basic OVI system.

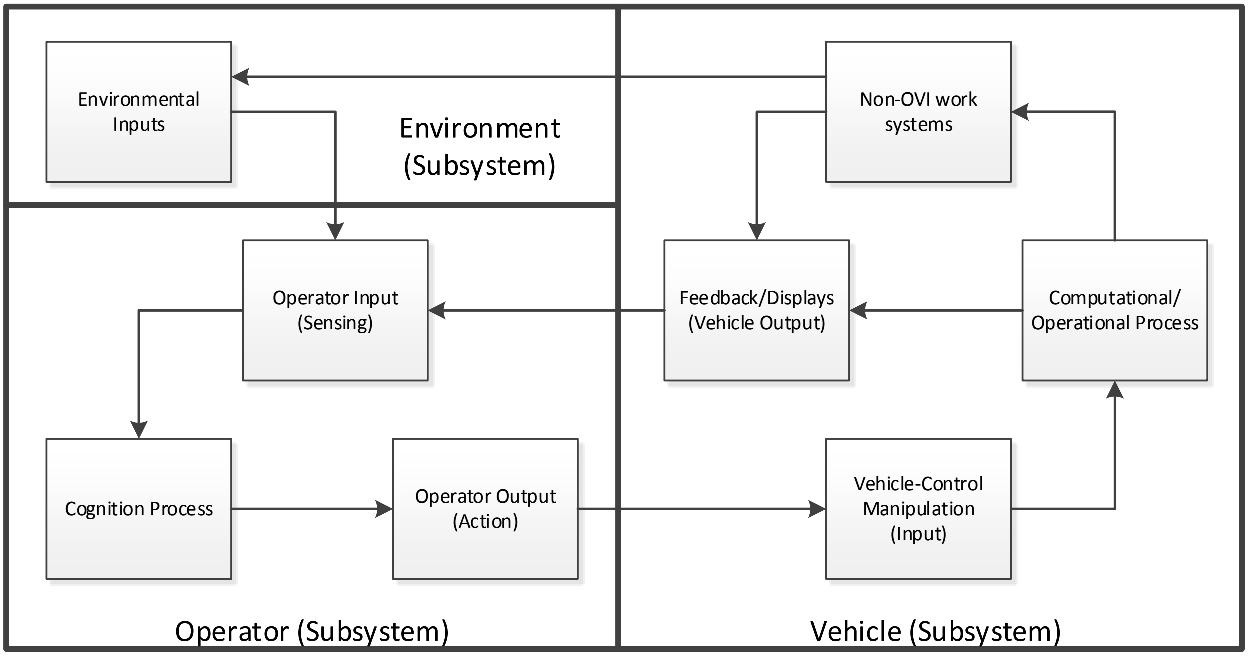

Figure 3-1. Operator-Vehicle Interaction System (Source: Author)

An example of this system is driving along a straight highway in clear daylight conditions. The operator receives environmental inputs in the form of visual information associated with the road conditions, lanes, traffic signs, other vehicles present, visual flow and direction of travel, and other factors. These inputs are continuously passed to the Cognition Process component for constant evaluation of the condition against the desired state of the vehicle. If the road begins to curve, this change is an environmental input to the operator subsystem. The Operator Input senses this curvature, the Cognition Process determines the need to adjust the vehicle heading, and the information is acted upon by the Operator Output. The Operator Output in this case becomes the hands on the steering wheel, changing the steering angle appropriately (determined through many iterations of this process during a short amount of time). The VCM – in this case, the steering wheel – provides a command input to the vehicle, thus prompting the COP[†] to appropriately act on the necessary non-OVI work system (e.g., steering wheel to pinion to rack and through tie-rods to steering knuckle). Some feedback is provided to the operator in one or more ways. In this example, the steering wheel angle change is a visual form of feedback in combination with the proprioceptive feedback of arm rotation and centrifugal force on the operator. Environmental feedback is provided through visual cues of vehicle heading change. These general processes continue through similar relationships during the driving experience.

Modes of Operation for the Current System

Current passenger vehicles vary in design, features, and age. Many of the features included in both the legacy vehicles and the latest models qualify for the L1 automated vehicle definition. Cruise control, for example, is a common feature allowing the human operator to cede control of the vehicle speed but requires the continuous operation of all other driving controls. Recent technologies such as lane keeping also qualify for the L1 definition. In these cases, as well as any other examples of L1 features, the operator is ultimately responsible for control of the vehicle, including maintaining situational awareness. The OVI system can function with these features either disengaged or engaged. The mode of operation while all features are disengaged is the normal operating mode of the system. However, within appropriate constraints, the system can be operated at the L1 mode by engaging one of these features.

Mode selection is primarily the responsibility of the operator within the system. The operator can choose to move the system from L0 to L1 by engaging an L1 feature, or the operator could move from L1 to L0 by disengaging the feature. Alternatively, the vehicle could detect a subsystem failure in the L1 feature and force the system to operate at L0. The current system is designed to function in either mode and requires the operator to make the appropriate decision as to which mode is best during system operation given environment, vehicle, and operator conditions.

[†] Note: The Computational/Operational Process can be mechanical components, electronic components, or a combination of both.

Chapter 4 Level 2 and Level 3 Systems

As stated, the purpose of this ConOps document includes defining the levels of automated vehicles and framing the research problem objectives for L2 and L3 systems to inform subsequent research and development efforts. The operational definition herein provides a common language with which to structure discussion and, ultimately, possible future research.

In comparison to the current OVI system (L0 and L1), L2 and L3 automated components place a greater emphasis on the management of the system as opposed to the operation. That is, along the continuum of vehicle control and decision-making, L2 and L3 OVI systems place greater control and decision-making on the vehicle subsystems and automated components. The operator retains ultimate authority of the vehicle but delegates well-defined tasks to the automated components. The operator's interactions with the vehicle subsystem tend towards the management of these components through processing inputs from the environment and vehicle subsystems.

Level 2 and Level 3 Automated Systems Operational Definition

The overall set of automated vehicles includes a variety of features that can range from safety features requiring no driver intervention to vehicles that do not require an operator. As mentioned in the Introduction, NHTSA has developed a five-level taxonomy of automated vehicles, with specific performance-based definitions for each of the five levels. This ConOps is focused on L2 and L3 automated vehicles. It should be noted that these L2 and L3 systems are defined in a manner general enough to allow for future technological advancement while maintaining sufficient detail to provide clear boundaries for discussion, research, and development efforts on the same systems.

With respect to the definition of the OVI system, the one key addition for the automated vehicle, regardless of the level, is the Automation Component. The Automation Component is a general term that describes those technologies that provide some sort of automation to the vehicle operation system. Although the individual subsystems that compose automated vehicle controllers are highly complex, they are not the focus of this model and can be represented in terms of a single addition to the model. The operator can choose to engage the Automation Component or operate the vehicle in a traditional (i.e., manual) manner. The Automation Component can act as a supervised agent of the operator in that environmental inputs and vehicle outputs can be acted upon by the Automation Component to continue operating the vehicle in a manner consistent with the operator's intent.

Thus, in an L2 system, the Automation Component can either supplement the operator or relieve the operator of one or more subtasks of the overall driving task. Examples of L2 vehicles are those that combine lane-keeping and adaptive cruise control (ACC) operations during which primary lateral and longitudinal control is ceded by the operator yet direct supervision is still required from the operator. The operator continues to receive system feedback and is responsible for much of the overall operation of the vehicle. In L3 vehicles, the Automation Component acts in a manner that removes the direct supervisory requirement and changes the operator's role to being available for control with some degree of notice. Figure 4-1 provides a representation of the OVI system with Automation Components for L2 and L3 automated vehicles.

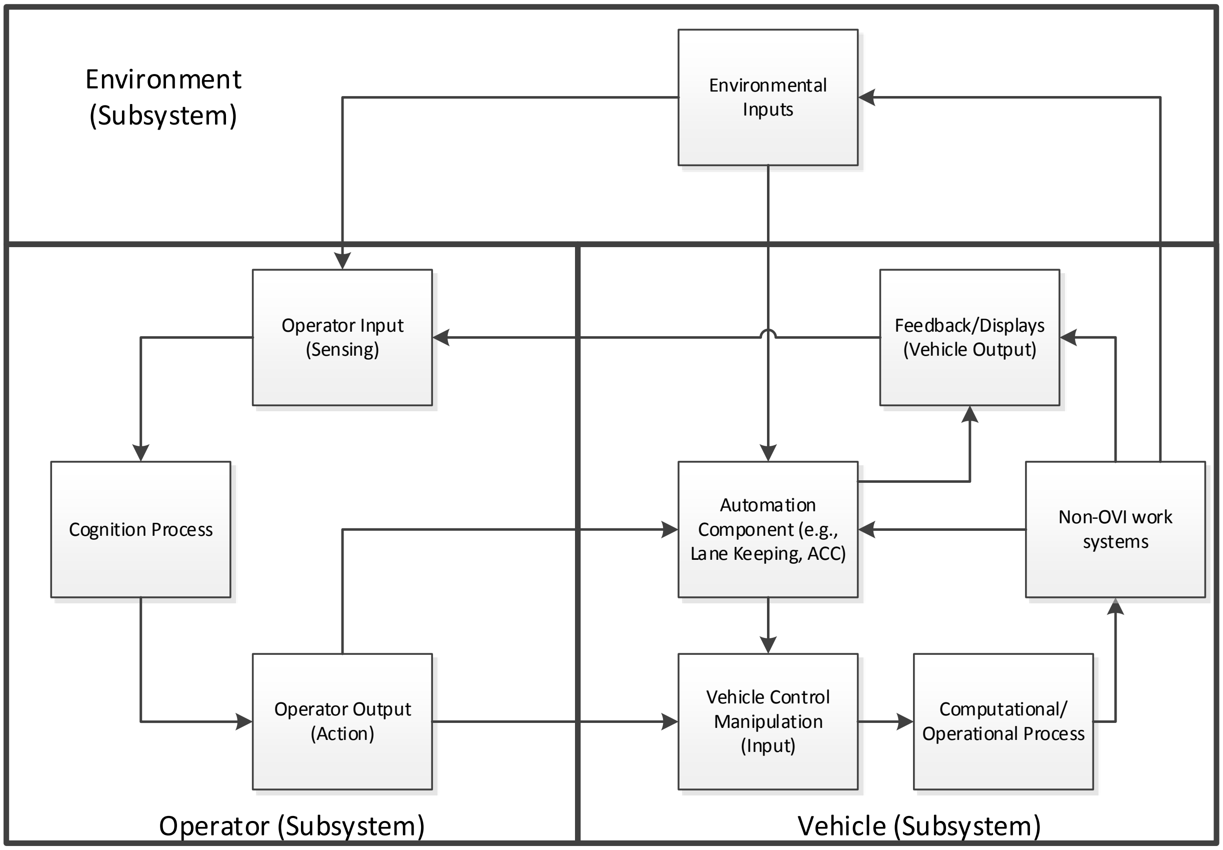

Figure 4-1. Automated Operator-Vehicle Interaction System (Source: Author)

One can consider lane keeping as an example Automation Component. When the driver engages the lane-keeping feature of the system, the system then acts on behalf of the driver to maintain the vehicle position within the travel lane. In this example, certain information about the vehicle is continuously provided to the operator, including confirmation of lane-keeping activation. However, assuming all else remains relatively static, the Automation Component acts to make corrections via the Vehicle-Control Manipulation component based on environmental inputs (e.g., machine vision verification of relative position of vehicle to lane lines). Each correction is fed through the COP and, as a result, is provided back to the Automation Component. This cycle continues until the operator resumes manual control or the Automation Component determines that it is outside the bounds of the system design. Throughout this cycle, pertinent information is provided to the operator through the Automation Component to the Feedback or Display component, thus allowing the operator to maintain an active role in the OVI system.

It is important to note that environmental inputs act on both the Automation Component and the Operator Input components. However, the operator still holds ultimate authority over, and control of, the system.

The operator has at all times the option to act through the VCM component. This action by the operator can bypass the Automation Component or could have a dual action (e.g., depressing the brake may turn off adaptive cruise control while simultaneously acting to slow the vehicle).

Lastly, the system as defined above is for a conceptual idealized process. In all systems there is the potential for component failure. The frequency and effects of component failure are variable and will not be defined for this proposed OVI system. However, it is important to understand that this proposed OVI system is no different and has the potential for failures, specifically in the feedback loops. For instance, should the Automation Component fail to act in a manner consistent with the perception of the operator, there may be no notification (for L2 systems) or awareness (for L2 and L3 systems) of this failure, which could result in an accident. While this idealized OVI system definition provides a baseline for discussion, it is expected that subsequent research will focus on these potential issues to characterize, understand, and propose solutions for the production of L2 and L3 systems.

Exposition of System Prototypes under Active Development

The purpose of this section is to gain a concrete sense of what systems are more likely to be introduced to the public. The industry has been very active in recent years in demonstrating prototypes of various automated vehicle concepts and in bringing early systems to the market. This section describes system approaches that have already moved into production or have the potential to do so during the coming years.

This section is not intended to be exhaustive; rather, it is intended to be indicative. It includes only automated vehicle research work in which the vehicle industry was involved.

This information will feed into later sections so that the selected concepts are relevant to likely future market offerings.

Traffic Jam Assist

For model year 2014 (MY14), both Mercedes and BMW have announced the availability of Traffic Jam Assist (TJA). TJA functions on limited-access highways at slow speeds. Building on Full Speed Range Adaptive Cruise Control, the system provides full control of driving in congested conditions. Press announcements for the availability of TJA by “mid-decade” have also been made by Audi, Ford, and Volvo.

The Mercedes S-Class system is representative of TJA.[7] The sensor suite is enhanced with stereo vision, which enables normal lane marker and car-following detection when in a traffic jam. Speed is adapted to the flow of traffic ahead, slowing as necessary. The system can brake to a full stop. When traffic moves, the driver can resume with a tap, or, if the stop is less than 1 s, automatically.[8] The driver is expected to be engaged, with his or her hands on the steering wheel. If the driver is not touching the steering wheel, the system issues a warning and will disable after a few seconds.

Within the European HAVEit project, the AQuA demonstrator was developed on a heavy-truck platform.[8] The AQuA function supported a truck driver in congested traffic by autonomously handling the speed and steering control. The AQuA aimed to relieve the driver of the monotonous tasks associated with driving a truck in congested traffic situations; that is, driver underload situations. The level of automated control was continuously adapted across L0 to L2 systems based on the states of the driver, the vehicle, and the environment. At the highest level of automation, the system autonomously handled steering, acceleration, and braking to keep the vehicle in the correct lateral position in the lane and at a safe distance from the preceding vehicle or at a desired speed. The system operated at speeds between 0 and 130 km/h.

Highway-Speed Automation

The General Motors (GM) “Super Cruise” system[10] is described in press releases as providing full-speed-range ACC and lane keeping, using cameras and radar to automatically steer, accelerate, and brake in highway driving. The GM system allows the driver to take his or her hands off the steering wheel until the driver wishes to change lanes, road conditions deteriorate beyond system functionality, or other system issues occur.

Infiniti has announced that MY14 vehicles will be equipped with “steer by wire,” which allows independent control of the tire angle and steering inputs.[11] This capability insulates the vehicle from unnecessary road-generated disturbances such as ruts or cross winds. This system enables a new “straight-line stability system” that assists “on-center driving.” The system reduces discrepancies between the intended path and the actual path. In addition, the company asserts that fewer fine-grained steering adjustments made by drivers reduce their fatigue/workload.

In Europe, the Honda Accord is available with a Lane Keeping Assist System (LKAS) that provides hands-off lane keeping for a limited period of time (tens of seconds). The vehicle can also be equipped with ACC, making simultaneous LKAS/ACC possible.

Audi offers an LKAS with an “early intervention” setting, which in effect provides a lane-keeping function that can be operated simultaneously with ACC. It requires the driver’s hands be on the wheel and disables if they are not. This version of the system is only available in Europe.

BMW[12] has demonstrated an L2 vehicle that provides lateral and longitudinal control at highway speeds. When slower traffic ahead prevents the vehicle from maintaining its set speed, the vehicle monitors the adjacent lane and performs a lane change when safe. The vehicle also responds to merging traffic on the right by adjusting speed.

Within the European HAVEit project, the Joint System Demonstrator (JSD)[13] was developed that provided L0 through L2 system automation. The vehicle was equipped with warning-/intervention-based active safety, ACC, and LKAS functions. Steering wheel buttons allowed drivers to choose a specific automation level. Detection of the driver’s hands on the steering wheel was implemented.

Google has developed an automated vehicle that currently can operate up to 75 mph at L2 in highway use and L3 for safe testing purposes (e.g., research). The vehicle does not change lanes. It will slow down or stop for moving traffic in front of it. The vehicle will stay in its lane in automated driving mode until the user is ready to retake control through a combination of virtual mapping, laser, radar, and cameras.

An in-dash user interface displays system state information and is used to notify the driver when automated mode is available, as well as to prompt the driver to retake control when needed.

Automated Assistance in Roadwork and Congestion[14]

The Automated Assistance in Roadwork and Congestion (ARC) demonstrator was developed within the European HAVEit project. The main focus was driving through a work zone in the highly automated mode (L2). This scenario could be an overload situation at speed or an underload situation if traffic is congested.

The roadwork assistant application considered the possibility that lane lines may not be visible or accurate. Therefore, additional objects such as trucks, beacons, and guide walls were used for guidance. A control algorithm called “virtual wall” steered the vehicle back into the lane when it got too close to a conventional or unconventional lane border. Otherwise, an LKAS provided lane keeping, and ACC provided longitudinal control. The automation operated at speeds between 0 and 80 km/h.

Emergency Stopping Assistant[15]

BMW developed this system for situations during which a driver becomes completely impaired at the wheel (e.g., a heart attack or stroke). An L4 system, the Emergency Stop Assistant, detects the situation of an incapacitated driver, turns on the vehicle hazard signals, and safely maneuvers the vehicle through traffic to park on the roadside.

On-Highway Platooning

Within the European SARTRE[16] project, Volvo cars and trucks were equipped for close-headway platooning (L3). The project investigated the business model of a human driver being paid to drive the lead vehicle by the occupants in the fully automated following vehicles in the platoon. Prototypes were developed using current production car/truck technology plus Dedicated Short-Range Communication (DSRC) for V2V communications. The cars drove automatically behind the lead vehicle at 85 km/h, separated by 5 to 15 meters. Several hundred kilometers of testing were performed.

City Street Automated Driving

The 2007 Defense Advanced Research Projects Agency (DARPA) Urban Challenge attracted dozens of teams with vehicles which could operate among each other in a residential street setting. The top three finishers (Carnegie Mellon University/General Motors, Stanford, and Virginia Tech, respectively) successfully handled traffic circles, four-way stops, parking lots, and road obstacles on designated streets.[17]

The University of Braunschweig in Germany built upon its entry into the DARPA Urban Challenge with its Leonie vehicle (L3).[18] This research focuses on urban driving, and the university regularly conducts testing in live traffic in the city “Stadtring,” a busy four- or more-lane arterial with traffic lights, turn lanes, pedestrians, etc. The vehicle executes turn maneuvers, responds to traffic lights, and performs lane changes as needed to flow within traffic. Partial funding for this work comes from the vehicle industry.

The European CyberCars[19] project has developed urban vehicles for L4 operation within city centers in lanes or districts segregated from normal traffic. Long-term demonstrations have been held in several European cities.

Automated Valet Parking

Audi[20] has developed a prototype system that enables the driver to depart the vehicle at a parking garage entrance and to instruct the vehicle to “go park” via a smartphone interface. The vehicle then proceeds, empty, into the garage, travels until it detects an empty space, and parks. Upon being summoned by the owner via smartphone, the vehicle proceeds to the garage exit area where the driver re-enters the vehicle and resumes driving. Nissan[21] has demonstrated a similar system.

All-Road Autonomous Operation

The U.S. Army[22] is sponsoring development of the Autonomous Mobility Appliqué System, a program designed to retrofit existing military trucks with a range of systems, from active safety to full automation (L3). The intent is for the vehicles to operate on any road type and off-road. BAE Systems, which produces military trucks, is the vehicle industry participant.

Table 4-1. Summary of Automated Vehicle System Products/Prototypes under Development by Industry

Operating Environment	System Function	Level	Status	0–5 years	5–10 years	10–15 years
Highway	Traffic Jam Assist	2	Product announced for MY14	✔		
Highway	On-Center Driving w/ACC (limited steering authority)	2	Product	✔		
Highway	Combined lateral/longitudinal control	2	Prototype	✔		
Highway	On-Highway Platooning	3	Prototype		✔	
Highway	Workzone Assistant	2	Prototype		Note 1*	
Highway	Emergency Stopping Assistant	4	Prototype		✔	
City	Segregated Urban Automated Vehicles	4	Trial Deployment	✔		
City	Open Road Urban Automated Vehicles	3	Prototype			✔
All Roads	Automated Operation on All Road Types for Military Applications	3	Prototype		✔	
Parking	Automated Valet Parking	4	Prototype	✔		

*Note 1: Workzone Assistant is expected to be integrated into full highway functionality when such products emerge.

Chapter 5 Modes of Operation

Model of Transitions

Many systems are designed to operate across multiple modes. There are a number of reasons for including this capability, including maintenance, failure, and process agility. The OVI system as defined in this document is multimodal. For the specific system considered herein, the two key modes of interest are when the vehicle subsystem is operating at (or transitioning into/out of) L2 or L3 automated driving. While alternative modes of operation are outside the bounds of the system in consideration for subsequent research, the transition between these two modes is of interest. Additionally, the system can transition from one level to another. Such transitions may include increasing from L0 or L1, to L2 or L3, or transitioning between levels. A transition from one level to another could be initiated by either the operator subsystem or the vehicle subsystem based on inputs to either. Figure 5-1 provides a static look at the dynamic system state of a multi-level autonomous vehicle. The current state of the system is always represented as L_S. The transition to a higher level of autonomy (up-select) is represented as L_{S+n} with a maximum of L4. Transitioning to a lower level of autonomy is represented as L_{S-n} with a minimum state of L0. A transition can be made from any level of autonomy to any other level (e.g., L0 to L3 or L2 to L1) depending on the design and function of the system. System transition can be initiated through an action of the operator subsystem or vehicle subsystem for any number of reasons.

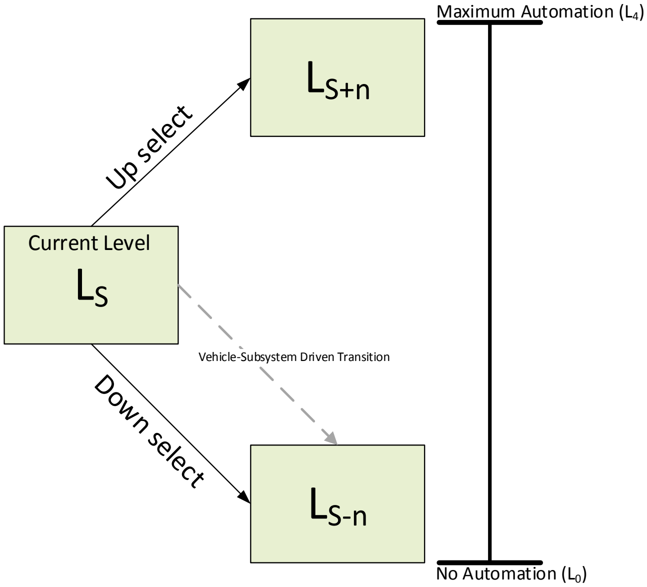

Figure 5-1. Transition of Automated Levels Model (Source: Author)

The transition between levels of automation can be complex. For instance, the operator starting a vehicle and manually shifting into gear to move the vehicle forward is an example of L0 automation. The driver has authority and responsibility for all movement and control of the system and components. If the driver chooses to engage ACC upon entering a highway lane, the overall system transitions to L1 automation. The driver (operator subsystem) has ceded limited control and authority of speed maintenance to a vehicle component (i.e., vehicle subsystem automation component). Transitioning through the model, assume the driver then engages a secondary automated subcomponent (e.g., lane centering) while still using ACC. Now the OVI system is operating at L2 automation. Conceivably, this could continue through full automation if the vehicle were so equipped. Although these up-transitions are rather straightforward, the down-transition process can be more complex from a human-automation interaction perspective.

For example, assume a system operating at L2 exceeds an operating parameter within either the lateral control or speed regulation component. Assuming both engaged automated components are capable of recognizing that the environment is no longer sufficient for supporting safe operation at L2, the vehicle subsystem will cede control to the driver (discussion about situations where the driver does not accept control can be found in the *Misuse in L2 and L3 Vehicles* and *Terminal State* sections below). When this transition occurs, the level transition is from L2 to L1 or L0, depending upon whether one or both of the components are disengaged. Therefore, OVI systems are, and will continue to be, capable of transitioning both one level at a time as well as multiple levels at once. This holds implications for how the warnings and alerts are developed and may have implications as to whether the operator understands the transitions completely before or as they occur.

Shared Authority

A key area of interest for future research is the process of transitioning between the various levels of automation and the concept of shared authority (or control).[23] Shared authority refers to the breakdown of all tasks necessary to operate the vehicle (i.e., complete task list for the OVI system) assigned to both the operator subsystem and the vehicle subsystem. While L2 operations are designed for the human to be present, to monitor the automation performance, and to be capable of taking control at any point, L3 operations are designed for the human to be present and available for occasional control given sufficient notification. Therefore, each level of automation has the capability to transition to an L0 vehicle that places all authority on the operator. However, some functionality of the vehicle will, at times, operate as shared authority.

Proper functioning of the OVI system in L2 and L3 systems requires some understanding of task assignment. For L2 systems, the operator subsystem is expected to monitor the roadway and be capable of taking over the entire set of driving tasks at any time. In L3 systems, shared authority is more coarse, requiring only that the operator subsystem understand when the vehicle subsystem is operating, and when provided sufficient notice take control for safe vehicle operation back from the vehicle-subsystem.

Communication and Feedback Loops

The OVI system can be considered somewhat decentralized based on the three major subsystems that compose the greater system. The two subsystems with control capabilities are the operator subsystem and the vehicle subsystem. While each of the three subsystems is integral to overall system functionality, there is a difference in communication across each of the systems. The environment subsystem has one-way information input (please note that this does not negate the fact that changes in the vehicle subsystem can affect the input from the environment to the other subsystems). Thus, no information from the other two subsystems will affect the environment subsystem. It simply exists and, as such, must be accounted for in the performance of the other two subsystems. Conversely, the operator and vehicle subsystems communicate with scenario-dependent variable frequency. This works in both directions, and failure of one of these communications segments presents the opportunity for OVI system conflict (e.g., failure to engage an automated component or physical conflict with an environmental input). The vehicle subsystem provides information to the operator, who may take actions that become feedback mechanisms. The simple model in Figure 5-2 summarizes the communication flow between subsystems.

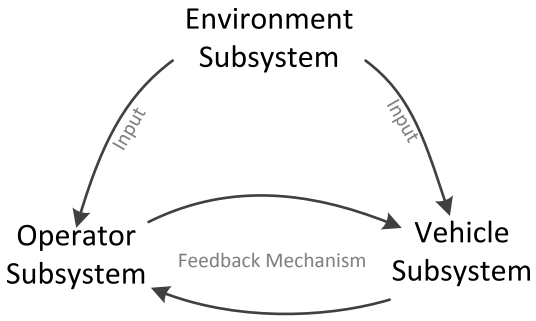

Figure 5-2. OVI Subsystem Communication Model (Source: Author)

Within the OVI system, the communication between subsystems should be unambiguous. The driver must take a specific action in order to result in a given vehicle output.

Engaging the Automated Component(s)

Performance

When the operator chooses to engage an automated component, the operator has certain expectations. The operator may expect the system to engage immediately, or the operator may expect the automated component to recognize an appropriate operating environment prior to fully engaging. The concept of performance is twofold. It refers to the operating performance of the automated component of the vehicle subsystem, and it refers to the operator’s interaction with the automated component.

Operation of an L2/L3 vehicle, or any vehicle for that matter, requires that a certain number of tasks be accomplished. A complete task list for the operator of a motor vehicle is long and complex. However, there is a base set of tasks necessary to safely and effectively accomplish the objective of operating the motor vehicle. In an L0 vehicle, each of these tasks is the responsibility of the operator. In a hypothetical L4 automated vehicle, each of these tasks would be the responsibility of the vehicle (conceivably, the operator is always capable of input but, by definition, this would not be necessary). Therefore, L2/L3 vehicles will exist somewhere between the two extremes of task responsibility. There will be a shared task authority, which will be dependent upon the level of automation and the choices of the operator to engage or disengage the automated component(s).

For safe and effective operation of the OVI system, it may be beneficial if the operator understands key tasks for which he/she has authority. There is a temporal aspect to this issue as well. The operator can choose to engage (or disengage) the automated component at any time, assuming a supportive environment (i.e., an environment within the requirements for the automated component to function properly as defined by the manufacturer). Thus, operator comprehension of the OVI system includes which tasks are assigned to the operator and when those tasks are the responsibility of the operator. Subsequent research about the operator's comprehension of task authority (specifically when transitioning from one level of automation to another) could be of benefit to future OVI system design.

To illustrate this concept, consider the use of two automated components: lane keeping and ACC. When the operator engages the cruise control, he/she is ceding task authority for maintaining speed. The operator has the ultimate authority in that he/she determines the set speed, engages the automated component, and can disengage when he/she chooses. However, while cruise control is engaged, there is no need for the operator to make constant subtle adjustments to the throttle (accelerator pedal) based on environmental factors (e.g., external inputs such as terrain, wind, traffic, etc.). Should the operator also engage a lane-centering automated component, he/she is also ceding task authority for maintaining vehicle heading. The constant adjustments for the vehicle position in the lane are left to the automated component within the vehicle subsystem. Therefore, two high-level task categories are controlled by the vehicle subsystem.

Consider an additional example: A driver engages a lane-keeping automated component. Subsequently, the driver chooses to change lanes. After manually changing lanes, the driver assumes that the lateral control functions of the lane-keeping automated component will re-engage. The system is not designed to re-engage without driver input, thus leaving the driver responsible for lateral control. This example of potential mode confusion could have the potential to lead to a safety-critical event. Research to understand the operator subsystem expectations and interactions with system design may provide greater insight into the possibility of mode confusion when engaging and disengaging automated components.

Trust In L2 and L3 Automated Vehicles

Automation across any domain has the potential to present difficulties when users' reliance upon the automation is not properly calibrated to the performance. The relationship between trust and automation can lead to several different outcomes, as defined by Lee and See.[24] Calibrated trust describes a system in which the user's trust matches the automation capabilities. Calibrated trust supports appropriate application of the automation. Overtrust describes a system in which the user's trust in the automation exceeds the actual capabilities. Overtrust can lead to misuse of the automated system, where the driver applies the automation to a roadway environment that is outside the automation operational scenarios. Distrust describes a scenario in which the user believes that the automation performance is less than it actually is. Distrust can lead to disuse of the automation, thus removing the possible benefits of the automation.

Although trust in automation has been studied across a number of domains, the applicability of these findings to the driving task is questionable due to fundamental differences between the operational characteristics of the different automated systems. Perhaps the best analogy may be drawn from aviation. Modern aircraft have multiple highly automated systems onboard. Modern autopilot systems have the ability to automate almost all phases of flight. This allows the pilot to transfer to a monitoring role. However, the analogy begins to fail when considering the fact that airspace is somewhat controlled, routes are mapped, and the potential for other airspace users to perform unexpected threatening maneuvers in very close ranges (i.e., less than 2 seconds) is not typically present. Therefore, while the lessons learned from other automation domains should be considered when approaching L2/L3 vehicle automation, they may not necessarily be directly applicable. More research about drivers' trust in L2/L3 automation can be beneficial to OVI system designers and stakeholders. Ultimately, the issue of drivers' trust in L2 and L3 automated vehicles is critical to how these technologies are both used and misused in the real world.

Misuse in L2 and L3 Vehicles

The concept of misuse within the context of automated vehicles and the aforementioned OVI system can be defined as the operator subsystem, when having knowledge and understanding of the automated component alert, cue, or other interaction, deliberately chooses not to act according to the intent and design of the automated component. That is, should a driver fully comprehend the alert provided by the L2 system and choose to ignore it for his/her reasons, it is a case of misuse. Cases when the operator subsystem does not comprehend or receive the alert (feedback from the vehicle subsystem) or confuses the alert for something else, are not misuse. The concept of misuse is independent of safety or convenience and hinges upon the knowledgeable choice of the operator based on his/her goals at the time of the decision.

In L2 vehicle systems, the operator subsystem, by definition, is expected to monitor the roadway and safe operation of the vehicle while remaining available to take full control at any time. Therefore, when the operator subsystem, potentially having full knowledge of this responsibility, chooses to engage in a secondary task that may disrupt or eliminate operator capability to effectively monitor the roadway and safe operation of the vehicle, this can qualify as or lead to misuse. Conversely, in an L3 system in which, by definition, the operator subsystem has sufficient time to transition from a separate task back to the driving task, the purposeful engagement of an alternative task is not necessarily misuse. However, in an L3 system, misuse could occur when the operator subsystem attempts to ignore warnings/alerts fully comprehended (including potential consequences for ignoring system communication) by the operator for reasons known to the operator. Misuse can occur in many different ways but always requires the operator to intentionally act in a manner inconsistent with, and with full knowledge of, the design of the system.

Disengaging the Automated Component(s)

Both the operator subsystem and the vehicle subsystem are capable of disengaging the automated component from operation. There is an unequal interaction in that the operator may typically expect immediate response to disengaging an automated component, whereas the vehicle subsystem will often provide a warning or alert process to attempt to facilitate operator awareness in preparation for disengaging. Each case is explored independently below.

Operator Chooses to Disengage

From an operator's perspective, the use of an automated component provides relief of some responsibility for driving tasks, the extent of which is dependent upon the type and number of automated components available within the OVI system. Evaluation, exploration, and understanding of operator disengagement are considered within three categories: Performance, Comprehension, and Misuse.

Performance

Performance refers to how well the interaction between subsystems functions when the operator chooses to disengage the automated component(s). The methods by which the operator provides disengagement input and the subsequent feedback loop can be measured to quantify performance. Specific to automated vehicles, performance is defined as how well the operator subsystem interacts with the vehicle subsystem. In cases of L2/L3 vehicles, performance considers the timing, reaction speed, and clarity of understanding between the operator and vehicle in modes of transition from one level of automation to another (or even changes within a level of automation).

Comprehension of Authority

A key issue with disengagement is whether the operator sufficiently understands the additional task authority placed on the operator subsystem. For example, assuming the OVI system is already functioning as an L2 automated vehicle, consider the act of disengaging ACC and lane centering. The operator must first provide a disengagement input (e.g., button press on dashboard) informing the vehicle subsystem that the operator is willing and prepared to take over responsibility for maintaining speed and/or heading. The vehicle subsystem may then acknowledge the input with a feedback mechanism(s) that provides confirmation to the operator. A time period then passes before the automated component disengages, and the operator becomes responsible for speed and heading.

There may be potential for operational issues if the operator is not aware of certain specific tasks for which he/she is accepting responsibility. Should the operator believe he/she has only accepted responsibility for speed maintenance, for example, a potential conflict arises regarding authority for vehicle heading. Essentially, the operator may incorrectly assume the vehicle is still maintaining heading when, in fact, neither subsystem is actively steering the vehicle. This concept of mode confusion is applicable beyond this simple example to other scenarios during which multiple automated components are engaged. Research to evaluate the operator’s comprehension related to component disengagement can benefit system design, as can research to determine methods that ensure accurate feedback mechanisms and necessary information are provided to the operator.

Disengage Misuse

There is the potential for an operator to choose to disengage an automated component with the intent of operating the OVI system in a manner inconsistent with design. Although the reasons for this may be many and varied, there is value in identifying when misuse is occurring. There is a clear distinction between not comprehending the automated component functionality and intentionally misusing the system. As previously noted, discussion about misuse in this document refers to willful actions to use the automated component incorrectly. When the operator chooses to disengage a working automated component during a time or in a manner that the operator knows to be against the design and intent of the automated component, this is considered misuse. Subsequent research could focus on understanding misuse, characterizing misuse, and potential solutions for misuse. Dealing with misuse falls within Misuse Handling and is discussed in detail below.

Vehicle Disengages Automated Component

There are scenarios where the vehicle subsystem automated component can determine it is no longer capable of operating at a sufficient level of performance. In these cases, the automated component within the system may attempt to disengage and shift control authority for the task to the operator subsystem. This presents a unique case in the OVI system during which the communication originates with the vehicle subsystem. This case also serves as an example of when the operator subsystem should provide feedback to the vehicle subsystem to complete the communication loop. However, it is conceivable that the automated component can fail and disengage or could function properly but determine the need for an immediate disengagement. Subsequent research and further exploration of these scenarios could provide a benefit to system design.

Notification Cues

Notification cues herein are considered those feedback mechanisms provided from the vehicle subsystem to the operator subsystem when indicating something specific to the driving tasks. These may take the form of alerts/warnings to the operator when the vehicle subsystem intends to transfer some or all control back to the operator. While the types and specifics of the cues may vary between levels of automation and manufacturers, they are designed to indicate some type of message for operator assessment.

Subsequent research into the types and methods of notification generated through vehicle subsystem cues can inform future system design. There may also be some benefit to future system design from research into methods or techniques to handle ignored cues or to determine why the cues were ignored (e.g., potential misuse). When a cue is present but no operator subsystem action is taken, it may be of value to investigate the best course of action for the vehicle subsystem (e.g., increase in cue volume or secondary alert [e.g., haptic] supplemental to original alert [e.g., auditory]). In addition, research could provide input into the timing, sequence, and presentation of such cues for optimal system function.

Terminal State

The terminal state refers to the system actions when a dynamic loop reaches a static state. This concept considers the steps taken by the automation component when the operator subsystem fails to maintain or provide the feedback mechanisms within the overall system. If the automated component requests operator control and – for any number of reasons – the operator fails to regain control, the terminal state may need to be pursued. An example of this in an L3 vehicle would be when the automated component(s) detects a need for the operator to assume full control of the vehicle and sends an alert. The operator, for whatever reason, fails to disengage the automated component. While continuing to attempt to get the operator to comply, the system may have to bring the vehicle to a safe state. In both L2 and L3 vehicles, existing prototypes and designs indicate that many methods for handling the terminal state are in development. An example of placing the vehicle in a terminal state is having the automated component move the vehicle to the side of the road and come to a complete stop. This document and subsequent research could help inform this issue of safely placing the vehicle in a terminal state or, where applicable, preventing the need for such actions. This may include research by academics, original equipment manufacturers (OEMs), and others into developing and understanding fail-safe and fail-operational requirements for automated vehicles.

Misuse Handling

As mentioned, there is potential to misuse an L2/L3 system, specifically the automated component. Although misuse is intentional, it is likely the operator believes that misuse will not increase the risk of operating the vehicle. Regardless of his/her perception of this matter, the handling of misuse could have the goal of combating any potential increased risk. For example, if a driver chooses to engage a lane-centering system but fails to disengage the system when appropriate, the vehicle may detect the need to move steering authority back to the operator. During this scenario, the vehicle subsystem may attempt to notify the driver, although it is conceivable that in some cases it would not make such an attempt. If the driver is aware of and understands the request but does not take the appropriate action—believing instead that the vehicle will continue to operate in the same manner—this qualifies as misuse. This adds a third aspect to shared authority in that neither control subsystem is actively taking authority of a necessary task for driving (e.g., steering).

A key difference between the two control subsystems (i.e., operator and vehicle with automated component) is that the vehicle subsystem does not choose its task assignment. The vehicle subsystem handles tasks as assigned or may provide a cue (dependent upon system implementation and use-case scenarios imagined for system design) to the operator that the task can no longer be handled by the vehicle subsystem. However, the operator subsystem has the ability to understand key aspects of the tasks assigned and to choose not to handle one or more of them. The vehicle subsystem with automated components may then potentially have methods for handling this or other types of misuse. Evaluation and research have the potential to identify cases of misuse, to characterize these cases, and to develop functional countermeasures that may prevent misuse from increasing a safety risk to the OVI system, other vehicles, or infrastructure.

Chapter 6 Risk Assessment

As stated, this document covers the concepts of automated vehicles as they are developing and may be developed in the future. Some discussion is warranted at this stage in the development process about the issues associated with shared authority systems. It is important to note that these issues may be well understood and handled effectively by manufacturers and system designers; this will become clearer as development and production continue.

Potential Issues with Automated Vehicles

Potential issues with automated vehicles include, but are not limited to, the following.

Mode Confusion. As stated, the concept of shared authority in an automated vehicle considers the tasks assigned to the operator and to the vehicle. Within the OVI system established in Chapter 3 Definition of the Current System of this document, this concept is defined by the two control subsystems. An operational risk exists when both systems simultaneously perceive the other to be the ultimate controlling authority. This issue is discussed to some extent in Chapter 7 Modes of Operation under Comprehension of Authority. It is reiterated here to emphasize the potential benefits from a human factors perspective of understanding this risk and designing systems accordingly. Across all levels of automation, there is the potential for the operator to misunderstand his/her authority and responsibilities within the OVI system, which may be associated with a safety-critical incident. Research designed to qualitatively and quantitatively assess this risk as it pertains to automated vehicles has a potential benefit to system designers. Although a singular concept, there may be a variety of ways in which this risk could manifest itself within different system designs.

Error Handling. A second aspect associated with automated vehicles is defining intent and ceding ultimate control. It is conceivable that automated components within the vehicle subsystem will be designed to account for a certain amount of human variability. That is, people will make mistakes, and many of these mistakes will likely be understood. The designs of these automated components will account for such mistakes and will act accordingly. The risk in this approach is that the automated component may not correctly account for the intentions of the operator subsystem and may act inconsistently with the expectations of the operator subsystem. For a detailed explanation and discussion of this risk, the reader is referred to the philosophical differences of Boeing and Airbus approaches to automation in the Literature Review document. To summarize, the designers of automated components can provide ultimate decision authority to the vehicle subsystem, or they can provide ultimate authority to the operator subsystem. In the case of an automated component inadequately adjusting to an unusual event, the operator can detect the situation and control the vehicle accordingly.

To some extent, the issues here are similar to error handling in current crash-avoidance products (e.g., collision imminent braking). Further research into shared authority and transitions between controlling subsystems could benefit system design and could lead to a better understanding of the nuances of design philosophies in the realm of automated motor vehicles.

Overreliance. There is a possibility of overreliance upon automation when drivers are able to use an L2 or L3 automated driving system for some period of time. That is, the potential exists for drivers to constantly seek to activate the automated driving component of the vehicle after becoming familiar with the automation and how it functions. Researchers have postulated that, over time, this overreliance can possibly lead to degradation in driver skill as the reinforcement from constant engagement in the driving task is now lacking. This issue is of concern in the aviation domain, where pilot skill has been observed to suffer in the presence of frequent and continuous use of automated functions.

Driver Underload. Automation removes some demand from the driver and places it upon the automated system. However, by removing some level of task demand from the driver, there may be an associated risk of drivers achieving a state of underload. This is a situation in which the driver is under-stimulated, which may lead to fatigue, boredom, reduced levels of operator alertness, and sensation-seeking behaviors. This is potentially of more concern in L2 vehicles where there is an expectation that the driver will monitor the performance of the automation. In L3 vehicles, the expectation is that drivers may become more disengaged from the driving task. Longitudinal human factors research could provide insight into the issue of driver underload during extended periods of time when the operator becomes comfortable with the overall system.

Potential Benefits of Automated Vehicles

Reduced Workload and Fatigue. There are expectations that automation can reduce or eliminate certain risks to the current OVI system. Human factors research has long shown certain deficiencies in human capabilities to interact with machines. Specifically, humans have issues with vigilance; humans can suffer from decreased attention and visual acuity; and, under duress, humans often fail to account for all available cues. Automated components within the vehicle subsystem have the potential to augment the operator's capabilities in several ways. First, automated components can aid in vigilance. For example, automated components can remain a constant sensor for forward collision or ensure vehicle heading while allowing the operator a break. Within driving tasks, there is a finite workload to which the human can be subjected without suffering fatigue. While the number of inputs, tasks, and responsibilities of the operator subsystem are not entirely in control of the operator, automated components can decrease the total operator workload. This can, in turn, decrease fatigue, add convenience, and improve the overall OVI system experience from the perspective of the operator. Subsequent research has the potential to provide data about driver fatigue relative to operating an automated vehicle.

Increased Performance in Handling Small Errors. Both L2 and L3 operations present the potential for greater performance in handling small driving errors that humans typically commit. These errors are committed for a number of reasons (e.g., distraction, confusion, disengagement, or fatigue) and are generally below the level of safety concern. An example of a small error is a steering reversal that does not result in a lane exit. While the human may be subject to many factors that affect performance, it is assumed that any L2 or L3 production automated system will be able to provide a constant level of environmental monitoring and will be able to provide an appropriate response to the extent that the system has an accurate recognition of the driving scenario.

Driver Distraction. As mentioned, driver distraction can lead to small driving errors typical in L0 and L1 vehicles. However, driver distraction is also responsible for significant driving errors, including events leading to a crash. A large collection of research indicates that driver distraction is responsible for many crashes, injuries, and even fatalities. While L2 systems, by definition, require monitoring by the driver and offer more of a respite of the hands and feet in the physical act of driving, the L3 system may offer some protection from the issue of driver distraction. In an L3 system, by definition the driver cannot be distracted (from the driving tasks) when the automated component is engaged because he or she is not expected to monitor the roadway or be responsible for safety systems. Thus, activities considered secondary in an L0/L1 system (e.g., texting, using a tablet, watching a movie) will be primary rather than secondary in an L3 system.

Novice Drivers. Research has shown that novice drivers can make mistakes that experienced drivers would not make. Simply by gaining experience using the system (i.e., vehicle), the drivers become more skilled with the system and perform at a higher level. The introduction of L3 systems has the potential to change this paradigm. L3 systems may be able to correct or prevent poor decisions of the novice driver while allowing them to gain valuable experience by providing real-time feedback. The potential benefits of this may require longitudinal human factors research to fully understand.

Chapter 7 Introduction of Automation-Relevant Parameters

Introduction

Because vehicle automation is a market-driven system, assessing industry activity and any market barriers is an appropriate way to define concepts that are most likely to be introduced to the public. Each parameter will be described via text and summarized in a chart. The chart will serve as the basis for down-selection in the following chapter.

The parameters include:

- Road Facility Type
- Automated Vehicle Segregation
- Infrastructure Adaptation
- Connected Automated Operation
- Inter-Vehicle Coordination
- Speed of Travel
- Traffic Density
- Awareness of and Operation Relative to Traffic Control Devices
- Awareness of Other Vehicle Indications
- Situational Awareness
- Vehicle Maneuvers under Automated Control
- Weather Conditions
- Roadway Surface Conditions
- Driver Ability in Manual Driving
- Driver Monitoring
- Driver Task Requirement to Maintain Engagement
- Intended Duration of Automation
- Engage/Disengage Method
- Driver Engagement Timing
- Driver Training

Definition of Parameters

Road Facility Type

Definitions:
Limited-access Highway: Interstate highway, high speed, absence of traffic lights, pedestrians, bicycles, merge and exit at speed
Rural Highway: High speeds, at-grade intersections, traffic lights, pedestrians, bicycles
Suburban Arterial: Moderate speeds, at-grade intersections, traffic lights, pedestrians, bicycles
City Streets: Moderate to slow speeds, frequent intersections, traffic lights, stop signs, pedestrians, bicycles
Residential Streets: Slow speeds, greater prevalence of pedestrians/bikes, stop signs
Off-street (parking facilities, etc.): Typical parking lot or multi-level parking garage with pedestrians and other slow-speed vehicle traffic

Discussion:
Several OEMs have prototyped and some have announced products for TJA, which provides full automation during low-speed congested highway situations. These are L2 systems. OEMs have also prototyped L2 combined lateral/longitudinal operations intended for limited-access highways. These systems typically assess lane boundaries via image processing. However, lane markings sufficient for lane detection may or may not be available on particular roadway sections.

Google has investigated the operation of automated vehicles that operate on a variety of road types. Vehicle OEMs have published research papers about situational understanding and threat detection in a variety of urban and residential environments.

Automotive suppliers have demonstrated “automated valet parking” (i.e., vehicles that drive, empty, into a parking facility to find a space and park).

Automated Vehicle Segregation

Definitions:
Mixed Traffic: Automated vehicles operating in current traffic streams found on roads today
Segregated Traffic: Automated vehicles operating only on facilities restricted to automated vehicles, with physical separation from human-driven vehicles.

Discussion:
While segregated traffic approaches were explored extensively in the Automated Highway Systems (AHS) program during the 1990s, all current industry activity focuses on mixed traffic.

Infrastructure Adaptation

Definitions:
Adapted Infrastructure: Road facilities modified to optimally support automated vehicles by simplifying the road environment and/or enhancing the environment for sensors. This may be in the form of physically separated lanes and/or specialized road furniture/markings optimized for onboard sensors.
Non-adapted infrastructure: The current road environment including human-driven traffic with lane markings of various types and quality.

Discussion:
Adaptation of the infrastructure was explored within the AHS program and other research projects that focused on “sensor-friendly highways.” State Departments of Transportation (DOTs) have shown no indication that investments into automated vehicles are forthcoming. Vehicle manufacturers do not want to wait for, or rely on,

state investments and deployment – which may vary from state to state – before offering products. Therefore, design activities are focused on roads as-is. This is reflected in the prototypes and products under development (see Chapter 6 Level 2 and Level 3 Systems).

Connected Automated Operation

Definitions:

Information derived from the Internet via cellular data communications and Global Positioning System (GPS) technology is assumed to be generally available with signal dropout a possibility in all cases.

V2V: Automation is implemented that uses IEEE 802.11p DSRC to exchange data between vehicles traveling in the vicinity of one another, including, but not limited to, the SAE J2735 Basic Safety Message.

Vehicle-to-Infrastructure (V2I): Automation uses IEEE 802.11p DSRC to receive data from the infrastructure, including curve geometry, weather/road conditions, signage, traffic signal phase and timing, and intersection geometry. Additionally, the infrastructure uses vehicle data to adapt traffic control devices and collect probe data to support area-wide traffic management.

Both: Use of both V2V and V2I.

None: Automated vehicles rely on onboard sensors and information derived from the Internet and GPS.

Discussion:

V2V and V2I are the subjects of a variety of field trials. NHTSA is considering regulatory action to require DSRC on all new passenger vehicles and heavy trucks. European automakers are planning to introduce DSRC in 2015 to support a variety of safety and non-safety applications. Industry discussions have focused on connected automated systems as key to new gains in mobility and environmental benefits. For instance, the Federal Highway Administration (FHWA) is planning research into Cooperative Adaptive Cruise Control (C-ACC), which can be considered a precursor to connected automation.

For initial products, OEMs are focusing on deployment of systems that are sensor based, with the expectation that V2V and V2I data will be incorporated into situational awareness algorithms when that information becomes available.

Inter-Vehicle Coordination

Definitions:

Platooning: Inter-vehicle communications are used to provide information about lead vehicle actuation to multiple automated vehicles following at close headways. The vehicular tasks are limited to following the vehicle ahead, maintaining the headway, and join/split maneuvers.

Cooperative Headway Management: Inter-vehicle communications are used to implement C-ACC, thus shortening the distance between a lead vehicle and a single following vehicle. This function can be implemented as longitudinal control alone or in combination with lateral control. C-ACC offers significant improvement in fuel economy due to the aerodynamics of shorter headways.

Individual Vehicle: “Free agent” operation; the automated vehicle coordination is typical of the operations regular drivers perform today; inter-vehicle communications do not play a role.

Discussion:

Platooning was first implemented in the FHWA AHS program in the 1990s, and similar work occurred in Japan during that period. The European SARTRE program, which ran from 2009 to 2012, implemented platooning based on a business model of a lead driver being paid to drive the lead vehicle by the occupants in the following vehicles. SARTRE partners Volvo Cars and Volvo Trucks assert that their SARTRE approach to platooning is a near-term system as it relies on the lead vehicle being human-driven. The human leader can react appropriately to any anomalies on the road such that the roles of the automated vehicles are limited to car following and headway maintenance. Others have countered that asking the public to accept both automation and close-headway operations in a first-generation automation offering may not be realistic.

Additionally, the success of this concept will require significant numbers of vehicles equipped with both communications and automation capabilities. FHWA is planning light-vehicle platooning trials under its Exploratory Advanced Research program.

Cooperative Headway Management: C-ACC user acceptance research has shown that drivers quickly become comfortable with smaller gaps than those offered by current ACC systems. C-ACC experiments conducted in Europe have demonstrated traffic flow and flow stability benefits from this technique. FHWA is planning truck-based C-ACC trials under its Exploratory Advanced Research program. Peleton Aerolink is a start-up company offering retrofit C-ACC capabilities for heavy trucks. Product introduction and its value depend on sufficient penetration of V2V-equipped vehicles for customers. In the case of the trucking industry, large-truck fleets could coordinate operations such that their equipped vehicles locate one another and connect via C-ACC, which could result in fuel economy benefits.

Individual Vehicle: Extensive product-oriented industry activity focuses on individual vehicle operations.

Speed of Travel

Definitions:
Low speed (0–30 mph): Applies to TJA
Higher speeds only (30–75 mph): Applies to operations conducted at typical highway speeds
Full speed range: Encompasses full range of speeds (i.e., a system that is not limited to a specific speed range)

Discussion:
The speed of travel must be considered in the context of the road environment. Low-speed systems for highway use imply a vastly different set of system requirements than do low-speed systems for city driving. This parameter focuses on highway speeds.

The auto industry has initially focused on TJA because lower speeds create a situation during which the performance requirements are less challenging. TJA is also considered to provide greater utility to drivers by relieving them of the most tedious driving situation: the traffic jam. TJA will serve as a learning ground and test case for systems operating within the full speed range.

Several OEMs and Google have focused on highway speed systems that combine ACC with lane-keeping ability. The Google and GM systems operate at the full speed range.

Traffic Density

Definitions (These are the FHWA Level of Service [LOS] definitions)**:**
LOS A: Free flow
LOS B: Flow with some restrictions
LOS C: Stable flow; maneuverability and speed more restricted
LOS D: Unstable flow, temporary restrictions momentarily slow vehicle
LOS E: Unstable flow, vehicles unable to pass, temporary stoppages
LOS F: Force traffic flow condition with low speed

Discussion:
Automakers are developing systems for higher-speed flowing traffic (LOSs A, B, C) during the near term and focusing on the TJA function (current product) for LOSs D, E, and F. Systems are also under development to cover the full range of traffic conditions.

Awareness of and Operation Relative to Traffic Control Devices

Definitions:

Traffic signal (circular): Detection of the state of traffic signals plus the lane assignment of traffic signals for more complex intersections

Traffic signal (turn indication): Detection/understanding of turn arrows and lane assignments to which the turn arrows are applicable

Traffic circles: Detection of traffic circles, number of lanes in traffic circles, and observing proper behavior in traffic circles

Pedestrian crossings: Detection of pedestrian crossing zones and observing local rules for allowing pedestrians to cross

Lane restriction indications: Detecting and observing turn-only lanes and/or restrictions to certain vehicle types; this includes electronic message signs

Work zones: Detecting work zones, special signed instructions, and lane designations via traffic cones or other markers.

One-way street signs: Detecting and observing signage indicating one-way streets

Yield signs: Detecting and observing yield signs

Stop signs: Detecting and observing stop signs and behaving according to appropriate order of precedence

Speed signs: Detecting speed signs and adjusting speed accordingly, including electronic speed signs

Discussion:

To some degree, automated vehicle systems will use highly accurate map data. However, the vehicles must be capable of detecting actual traffic control devices on the road to avoid a violation.

Traffic Sign Detection is a product that has been available in Europe since approximately 2010. Systems that will work in the U.S. are still under development because the U.S. does not follow international sign conventions. Detection of traffic signals has been implemented on prototypes; the robustness of detection is the focus of further technical development. Research has also been performed on operation in traffic circles.

Awareness of Other Vehicle Indications

Definitions:

Brake lights: Detection of brake lights on a lead vehicle as a redundant indication of deceleration (i.e., a backup to sensors and communication)

Turn signals: Detection of turn signals on lead and/or adjacent vehicles as a means of assessing the intentions of other drivers

Discussion:

No information was found in the literature about prototypes that detect either brake lights or turn signals.

Situational Awareness

Definitions:

Vehicles: Nearby vehicles

Motorcycles: Nearby motorcycles

Road condition: Detection of surface traction condition, potholes, etc.

Road debris: Detection of debris on the road (e.g., tire/animal carcasses, items that may have fallen off other vehicles)

Pedestrians: Pedestrians relevant to the planned travel path, particularly in right-turn movements made across crosswalks when the pedestrian is traveling in the same direction (the pedestrian may be in the driver’s blind spot)

Bicyclists: Nearby bicyclists, particularly in right-turn movements made across crosswalks when the bicyclist is traveling in the same direction (the bicyclist may be in the driver’s blind spot)

Animals: Awareness of animals on the road and those on the roadside who may bolt across the road
Discussion:
Prototypes and products designed for current highway operations are aware of other vehicles, motorcycles, and pedestrians based on active safety offerings that have been available for several years.

The road condition can be derived from traction control systems. However, preview information is more important, though this is not possible with onboard sensors. Information obtained from lead vehicles using V2V communication will be helpful in this situation.

Some road debris may be detectable by current systems. Again, V2V communication systems will be helpful in this situation.

Prototypes for intersection crash avoidance[23] and urban automated driving have been designed to detect bicyclists.

Tier One suppliers are now working on systems designed to detect large animals[26].

Vehicle Maneuvers under Automated Control

Definitions:
Stay in Original Lane Only: Cruising at set speed; lane markings sufficient for lane detection may or may not be available
Lane Change: Monitor adjacent lane for adequate gap; signal and execute lane change; lane markings sufficient for lane detection may or may not be available
Freeway-to-Freeway Interchange: Maneuver to proper lane for merging onto the desired freeway and direction; merge into traffic on new freeway
Diverge from Freeway to Surface Street: Signal for exit from freeway; detect and understand configuration at end of departure ramp; select proper lane and observe yield/stop/signal information
Merge into Traffic: Merge into freeway traffic from surface street ramp with awareness of merging distance available
Left Turn across Traffic: Make a left turn with awareness of any crossing pedestrians or bicyclists; awareness of any oncoming vehicles that may come into sensor view during the maneuver
Right Turn: Make a right turn with awareness of any crossing pedestrians or bicyclists who have the right of way
Stop/Start at Traffic Signal: Awareness of traffic signal state for travel lane; maintain proper gap behind lead vehicle while accelerating on green signal
Stop-Controlled Intersections: Awareness of stop sign and configuration (two-way, four-way); awareness of other vehicles at intersection and which vehicles have right of way; observance of order of precedence when multiple vehicles are at the intersection
Traffic Circles: Awareness of traffic circle configuration, including number of lanes; observance of proper lane behavior; awareness of vehicles already in the traffic circle; awareness of right of way for each vehicle; enter and depart traffic circle following local rules
Work Zones: Detection of lane boundaries (possibly unconventional) and/or stop indications; maneuver through work zone with awareness of other traffic and work zone speed limits; merge into adjacent lane in lane-drop situations
Respond to Emergency Vehicles: Awareness of emergency vehicle and location relative to other vehicles; determine need to move out of the path of the emergency vehicle; determine safe and legal options to move out of the emergency vehicle path and execute the ideal maneuver

Yield as Appropriate: Awareness of yield signs and road rules for yielding in the absence of signs; awareness of other vehicles and their right-of-way status; proceed in accordance with right of way
Discussion:
The vehicle industry is developing prototypes designed for lane changes, freeway-to-freeway merging, handling traffic circles, and negotiating work zones.

Researchers focusing on automated urban driving have developed prototypes capable of making left/right turns and responding to traffic signals and yield/stop situations.

Activity is either focused on freeways or urban driving, not both. Therefore, no activity has been detected to accomplish divergence from a freeway onto a surface street or vice-versa.
No activity has been detected for automated vehicles responding to emergency vehicles.

Weather Conditions

Definitions:
No Adverse Conditions: Dry, clear
Rain: Adapting speed as needed due to wet pavement and visibility
Sleet: Adapting speed as needed due to pavement condition and visibility; alerting driver when automated control is no longer possible
Snow: Adapting speed as needed due to pavement condition and visibility; alerting driver when automated control is no longer possible (e.g., due to obscured lane markings)
Fog: Adapting speed as needed due to visibility; alerting driver when automated control is no longer possible
Other (Smog, Smoke, Sand/Dust, Crosswind, Hail): Adapting speed as needed due to visibility; alerting driver when automated control is no longer possible; adapting steering as needed in crosswinds
All Conditions: Automated vehicle can operate at minimum performance standards regardless of weather
Discussion:
Regarding the full range of weather conditions, systems may not be able to determine when the weather falls outside of the verified performance envelope.

First-generation automated vehicle systems will most likely disable under heavy rain (poor visibility) conditions using rain detection systems already available on production cars. The ability to transfer control back to the driver during these cases (e.g., instantaneous heavy rain in a thunderstorm) will be critical.

Current systems are capable of operating during at least moderate rainfall. Active safety systems (i.e., the technology basis for automation) have the ability to “see” through fog and other visual obscurations. However, the majority of current work focuses on moderate-to-good weather conditions, leaving inclement weather operation to later-generation systems.

Roadway Surface Conditions

Definitions:
While metrics for roadway surface conditions are important in a requirements document, they are not needed for this high-level ConOps document.
Discussion:
Similar to discussion about weather parameters (above), current work focuses on ideal pavement conditions. Operation during degraded conditions (e.g., snow/ice/oil) will be left to future-generation systems.

Driver Ability in Manual Driving

Definitions:

Novice: A learning driver or one with less than one year of experience

Experienced: A driver with one or more years of driving experience

Impaired Due to Age or Disability: Drivers whose driving skills have started to degrade due to age; drivers whose cognitive and/or motor skills are degraded due to a medical condition

Discussion:

Current work focuses on the average driver (i.e., an experienced driver).

Research has shown that novice drivers (e.g., teens) can make errors due to lack of skill and/or impulsive behavior. Current automation prototypes can support novice drivers, and driver interfaces could be developed to coach novice drivers. Coaching systems have been developed for some insurance products that could serve as a starting point.

Driver impairment can result from drowsiness; this condition is addressed to some degree by current driver fatigue countermeasures offered by several automakers. Automated systems that allow persons incapable of driving to "be driven" are being explored by the industry. The Emergency Stopping Assistant developed by BMW provides safe stopping when a driver becomes unresponsive.

Driver Monitoring

Definitions:

Yes: Systems are implemented that monitor some or all of lane-keeping stability, pedal application, steering inputs, manipulation of other controls, seating position, eye-blink rate, and gaze (on or off road)

No: No monitoring at all

Discussion:

Driver fatigue systems currently available on the market monitor driver activity in a basic way (e.g., by noting lane-keeping stability, pedal application, steering inputs, and manipulation of other controls [e.g., radio and climate control]). However, as noted by HAVEit researchers, automated driving reduces or eliminates these data elements.

A key driver-monitoring technology is "hands on wheel" detection achieved through counter-torque detection or capacitive touch sensing. Several LKASs on the market now implement some form of this technology.

In terms of driver visual attention, driving distraction activity has led to research into driver-monitoring techniques. However, the auto industry has not yet extensively deployed driver monitoring. Some industry executives have made public statements that driver monitoring is essential for L2 automated driving.

Based on experiments, the HAVEit researchers concluded that the most promising measures for driver state assessment during highly automated driving were vision-based measures that analyze the driver's eye closure behavior for drowsiness detection and analyze the driver's head or gaze direction for distraction.

Overall, driver monitoring is an active discussion topic within the vehicle industry. However, no public exhibitions of automated driving combined with driver monitoring have occurred at this point. Based on information released by the industry, TJA products that have been announced do not implement driver monitoring.

Driver Task Requirement to Maintain Engagement

Definitions:

Yes: Driver must take an action of some sort at defined intervals for the automated system to continue operation

No: The driver needs to take no action for the automated system to continue operation

Discussion:

A task requirement to maintain driver engagement could assume a variety of forms in terms of the action itself, time periods, and specific conditions. A driver task requirement may work in tandem with driver monitoring as well (i.e., the vehicle may prompt the driver to perform a task only after first determining via driver monitoring that the driver's visual attention to the driving scene is inadequate).

For the TJA system on the 2014 Mercedes S-Class, the driver is expected to be engaged, with his or her hands placed on the steering wheel. If the driver is not touching the steering wheel, the system will disable after a few seconds.

Press materials from other automakers do not comment about the possibility of a driver task requirement. Press reports from the Audi TJA demonstration made during the 2013 Consumer Electronics Show[27] note that the system offers video entertainment to the driver once the system assumes control of driving.

Intended Duration of Automation

Definitions:

Short: Less than 1 minute
Medium: 1–10 minutes
Extended: 10–30 minutes
Long: Greater than 30 minutes

Discussion:

There is no indication in the literature that the vehicle industry and researchers are defining their systems in terms of duration of automation.

Engage/Disengage Method

Definitions:

System Request: The system makes a request to the driver to engage or disengage

Driver-Initiated: The driver requests the system to engage or disengage from driving

Both: Both options are implemented

Forced Disengage/Failure: The system requests the driver to resume control due to inadequate road conditions or a system failure; in the case of a non-responsive driver, the system brings the vehicle to a (relatively) safe state

Discussion:

Published information about TJA systems indicates that the vehicle system will inform the driver when the conditions have been met for TJA operation to commence; the driver then decides whether or not to engage the system.

When a TJA system detects a condition requiring driver control, the system will request that the driver reassume control. In the case of the Audi prototype, if the driver does not respond, the vehicle will tap the brakes after five seconds. If there is still no response, the car begins to gradually brake to a stop within the next 10 seconds and activates the hazard lights. The specific actions of TJA systems developed by other OEMs have not been published.

The European HAVEit project focused on the human factors design of the transitions between lower and higher degrees of automation, including development of a progressive step-by-step approach to transfer the driving task from the automated system to the driver. When returning control to the driver, the interaction began early in the event chain (i.e., a few seconds before a potentially critical situation occurred). According to the research report, “the system brought the driver back into the loop in advance of the critical situation and provided him or her with the optimum level of automation and assistance needed in critical situations.”

Driver Engagement Timing

Definitions:

Engagement timing refers to the amount of time the system allows the driver to re-engage operations after a period of automated driving.
Short: Less than 3 seconds
Medium: 3–10 seconds
Long: 10–30 seconds
Extended: Greater than 30 seconds

Discussion:

Engagement timing is critical to assessing the safety of automated driving concepts and relates to the engagement methods, any driver task requirements, and the potential need for driver monitoring. The driver engagement time could vary by the driver type (e.g., novice, experienced, impaired). In the case of a person incapable of driving, driver engagement time becomes infinite (i.e., the system becomes an L4 system and must handle all aspects of driving at all times).

Public information about TJA products and prototypes does not list specific engagement timing. Information about the Audi prototype indicates a 15-second engagement period.

Assumptions about engagement timing relate to the risk of non-engagement. Information about the Audi prototype indicates that its TJA system may bring the car to a halt, and activates hazard lights, when the driver is unresponsive. This operation is relatively safer than proceeding when the system is incapable of driving the vehicle.

The European HAVEit project defined two “Minimum Risk Maneuvers” during this type of situation:

- Bring the vehicle to a stop on-road
- Change lanes as needed to bring the vehicle to a stop on the shoulder of the road

Driver Training

Definitions:

None: No driver training; the driver discovers system operation and forms his/her mental model of system operation
Minimal: The driver is provided information (e.g., a video shown at the car dealership) before driving the vehicle for the first time
Substantial: Before driving an automated vehicle, a special driving certification based on training must be obtained.

Discussion:

No information was discovered that indicates automakers are designing systems that require training.

The Nevada autonomous driving law[28] requires that drivers obtain a special endorsement on their driver’s licenses.

Chapter 8 Selected Automation Concepts for Human-Machine Interface Evaluation

Down-selected Parameters

In *Chapter 7 Introduction of Automation-Relevant Parameters*, a broad set of parameters was identified for the L2 and L3 automated vehicle concepts. From that larger set, a down-selected set was identified based on industry activity in research and development. Table 8-1 provides this smaller set by Parameter and High-ranking Modality.

Table 8-1. Vehicle Automation Parameters with High Industry Activity and Likely Near- or Mid-term Introduction

Parameter	High-ranking Modality
Road Facility Type	Limited-access highway
Automated Vehicle Segregation	None (mixed traffic)
Infrastructure Adaptation	None
Connected Automated Operation	Cellular/GPS only
Inter-Vehicle Coordination	Platooning (research)
Inter-Vehicle Coordination	No coordination (individual vehicle; industry)
Speed of Travel	0–30 mph (earliest market timing)
Speed of Travel	30–75 mph (near term)
Traffic Density	All LOSs
Awareness of and Operation Relative to Traffic Control Devices	Speed signs
Awareness of Other Vehicle Indications	None
Situational Awareness	Vehicles, motorcycles, pedestrians
Vehicle Maneuvers Under Automated Control	Stay in original lane
Weather Conditions	Dry, clear, rain
Roadway Surface Conditions	Dry, wet
Driver Ability in Manual Driving	Novice, experienced
Driver Monitoring	Both monitored and unmonitored
Driver Task Requirement to Maintain Engagement	Yes and no
Intended Duration of Automation	All
Engage/Disengage Method	Initiated by driver/system/both
Driver Engagement Timing	All
Driver Training	None

Selected Automation Concepts for Human-Machine Interface Evaluation

The following factors were identified as common to all automation concepts:

- Highway
- Mixed traffic
- Infrastructure as-is
- Only cellular and GPS connectivity
- No vehicle coordination (individual vehicle operation)
- Awareness of vehicles, motorcycles, pedestrians
- Dry and wet weather/road conditions
- Novice and experienced drivers
- Engage/disengage by driver or system

The following figure (8-1) represents a model for investigating the relevant operational parameters for each chosen concept. Each channel represents a different set of conditions for evaluation. There are 32 channels total, thus ensuring a thorough investigation of each concept under each of the conditions presented.

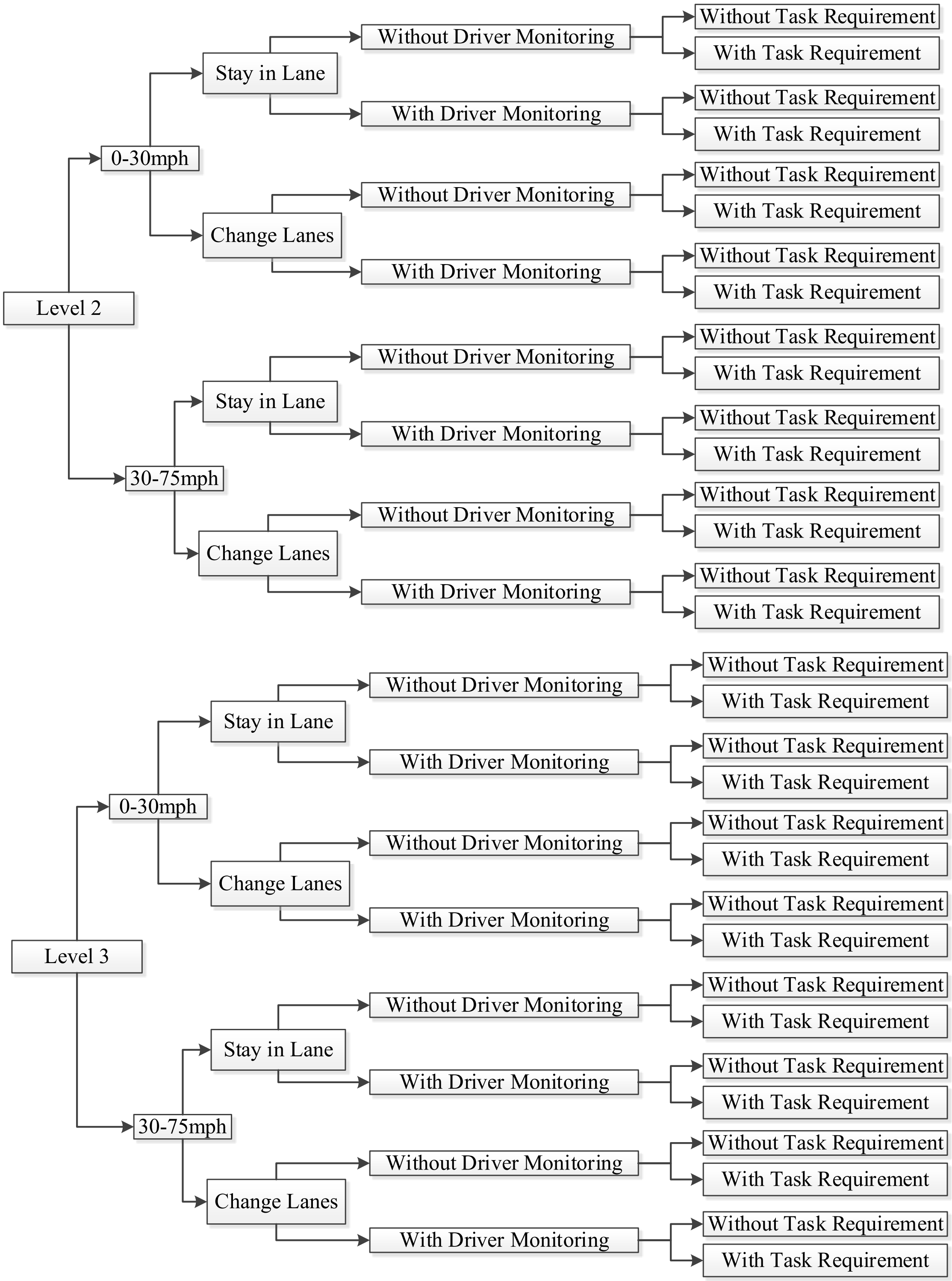

Figure 8-1. Relevant Operational Parameter Investigation Model for L2 and L3 Systems (Source: Author)

Chapter 9 Operational Scenarios

This ConOps document identifies the existing systems, the proposed systems, and the current state of vehicle automation efforts (in combination with the Literature Review document). This ConOps may also be used to inform subsequent research about L2 and L3 systems. Operational scenarios are descriptions of vehicle operations, which include operator actions, that define a specific transport situation. For the operational scenarios, a specific literature search was conducted that identified analyses of data sets providing insight into the most common pre-crash indicators (or scenarios, depending on the study). Pre-crash indicators (or scenarios) are the kinematic attributes of the vehicle prior to, or operator actions leading to, a crash or near-crash.

More than 20 reports or journal articles about transportation data sets were reviewed to identify the key attributes and characteristics of pre-crash scenarios. Of these, six studies stated findings related to the vehicle kinematics or operator actions associated with negative outcomes. The following six studies were evaluated for pre-crash scenarios:

- Integrated Vehicle-Based Safety Systems (IVBSS) Light Vehicle Extended Pilot Test Summary Report (IVBSS)[6]
- Heavy Vehicle-Light Vehicle Interactions Data Collections and Countermeasure Research Project Phase 1 – Preliminary Analysis of Data Collected in the Drowsy Driver Warning System Field Operational Test: Task 5, Preliminary Analysis of Drowsy Driver Warning System Field Operational Test Data, DTNH22-00-C-07007, Task Order #21 (34 Truck)[5]
- Frequency of Target Crashes for IntelliDrive Safety Systems, DOT HS 811 381 (VOLPE, GES)[3]
- The 100-Car Naturalistic Driving Study, Phase II – Results of the 100-Car Field Experiment, DOT HS 810 593 (100 Car)[2]
- Naturalistic assessment of novice teenage crash experience (40 Teen)[25]
- Investigating Critical Incidents, Driver Re-start Period, Sleep Quantity, and Crash Countermeasures in Commercial Vehicle Operations Using Naturalistic Data Collection (8 Truck)[4]

The OVI system is concerned with both the operator and the vehicle. Thus, all applicable attributes were collected regardless of which subsystem was the most appropriate. The resulting relationships of attributes were mapped with and between studies. Figure 9-1 provides this map and indicates through line thickness which attributes were most common. It should be noted that the parenthetical names of the aforementioned studies are used in the figure (e.g., IVBSS, 100 Car). Often, a different term or phrase was used to describe a similar pre-crash scenario (indicator) across studies. To simplify the mapping where possible, multiple attributes were combined where similar definitions existed.

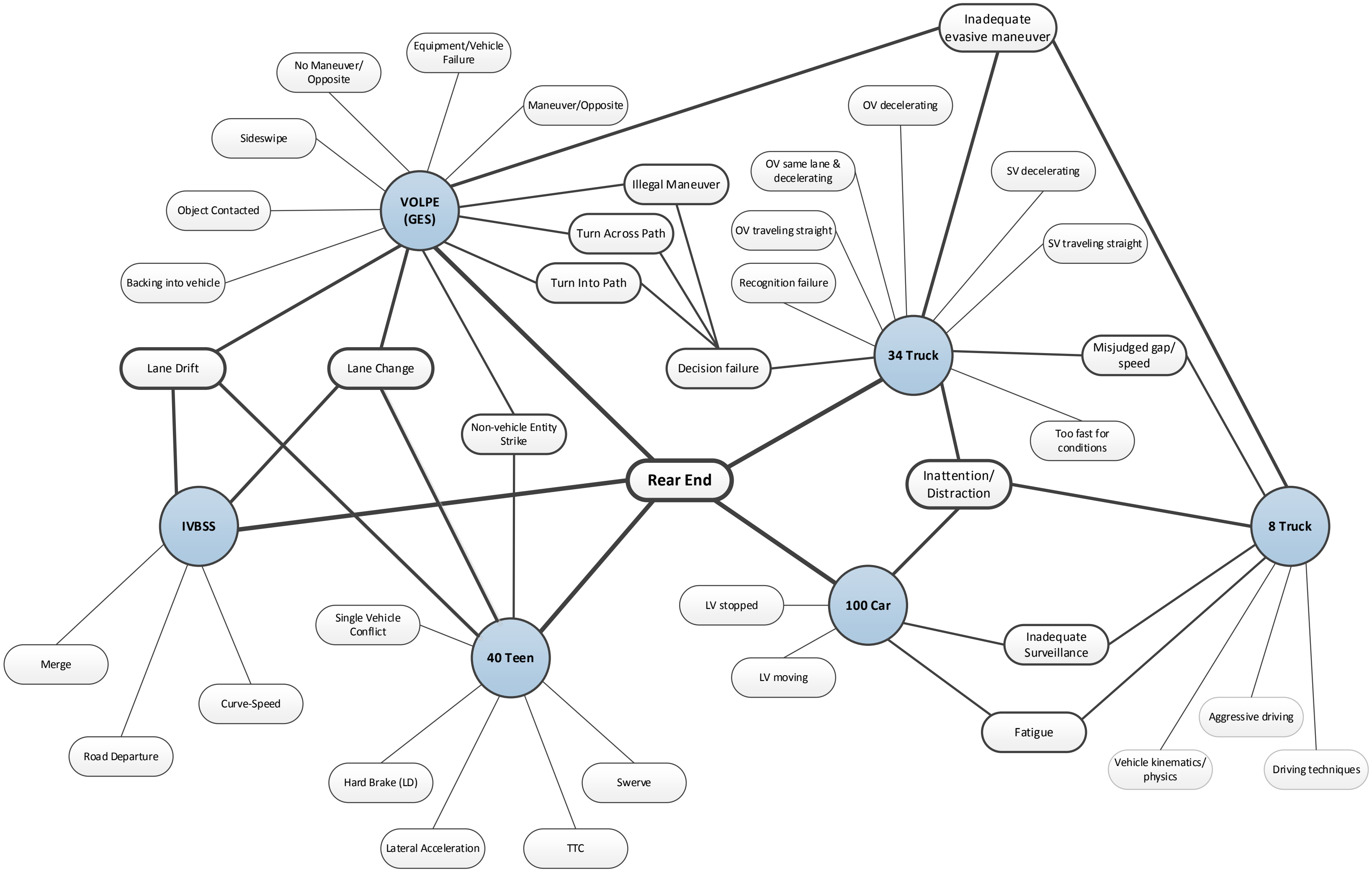

Figure 9-1. Pre-crash Scenario Mapping (Source: Author)

Note on abbreviations: lane drift (LD); time-to-collision (TTC); lead vehicle (LV); subject vehicle (SV); other vehicle (OV)

There are some inherent biases in this evaluation. For instance, the 34-Truck data set was collected from a study evaluating a drowsy driver warning system, which may be one reason fatigue was not specifically mentioned in the report. While this type of bias exists, the objective of this evaluation was to aggregate the findings of multiple data sets (five of the six data sets are derived from naturalistic studies) to indicate potential areas of focus for research. The 10 most common pre-crash indicators/scenarios found during this effort were as follows (the number of studies mentioning these indicators/scenarios are noted in parentheses):

1. Rear-end (5)
2. Lane Drift (3)
3. Lane Change (3)
4. Inattention/Distraction (3)
5. Inadequate Evasive Maneuver (3)
6. Inadequate Surveillance/Eyes off Roadway (3)
7. Fatigue (2)
8. Conflict with Non-vehicle (2)
9. Decision Failure (2)
10. Misjudge Speed or Gap (2)

Purpose of Scenarios

Scenarios serve to place concepts into specific environments to flesh out their functional characteristics in the real world. The following are four categories of scenario attributes intended to replicate the majority of situations anticipated for follow-on testing and evaluation.

Roadway environments:

- Rural interstate: I-81 Blacksburg via I-66 to Washington, D.C.
- Urban interstate: D.C. Beltway
- Rural highway (two-lane): Blue Ridge Parkway
- Urban streets: Downtown Detroit
- Residential streets: Typical neighborhood

Type of traffic:

- Congested
- Free-flowing

Maneuvers:

- Cruising (moving at set speed unimpeded by traffic)
- Vehicle following
- Lane change
- Freeway-to-freeway interchanges
- Negotiating work zones
- Normal stop and go
- Reacting to cut-ins by other traffic
- Detecting/obeying turn-only lanes
- Observing proper right-of-way for pedestrians and bicyclists
- Detecting/avoiding non-vehicle obstacles

Traffic control devices:

- Stop/yield signs
- Speed signs
- Turn restrictions
- Lane restrictions
- One-way streets
- Ramp meters
- Traffic signals

These scenarios are not meant to be inclusive. Instead, they are designed to provide guidance in combination with other factors for developing experimental designs. Other factors include the identified pre-crash scenarios and selected automation concepts for human-machine interface evaluation. Table 9-1 maps these attributes across roadway types.

Table 9-1. Roadway to Attribute Mapping

Attributes	Rural Interstate	Urban Interstate	Rural Highway	Urban Streets	Residential Streets
Cruising	✓	✓	✓	✓	✓
Vehicle following	✓	✓	✓	✓	✓
Lane change	✓	✓		✓	
Freeway-to-freeway	✓	✓			
Negotiating work zones	✓	✓	✓	✓	✓
Normal stop and go	✓	✓	✓	✓	✓
Reacting to cut-ins	✓	✓		✓	
Detecting/obeying turn-only lanes	✓	✓	✓	✓	✓
Interactions with pedestrians and bicyclists			✓	✓	✓
Detecting/avoiding non-vehicle obstacles	✓	✓	✓	✓	✓
Stop/yield signs			✓	✓	✓
Speed signs	✓	✓	✓	✓	✓
Turn restrictions			✓	✓	✓
Lane restrictions	✓	✓		✓	
One-way streets				✓	✓
Ramp meters	✓	✓			
Traffic signals			✓	✓	✓

It is important to note that the scenarios identified in this section along with the parameters identified in Chapter 10 and all other information presented herein are designed to better specify the domain of system operations with respect to L2 and L3 automated vehicles. There is a bias towards those technologies expected to arrive first in the marketplace. To the extent possible, the information provided in this document is intended to inform the reader of the operational framework for these vehicles and to provide focus for proposed follow-on research.

Chapter 10 Summary of Impacts

Implementation of the proposed L2/L3 systems may have broad impacts on all system stakeholders. The following sections identify potential operational impacts, organizational impacts, and developmental impacts that should be considered for development, testing, and evaluation of the L2/L3 systems.

Operational Impacts

The OVI system is a general description of L2/L3 systems expected to be developed and implemented in multiple ways. Each manufacturer will develop the system as they see fit. Thus, there is some uncertainty regarding the specific types of L2/L3 systems that will be initially produced. This ConOps document is meant to be general in nature so as to be applicable to all system types. Therefore, consideration of potential operational impacts could include the following:

- Methods for controlling the system
- Information presented to operator
- Human-machine interface efficacy
- Human factors issues (disadvantages and limitations of various human-machine interface approaches)
- Modes of operation per system
- System malfunction/failure transition
- Novice user barriers

This list is not meant to be exclusive. It instead offers guidance as the development and testing phases continue. It is expected as systems finish development and move to production, information about specific systems will be available for a complete review of operational impacts. The OEMs of L2/L3 systems are expected to be organizations with experience in equipment development, testing, and evaluation. While implementation of these systems may qualify as disruptive to the operator (i.e., technology sufficiently different such that there is a learning curve for the operator), it is not expected that these systems will be disruptive to OEM operations. It should be noted that issues such as manufacturing re-engineering, component redesign, and market impacts are beyond the scope of this ConOps document.

Organizational Impacts

Currently, NHTSA is responsible for implementing and enforcing the National Traffic and Motor Vehicle Safety Act of 1966, as amended, 49 U.S.C. Chapter 301 (the Vehicle Safety Act), and certain other laws relating to motor vehicle safety.[29] Under that authority, NHTSA issues and enforces Federal motor vehicle safety standards (FMVSS) that apply to motor vehicles and to certain items of motor vehicle equipment. The Vehicle Safety Act requires that motor vehicles and regulated items of motor vehicle equipment manufactured for sale in the United States be certified to comply with all applicable FMVSS. Type approval is not required for motor vehicles and motor vehicle equipment sold in the United States. NHTSA does not issue type approval certifications and does not certify any motor vehicles or motor vehicle equipment as complying with applicable FMVSS. Instead, in accordance with 49 U.S.C. 30115, a “self-certification” process is in place, which requires the manufacturer to certify the vehicle or equipment item as complying with the applicable FMVSS.[29] In general, it is possible that introduction of L2/L3 systems may require standards to ensure aftermarket systems can be integrated post-production without adverse effects to the OVI system. Consideration should be given to the nature in which such standards should exist.

Impacts during Development

The development and implementation of L2/L3 systems may require involvement from multiple stakeholders, including government, vehicle manufacturers, system developers, and other support organizations. The development process requires consideration of the integration of these various partners. Furthermore, collaboration during the early stages of development could benefit from discussion of functional standards for the L2/L3 systems to evaluate the potential impacts of a consistent experience to the operator with regards to functionality and expectation.

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