

SURFACE VEHICLE INFORMATION REPORT

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Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems

RATIONALE

This Information Report provides a taxonomy describing the full range of levels of automation in on-road *motor vehicles*. It also includes operational definitions for advanced levels of automation and related terms. This document provides a foundation for further standards development activities and a common language for discussions within the broader “Automated/Autonomous Vehicle” community.

1. SCOPE

This Information Report provides a taxonomy for motor vehicle automation ranging in level from no automation to *full automation*. However, it provides detailed definitions only for the highest three levels of automation provided in the taxonomy (namely, *conditional*, *high* and *full automation*) in the context of *motor vehicles* (hereafter also referred to as “*vehicle*” or “*vehicles*”) and their operation on public roadways. These latter levels of advanced automation refer to cases in which the *dynamic driving task* is performed entirely by an *automated driving system* during a given *driving mode* or *trip*. Popular, media, and legislative references to “autonomous” or “self-driving” vehicles encompass some or all of these levels of automation. These definitions can be used to describe the automation of (1) on-road *vehicles*, (2) particular systems within those vehicles, and (3) the operation of those vehicles. “On-road” refers to public roadways that collectively serve users of *vehicles* of all classes and automation levels (including no automation), as well as motorcyclists, pedal cyclists, and pedestrians.

This document does not provide complete definitions applicable to lower levels of automation (namely, no automation, assisted, or partial automation), but they are described as points of reference to help bound the full range of vehicle automation. Active safety and driver assistance systems that partially and/or temporarily automate certain aspects of *vehicle* operation (including systems that automatically intervene to avoid and/or mitigate an emergency situation and then immediately disengage), but otherwise rely on a *human driver* to operate the motor vehicle in real time, are also not included within the *conditional*, *high*, and *full automation* taxonomy types that are the focus of this document.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

Tom M. Gasser and Daniel Westhoff, *BAST-study: Definitions of Automation and Legal Issues in Germany*, 2012 Road Vehicle Automation Workshop, Transportation Research Board, July 25, 2012, onlinepubs.trb.org/onlinepubs/conferences/2012/Automation/presentations/Gasser.pdf at 6.

“Preliminary Statement of Policy Concerning Automated Vehicles,” National Highway Traffic Safety Administration, May 30, 2013, <http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development>

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http://www.sae.org/technical/standards/J3016_201401

Bryant Walker Smith, SAE Levels of Automaton, <http://cyberlaw.stanford.edu/LoDA> (December 18, 2013)

49 U.S.C. § 30102(a)(6) – definition of motor vehicle.

Michon, J.A., 1985. A CRITICAL VIEW OF DRIVER BEHAVIOR MODELS: WHAT DO WE KNOW, WHAT SHOULD WE DO? In L. Evans & R. C. Schwing (Eds.). Human behavior and traffic safety (pp. 485-520). New York: Plenum Press, 1985.

3. TAXONOMY OF AUTOMATED DRIVING

TABLE 1 - SUMMARY OF LEVELS OF *DRIVING* AUTOMATION FOR ON-ROAD VEHICLES

SAE's levels of *driving* automation are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. In this table, "system" refers to the driver assistance system, combination of driver assistance systems, or *automated driving system*, as appropriate. This table also shows how SAE's levels definitively correspond to those developed by the Germany Federal Highway Research Institute (BASt) and approximately correspond to those described by the National Highway Traffic Safety Administration in its May 30, 2013, paper titled "Preliminary Statement of Policy Concerning Automated Vehicles." (See section 6.3, below.)

SAE level	SAE name	SAE narrative definition	Execution of steering and acceleration/deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (driving modes)	BASt level	NHTSA level
Human driver monitors the driving environment								
0	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	Driver Assistance	the <i>driving mode</i> -specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	Partial Automation	the <i>driving mode</i> -specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes	Partially automated	2
Automated driving system ("system") monitors the driving environment								
3	Conditional Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes	Highly automated	3
4	High Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes	Fully automated	3/4
5	Full Automation	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes		

TABLE 2 - ROLES OF HUMAN DRIVER AND SYSTEM BY LEVEL OF DRIVING AUTOMATION

Table 2 describes the various levels of *driving* automation, covering the full spectrum from no automation to full automation. The descriptions provided in column 2 indicate the role (if any) of a *human driver* in the *dynamic driving task*. The descriptions provided in column 3 indicate the role (if any) of the *automated driving system* in the *dynamic driving task*. These roles describe technical capability and not legality. As in Table 1, "system" refers to the driver assistance system, combination of driver assistance systems, or *automated driving system*, as appropriate.

Level of Driving Automation	Role of <i>Human Driver</i>	Role of System
HUMAN DRIVER MONITORS DRIVING ENVIRONMENT		
Level 0 - No Automation	<ul style="list-style-type: none"> Monitors <i>driving</i> environment Executes the <i>dynamic driving task</i> (steering, accelerating, braking) 	<ul style="list-style-type: none"> No active automation (but may provide warnings)
Level 1 - Driver Assistance	<ul style="list-style-type: none"> Monitors <i>driving</i> environment Executes either longitudinal (accelerating, braking) or lateral (steering) <i>dynamic driving task</i> Constantly supervises <i>dynamic driving task</i> executed by driver assistance system Determines when activation or deactivation of driver assistance system is appropriate, except for systems that automatically intervene in an emergency Takes over immediately when required 	<ul style="list-style-type: none"> Executes portions of the <i>dynamic driving task</i> not executed by the <i>human driver</i> (either longitudinal or lateral) when activated Can deactivate immediately with request for immediate takeover by the <i>human driver</i>
Level 2 - Partial Automation	<ul style="list-style-type: none"> Monitors <i>driving</i> environment Constantly supervises <i>dynamic driving task</i> executed by partial automation system Determines when activation or deactivation of partial automation system is appropriate, except for systems that automatically intervene in an emergency Takes over immediately when required 	<ul style="list-style-type: none"> Executes longitudinal (accelerating, braking) and lateral (steering) <i>dynamic driving task</i> when activated Can deactivate immediately with request for immediate takeover by the <i>human driver</i>

AUTOMATED DRIVING SYSTEM MONITORS DRIVING ENVIRONMENT

Level 3 - Conditional Automation	<ul style="list-style-type: none"> • Determines when activation of <i>automated driving system</i> is appropriate • Takes over upon request within lead time • May request deactivation of <i>automated driving system</i> 	<ul style="list-style-type: none"> • Monitors <i>driving</i> environment when activated • Permits activation only under conditions (use cases) for which it was designed • Executes longitudinal (accelerating, braking) and lateral (steering) portions of the <i>dynamic driving task</i> when activated • Deactivates only after requesting <i>driver</i> takeover with a sufficient lead time • May, under certain, limited circumstances, transition to <i>minimal risk condition</i> if <i>human driver</i> does not take over • May momentarily delay deactivation when immediate human takeover could compromise safety
Level 4 - High Automation	<ul style="list-style-type: none"> • Determines when activation of <i>automated driving system</i> is appropriate • Takes over within lead time, if requested • May request deactivation of <i>automated driving system</i> • Some applications in this category may not entail a human driver. 	<ul style="list-style-type: none"> • Monitors <i>driving</i> environment when activated • Permits activation only under conditions (use cases) for which it was designed • Executes longitudinal (accelerating, braking) and lateral (steering) portions of the <i>dynamic driving task</i> when activated • Initiates deactivation when design conditions are no longer met • Deactivates only after <i>human driver</i> takes over • Transitions to <i>minimal risk condition</i> if <i>human driver</i> does not take over • May momentarily delay deactivation when immediate human takeover could compromise safety
Level 5 - Full Automation	<ul style="list-style-type: none"> • May activate <i>automated driving system</i> • May request deactivation of <i>automated driving system</i> • This category may not entail a human driver. 	<ul style="list-style-type: none"> • Monitors <i>driving</i> environment when activated • Executes longitudinal (accelerating, braking) and lateral (steering) portions of the <i>dynamic driving task</i> when activated • Deactivates only after <i>human driver</i> takes over or <i>vehicle</i> reaches its destination • Transitions to <i>minimal risk condition</i> as necessary if failure in the <i>automated driving system</i> occurs • May momentarily delay deactivation when immediate <i>human driver</i> takeover could compromise safety

TABLE 3 - SIMPLIFIED TO HIGHLIGHT ROLES OF *HUMAN DRIVERS* AND *AUTOMATED DRIVING SYSTEM*

Table 3 mirrors Table 2, but focuses specifically on the relative roles of a *human driver* versus the system. As in Tables 1 and 2, "system" refers to the driver assistance system, combination of driver assistance systems, or *automated driving system*, as appropriate. The characteristics presented below represent minimum, rather than maximum capabilities, for each level of automation. For example, a particular *conditional automated driving system* might be capable of transitioning to a *minimal risk condition* in many but not all situations.

Level of Driving Automation	Execution of steering / acceleration / deceleration	Monitoring of driving environment	Transition time between <i>human driver</i> and system?	<i>Minimal risk condition</i> capable at all times?	<i>Human driver</i> necessary while system is engaged?	<i>Driving modes</i> of the <i>automated driving system</i>
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HUMAN DRIVER MONITORS DRIVING ENVIRONMENT

Level 0 - No Automation	<i>Human driver</i>	<i>Human driver</i>	n/a	n/a	Yes	None
Level 1 – Driver Assistance	<i>Human driver</i> and System	<i>Human driver</i>	No	No	Yes	Some
Level 2 - Partial Automation	System	<i>Human driver</i>	No	No	Yes	Some

AUTOMATED DRIVING SYSTEM MONITORS DRIVING ENVIRONMENT

Level 3 - Conditional Automation	System	System	Yes	No	Yes	Some
Level 4 - High Automation	System	System	Yes	Yes	No	Some
Level 5 – Full Automation	System	System	Yes	Yes	No	All

4. DEFINITIONS

4.1 AUTOMATED DRIVING SYSTEM

The hardware and software that is collectively capable of performing all aspects of the *dynamic driving task* for a *vehicle* (whether part time or full time).

4.2 DRIVE

To operate a *vehicle* on a public or private roadway at any point at or between an origin and a destination, whether or not the *vehicle* is in motion.

4.3 DRIVING MODE

A type of *driving* scenario with characteristic *dynamic driving task* requirements (e.g., expressway merging, high speed cruising, low speed traffic jam, etc.).

4.4 DYNAMIC DRIVING TASK

All of the real-time functions required to operate a *vehicle* in on-road traffic, excluding the selection of destinations and waypoints (i.e., navigation or route planning) and including without limitation:

- Object and event detection, recognition, and classification;
- Object and event response;
- Maneuver planning;
- Steering, turning, lane keeping, and lane changing;
- Acceleration and deceleration;
- Enhancing conspicuity (lighting, signaling and gesturing, etc.).

4.5 HUMAN DRIVER

The person who *drives* a particular *vehicle*, and who, in a vehicle equipped with an *automated driving system*, exchanges the *dynamic driving task* with such a system as necessary during vehicle operation.

4.6 MINIMAL RISK CONDITION

A low risk *motor vehicle* operating condition to which an *automated driving system* automatically resorts upon either a system failure or a failure of a *human driver* to respond appropriately to a request to take over the *dynamic driving task*.

NOTE: A *minimal risk condition* will vary according to the type and extent of a given failure. A *minimal risk condition* could entail automatically bringing the vehicle to a stop, preferably outside of an active lane of traffic (assuming availability).

4.7 MONITOR

The activities and/or automated routines that accomplish comprehensive object and event detection, recognition, classification, and response preparation, as needed to competently perform the *dynamic driving task*.

NOTE: When driving vehicles that are not equipped with *automated driving systems*, *human drivers* visually sample the road scene sufficiently to competently perform the *dynamic driving task*, while also performing secondary tasks that require short periods of eyes-off-road time (e.g., adjusting cabin comfort settings, scanning road signs, tuning a radio, etc.). Thus, *monitoring* does not entail constant eyes-on-road time by the *human driver*.

4.8 MOTOR VEHICLE (and VEHICLE)

A vehicle driven or drawn by mechanical power and manufactured primarily for use on public streets, roads, and highways, but does not include a vehicle operated only on a rail line. [Source: 49 U.S.C. § 30102(a)(6)]

4.9 REQUEST TO INTERVENE

Notification by the *automated driving system* to a *human driver* that s/he should promptly begin or resume performance of the *dynamic driving task*.

4.10 TRIP

The traversal of an entire travel pathway by a *vehicle* from the moment it is turned “on” at a point of origin to when it is turned “off” at a waypoint or destination.

5. LEVELS OF DRIVING AUTOMATION

5.1 LEVEL 0 - NO AUTOMATION

The full-time performance by the *human driver* of all aspects of the *dynamic driving task*.

5.2 LEVEL 1 - DRIVER ASSISTANCE

The part-time or *driving mode*-dependent execution by a driver assistance system of either steering or acceleration/deceleration with the expectation that the *human driver* performs all other aspects of the *dynamic driving task*.

5.3 LEVEL 2 - PARTIAL AUTOMATION

The part-time or *driving mode*-dependent execution by one or more driver assistance systems of both steering and acceleration/deceleration with the expectation that the *human driver* performs all other aspects of the *dynamic driving task*.

5.4 LEVEL 3 - CONDITIONAL AUTOMATION

The part-time or *driving mode*-dependent performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*.

5.4.1 Notes

- *Conditional automation* requires a *human driver* to initiate an *automated driving system* at the appropriate point during a *trip* and requires a *human driver* to resume the *dynamic driving task* when s/he receives a *request to intervene* (e.g., due to a vehicle or system malfunction or a change in driving conditions that exceed the *automated driving system's driving mode*-dependent capability).
- As a technical matter, a *human driver* need not monitor the *automated driving system's* performance while it is engaged, but must be prepared to resume the *dynamic driving task* when the *automated driving system* issues a request to intervene.
- A *conditional automated driving system* will alert (i.e., by issuing a *request to intervene*) the *human driver* of the need to resume the *dynamic driving task* with sufficient time for a typical *human driver* to respond appropriately.
- An "appropriate" response by a *human driver* to a *request to intervene* may vary depending upon immediate circumstances (e.g., steering, braking, or simply maintaining current input levels), but otherwise entails the timely, safe and correct performance of the *dynamic driving task* for the prevailing circumstances.

5.4.2 Examples

EXAMPLE: A *vehicle* equipped with an *automated driving system* capable of performing the complete *dynamic driving task* in low-speed traffic, such as in stop-and-go urban or freeway traffic.

5.5 LEVEL 4 - HIGH AUTOMATION

The part-time, *driving mode*-dependent, or geographically-restricted performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* fails to respond appropriately to a *request to intervene*.

5.5.1 Notes

- *High automation* generally requires a *human driver* to engage an *automated driving system* at the appropriate point during a *trip* (e.g., a *human driver* may activate the *automated driving system* during a specific *driving mode*, such as freeway driving, for which the *high automated driving system* is designed).
 - Examples of exceptions to the general case:
 - A high automation parking application for which a human driver is not present in the vehicle during the maneuver.
 - A high automation shuttle system that is geographically restricted to operation on a closed or semi-closed campus (e.g., residential community, military base, etc.)
- As a technical matter, a *human driver* need not monitor the *automated driving system*'s performance while it is engaged, but should in the general case be prepared to assume performance of the *dynamic driving task* when the *automated driving system* issues a *request to intervene*.
- A *high automated driving system* will alert a *human driver* several seconds in advance of the need to resume the *dynamic driving task* (i.e., by issuing a *request to intervene*); however, the *automated driving system* is capable of restoring the vehicle to a *minimal risk condition* automatically if a *human driver* fails to resume the *dynamic driving task* when prompted. This capability to automatically restore the vehicle to a *minimal risk condition* is the only difference between *high automation* and *conditional automation*, above.

5.5.2 Examples

- EXAMPLE 1: A vehicle equipped with an *automated driving system* capable of performing the complete *dynamic driving task* during a valet parking operation (i.e., curb-to-door or vice versa) without any human agency or monitoring. (Note: The presence of a *human driver* in the vehicle during the parking maneuver is not required as a technical matter.)
- EXAMPLE 2: A vehicle equipped with an *automated driving system* capable of performing the complete *dynamic driving task* during sustained operation on a motorway or freeway. (Note: The presence of a *human driver* in the vehicle is required, as a technical matter, in order to perform the *dynamic driving task* before entering, and after leaving, the motor way or freeway.)
- EXAMPLE 3: A vehicle equipped with an *automated driving system* capable of performing the complete *dynamic driving task* while following a pre-defined route within a confined geographical area, such as a campus shuttle. (Note: The presence of a *human driver* in the vehicle is not required, as a technical matter, while completing the prescribed delivery route.)

5.6 FULL AUTOMATION (LEVEL 5)

The unconditional, full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under, at minimum, all roadway and environmental conditions that can be managed by a *human driver*, including the ability to automatically bring the motor vehicle into a *minimal risk condition* in the event of a critical vehicle or system failure, or other emergency event.

5.6.1 Notes

- As a technical matter, a *human driver* need not monitor the *automated driving system*'s performance.
- When the *automated driving system* reaches the limits of its functional capabilities, it will restore the *vehicle to a minimal risk condition* automatically.

5.6.2 Examples

EXAMPLE: A *vehicle* with an *automated driving system* that, once programmed with a destination, is capable of fully performing the *dynamic driving task* throughout complete *trips* on public roadways, regardless of the starting and end points or intervening road, traffic, and weather conditions.

6. OTHER TERMS USED FOR HIGH OR FULL AUTOMATION

6.1 The following are common, but often confusing, vernacular terms for *high* or *full automation* of the *dynamic driving task*:

- Autonomous
- Self-driving
- Driverless
- Unmanned
- Robotic
- Autonomated

7. ADDITIONAL DISCUSSION

7.1 No automation, driver assistance, and partial automation

The three lower levels of *driving* automation are defined for the sake of taxonomical completeness. These levels of automation may feature certain driver assistance systems, including certain automatic emergency intervention systems, that operate with the expectation that the *human driver* monitors the driving environment. (In contrast, the *automated driving systems* that are characteristic of the three upper levels of *driving* automation operate with the expectation that the *human driver* need not, and therefore will not, continuously monitor the driving environment.)

7.2 Conditional, high and full automation

Conditional and *high automation* are the same, except that the former may or may not include limited automated capability to bring the vehicle to a *minimal risk condition*, while the latter always includes *minimal risk condition* capability. Both *conditional* and *high automation* entail that the *automated driving system* performs the *dynamic driving task* normally performed by a *human driver*, but only when enabled by one, and only for a limited period of time and/or in a specified geographical location, *driving mode*, or during specific, finite maneuvers. By contrast, *full automation* is capable of complete performance of the *dynamic driving task* throughout complete trips, and – at minimum – under all roadway and environmental conditions that can be managed by a human driver.

- During *conditional automated driving*, a *human driver* is present in the vehicle and is in a position to take over the *dynamic driving task* within a reasonable period of time after being prompted by the *automated driving system* with a *request to intervene*, or when the *human driver* otherwise chooses to resume the *dynamic driving task*.
- During *high automated driving*, the presence of a *human driver* in a position to assume the *dynamic driving task* is not always necessary as a technical matter, depending upon the application in question.
- During *full automated driving*, there is no need for a *human driver* to be present and in a position to assume the *dynamic driving task*, because the *automated driving system* is capable of performing all aspects of the *dynamic driving task*, including restoring the motor vehicle to a *minimal risk condition* in the event of a critical vehicle or system malfunction, or other emergency event, such as a weather condition requiring evacuation or other evasive action.