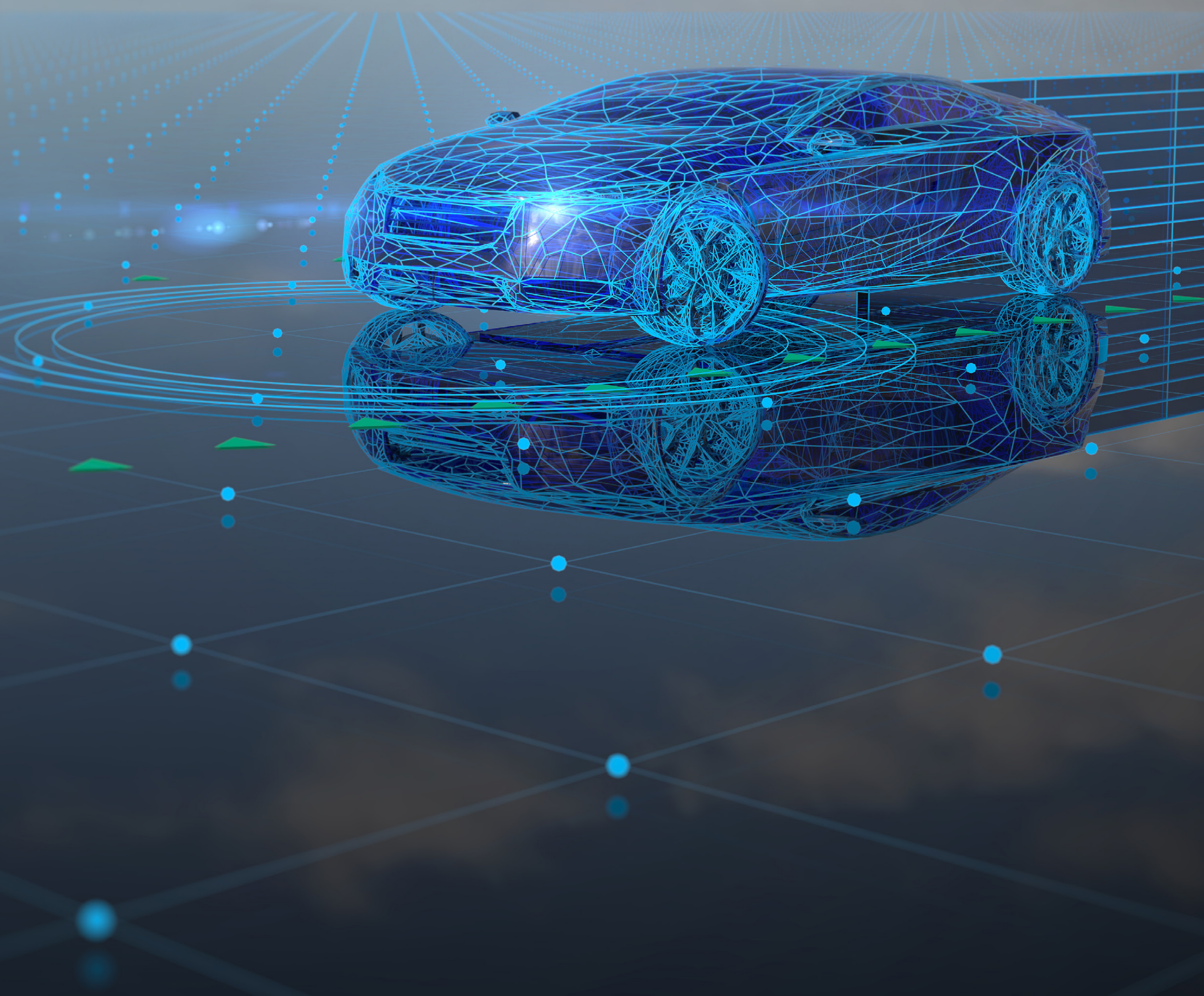
In collaboration with the
Boston Consulting Group

Centre for the Fourth Industrial Revolution

Advancing a Safe Vehicle Autonomy Future

BRIEFING PAPER

MAY 2024



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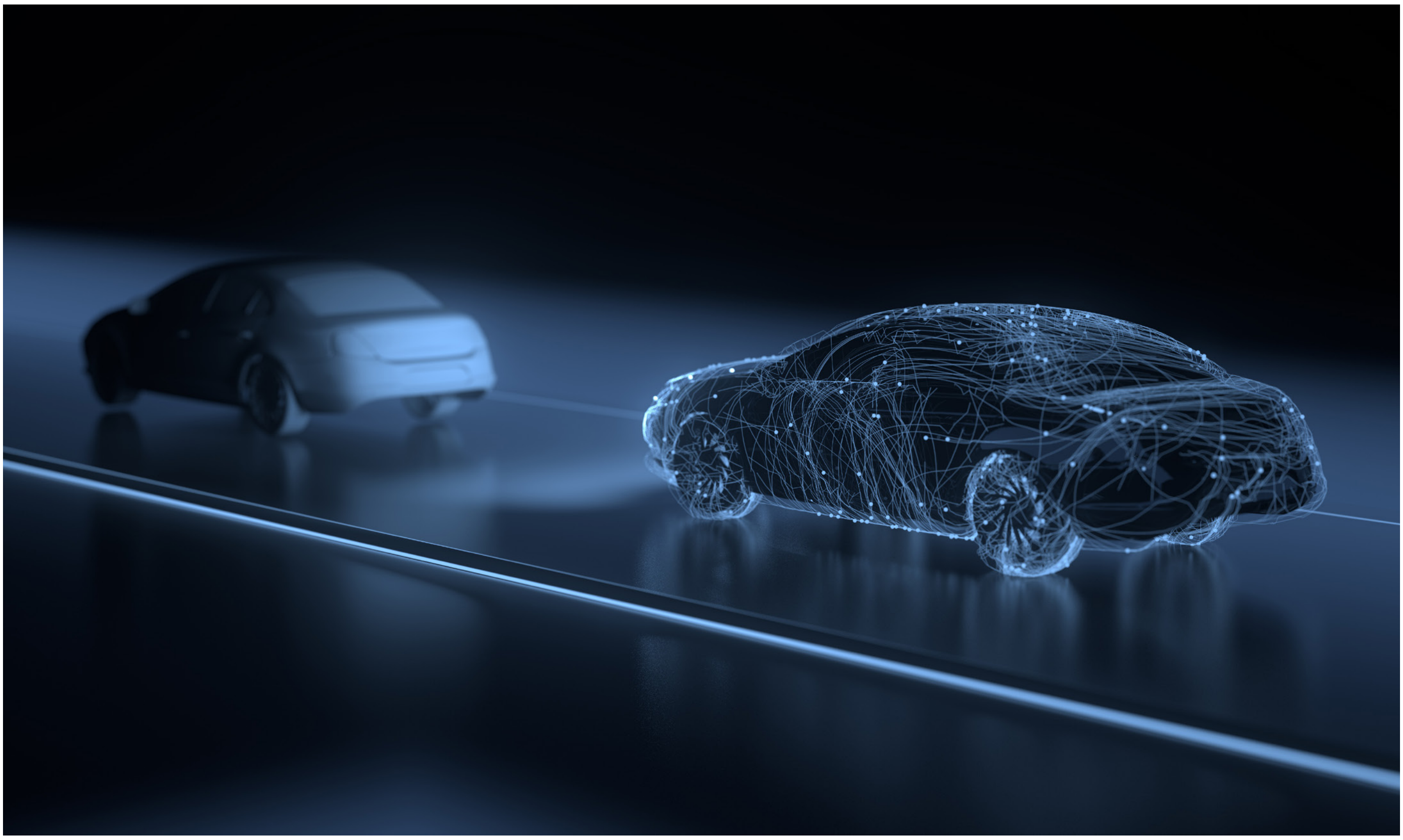
DRIVE-A vehicle autonomy initiative

The automotive industry faces its most significant transformation in over a century. Three key trends are happening simultaneously, all of them enabled by the move towards the software-defined vehicle: vehicle autonomy, electrification and the development of a user-centred smart digital experience.

The first of these trends, vehicle autonomy, has the potential to bring considerable safety benefits to the roads. Currently, 94% of vehicle accidents are due to human error, a large share of which could be prevented by reliable vehicle autonomation features.[1] The business value is also clear: the market value for advanced driver assistance systems (ADAS) and automated/autonomous driving (AD) is estimated to be worth $230 billion by 2030 and $400 billion by 2035.[2]

To ensure the safe and responsible development and deployment of automated and autonomous vehicles, the World Economic Forum launched the DRIVE-A (Delivering Responsible Implementation of Vehicle Autonomy) initiative. Its three key objectives are to: advance the vehicle autonomy transformation, shape the path towards responsible deployments, and inform on-the-ground sandboxes and regulations.



The challenge

Full autonomy is the ultimate destination, yet assisted driving and partial autonomy are at the forefront of the industry's current offerings (see Box 1 for more information on the different vehicle autonomy levels).

Partial autonomy levels can already positively contribute to road safety and a more comfortable driving experience. However, the mix of tasks and responsibilities between the driver and vehicle needs to be correctly addressed to achieve the desired safety increases.

This is especially important for Levels 2+/2++ and 3, where collaboration between drivers and vehicles is paramount. How can the tasks and responsibilities between drivers and the vehicles be ensured? How can the use of assisted and automated technologies be facilitated while also preventing over-reliance on them?

This briefing paper contributes to ensuring and advancing safety in assisted and automated driving. It identifies six key barriers to the safe scaling of assisted and automated driving (with a focus on L2+/ L2++ and L3 features) and outlines a series of actions to tackle them. The key focus on L2+/2++/3 mirrors the current technology level of most leading manufacturers, and, hence, targets the levels where vehicle autonomy can have the most impact in the short term.

BOX 1 | **Levels of vehicle autonomy**

As per the SAE vehicle autonomy standard,[3] vehicle autonomy is categorized into six levels: Levels 0 to 5. The higher the level, the more tasks that the vehicle takes over from the driver. Figure 1 provides an overview of what these levels mean for the different driving tasks and the liability in case of error or accident.

Three important notes need to be highlighted regarding these levels:

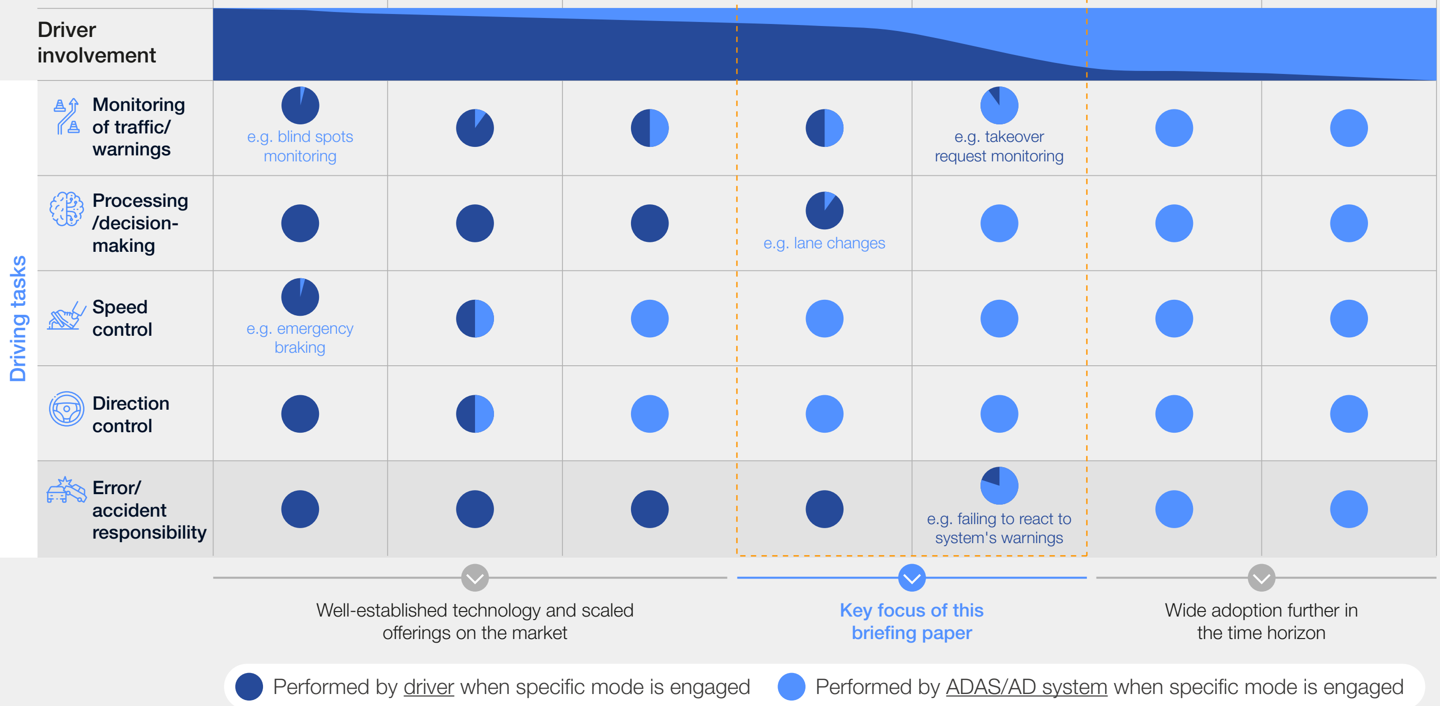
1. As long as the vehicle is not autonomous (L4 or L5), there is a split of tasks between the system (i.e. the vehicle) and the driver. To ensure safety, it is important to ensure clarity in the sub-tasks that the driver is responsible for and those the vehicle will take on when a specific level is engaged.

2. Liability for L3 and above lies with the vehicle manufacturer. Liability for levels below L3 lies with the driver. Thus, reaching L3 is an important step for an OEM. To differentiate autonomy capabilities beyond those of L2, while being cognisant that technology is not yet L3 ready (where the liability shift takes place), sublevels L2+ and L2++ have emerged.

3. The mentioned levels are not "vehicle levels", as one vehicle can be operating in different levels depending on the operating design domain (ODD) as well as the decision of the driver to engage (or not) the assisted or automated driving functions. The mentioned levels are time-bound in a specific situation. With any change of levels, there is a change in the driver-vehicle tasks and responsibilities. Changes in the level that is active at a specific moment need to be clear to avoid safety challenges.

FIGURE 1 | **Vehicle autonomy levels**

	Assisted driving (ADAS)				Automated/autonomous driving (AD)		
Mode	**L0**	**L1**	**L2**	**L2+/++**	**L3**	**L4**	**L5**
Description	**Manual** The driver fully controls the vehicle, but receives assistance from alert and protection systems	**Assisted driving** Auxiliary driving system can control either steering wheel or speed Other driving tasks are done by the driver	**Partially automated driving** System can control both steering wheel and speed Other driving tasks are done by the driver	**Partially automated driving** L2 capability plus additional features, e.g. hands-off driving, automated lane changing, traffic lights detection, or end-to-end automated driving	**Automated driving under conditions** The system performs all driving tasks if the necessary conditions apply Drivers step in when/if requested by the system	**Autonomous driving under conditions** The system performs all driving tasks if the necessary conditions apply Drivers don't have to respond	**Autonomous driving in all conditions** The system performs all driving tasks in all roads and conditions Drivers don't have to respond (and vehicle may not even have a steering wheel)



Note: L2+/++ are not officially standardized by SAE J3016, unlike other levels of automation

Source: Figure developed during the project, based on the SAE Levels of Driving Automation

Barriers to safe scaling

The World Economic Forum, in collaboration with the Boston Consulting Group and with inputs from the Forum's Automotive in the Software-Driven Era executive community, has identified six key barriers to unlocking the safe scaling of assisted and automated driving, in particular L2+/++ and L3. Figure 2 shows an overview of these six barriers.

Barriers were identified following a threefold methodology: literature review, online study-specific survey in China, Germany and the US, and focus groups in Germany and the US among individuals who test-drove a vehicle with L2+ functionalities.

The six barriers identified can be split into two groups:

Drivers' knowledge/drivers' perception barriers

These are barriers A (user knowledge), B (value perception) and C (willingness to use) of Figure 2. Barrier A highlights the importance of accurate information in social media and advertising, as these means are frequently used information sources for ADAS/AD knowledge.

Accurate knowledge can, in turn, influence value perception and willingness to use (barriers B and C). For example, data suggests that individuals are currently less inclined to use and buy vehicles with higher levels of autonomy, while they very much value having "better use of time while driving" (value added, which is only relevant if the vehicle is engaged in L3 or above).

Drivers' behaviour

These barriers relate to the usage of vehicle autonomy. These are barriers D (driver alertness), E (required oversight) and F (control takeover). It is key to ensure that the driver is sufficiently alert to engage in (additional) driving functions when necessary, and that, overall, the workload for the driver is similar or lower to that of driving manually. Similar workload levels could still be considered acceptable given the gained safety benefits. Further, there needs to be clarity regarding the engaged ADAS/AD level and a simple takeover process.

All six barriers need to be addressed to ensure safe and scaled adoption of L2+/++/L3 vehicle autonomy. The following section provides collaborative actions to do so.

FIGURE 2 | **Key barriers for safe scaling of Level 2+/3 autonomy**

A User knowledge

Need to ensure sufficient ADAS/AD skills and knowledge

1-5%
Of users have an accurate understanding of L2+/L3 systems capabilities, risks and liabilities[1]

ADAS/AD key information sources include social media and advertisements (top 4)[2]:

	USA	Germany	China	
Vehicle dealership	46%	42%	49%	
Vehicle manufacturer	41%	49%	45%	#1 in Germany
Social media	39%	31%	60%	#1 in China
Vehicle advertisement	48%	41%	41%	#1 in USA

B Value perception

Need to effectively communicate benefits and risks

Consumers value additional comfort, safety and better use of time, while over 50% of consumers are worried about system reliability[2]

- **55%** Better driving comfort
- **52%** Improved road safety
- **42%** Better use of time during driving
- **41%** Better fuel/energy efficiency
- **30%** Reduced road congestion

- **58%** System errors leading to accidents
- **56%** Decisions in complex situations
- **50%** Misuse by drivers
- **47%** Unclear liability in case of an accident
- **35%** Cybersecurity risks

C Willingness to use

Need to ensure trust in higher automation levels

The more automation the system provides, the less trust/willingness to use expressed by users[2]

How likely is it that you would consider having each of these functions available in your next vehicle?[2]

	Definitely not (%)				Definitely yes (%)
L2	3	5	9	46	37
L2+	4	7	15	40	33
L3	13	12	18	31	26

D Driver alertness

Need to keep drivers engaged and alert

Studies suggest that, in combination with DMS, L2+ does not lead to significantly decreased attention[3]

However long-term risks are yet insufficiently studied and potential misuse could be more common in real application vs testing[3]

75%
of users prefer engaging L2+ features on the highway.[2] Even a small attention decrease could potentially lead to increased safety risks

“Even with standard cruise control I get easily distracted, I think with hands off it becomes even more obvious.[4]

E Required oversight

Need to reduce the workload of monitoring the system

Overall driver workload with L2+ is not lower than with manual driving

DRT reaction time[5]: Manual / L2+

46% of users feel they had to pay more attention when the system engaged vs manual driving. Top 3 reasons for that:[2]

- **31%** Felt like I had to be consistently monitoring what the system was doing
- **29%** Don't trust the system fully to keep me safe while engaged
- **27%** Don't like not being in full control while driving

F Control takeover

Need to clarify which level is engaged and ease takeover

Human drivers require 10-14 sec to fully takeover control.[6] These are the 2 key challenges of the takeover process:

1 Mode awareness | 2 Takeover time

System → Driver	System engaged	Transition: Reaction	Transition: Readiness	Manual driving: Intervention	Manual driving: Stabilization
L2+	Driver is monitoring the traffic, no active driving engagement	Cognitive reaction delay	Put hands on steering wheel, prepare to take over control	React on traffic situation	Continued manual driving
L3	Driver is engaged in non-driving related tasks (NDRT), e.g., reading, playing, watching videos	Cognitive reaction delay	Stop NDRT, prepare to take over control	React on traffic situation	Continued manual driving

“Visual difference between L2 and L2+ needs to be more transparent.[4]

Sources: 1. Estimated based on combination of studies: L3Pilot User acceptance survey (2021), https://l3pilot.eu/index.html; AAA Foundation for traffic safety, Expectations and understanding of advanced driver assistance systems among drivers, regional surveys UK, US and EU pedestrians, bicyclists, and public transit riders (2021), https://aaafoundation.org/expectations-and-understanding-of-advanced-driver-assistance-systems-among-drivers-pedestrians-bicyclists-and-public-transit-riders/. **2.** Boston Consulting Group, Consumer survey around ADAS/AD conducted among 1929 respondents in China, USA and Germany (2023). **3.** VDA, Level 2 hands-off Recommenda-tions and guidance (2023), https://www.vda.de/de/aktuelles/publikationen/publication/level-2-hands-o---recommendations-and-guidance. **4.** Boston Consulting Group, User interviews, test drives and focus group study conducted in Germany and USA (2023). **5.** Based on inputs from a combination of studies: AAA Foundation for Traffic Safety, Driver's Arousal and Workload under Partial Vehicle Automation (2020), https://aaafoundation.org/drivers-arousal-and-workload-under-partial-vehicle-automation/; University of Leeds, Driver Attentiveness to the Driving Task During ADAS Use (2023) https://eprints.whiterose.ac.uk/201448/1/ADAS%20user%20attentiveness%20report%20final.pdf; DRT (Detection response task)–standard research tool developed to measure cognitive workload of drivers (driver need to response to a minor distraction–the higher the workload, the longer the reaction time). **6.** Visteon, Takeover at Level 3 Automated Driving (2019) ,https://www.visteon.com/wp-content/uploads/2019/01/takeover-at-level-3-automated-driving.pdf

From knowledge to action

The journey towards vehicle autonomy has proven to be harder and more costly than expected. Collaboration is necessary to help advance this journey in a safe and cost-efficient manner. While there are aspects of assisted, automated and autonomous driving that are highly competitive, there are still important non-differentiating elements where the industry can collaborate. The following outlines five key actions to address the previous barriers collaboratively, and, with that, help advance the safe scaling of L2+/++ and 3.

1. Agree on a unified nomenclature and definitions

While various levels of autonomy (see Figure 1) are widely recognized and agreed upon by the industry, these are not necessarily straightforward to the average driver. There are a lot of variables to take into account. A way to ease understanding is to use simplified definitions that reinforce the liability and takeover components: "assisted driving", "automated driving" and "autonomous driving".

Assisted driving: The driver is responsible. The system can temporarily take over certain driving tasks, but the driver is still liable and must always be ready to take back any required driving task (L0-2+/++ on Figure 1).

Automated driving: When engaged, the system/ vehicle is responsible. In certain conditions, the system can be fully responsible for the driving. While this is the case, the driver can engage in other activities, but not in any activity, as the driver may be asked to regain control of the vehicle (L3 in Figure 1).

Autonomous driving: In the functioning designed operating environment, the vehicle is fully responsible for the driving. There does not even need to be a driver behind the steering wheel, and there may not even be a steering wheel (L4 and L5 in Figure 1).

One note should be highlighted at all times: even if a vehicle has automated or autonomous driving capabilities, what matters is the level it is operating under (not the highest level it can operate in).

The industry needs to have unified definitions to avoid misleading terms or communications that may induce drivers to believe the vehicle's capabilities are more advanced than they are in reality – which can lead to erroneous overreliance on the system.

2. Establish a holistic user learning journey across the industry

The safety benefits of assisted and automated technologies can only be leveraged if users have sufficient knowledge of their real capabilities and shortcomings. Sufficient knowledge ensures drivers turn on these functionalities when available (currently ~8% of drivers do not use specific ADAS/ AD functions even if they know they are available in their vehicle[4]), and avoid overreliance.

To maximize learning, the industry can support a holistic user learning journey. Figure 3 outlines a simplified user journey and the key learning aspects in each step of the way.

FIGURE 2 **User learning journey**

	Learning to drive	Learning about technology	Getting to know specific vehicle	Driving
High-level user journey aspects				
Key learning aspects	Risks, liability and system capabilities Types of functions Definitions	Accuracy of marketing communications ADAS/AD offerings	HMI specifics Warnings logic (lights, icons, etc.) Personal settings (e.g., distance to the car in front)	Function engagement process Required driver involvement Control takeover process System thinking and limitations/ errors

Collaboration will be key to ensuring consistent messaging along the user journey. For example:

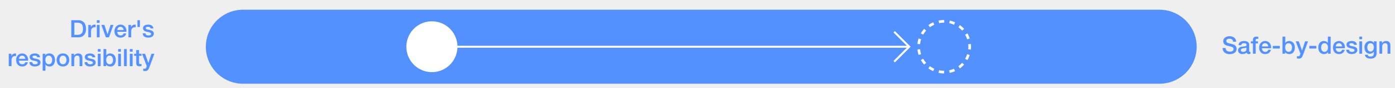
- *Getting (or renewing) the driving licence:* Assisted and automated driving basic knowledge needs to be embedded in the compulsory driving license curriculum. Policy makers can help enable this change and ensure a unified approach. Key learning aspects include the different levels of vehicle autonomy, their capabilities and limitations.

- *Getting to know the vehicle*: User design and customization are competitive aspects, but certain basic functionalities are non-competitive and shared across vehicle manufacturers. For example, industry players can collaborate on how salespeople explain the functions of assisted and automated driving functionalities and their shortcomings, and how these should be advertised.

3. Shift the responsibility from the driver to the system

As ADAS/AD technology develops, it is crucial to ensure that the system operates "safe-by-design" and that it accounts for possible drivers' mistakes. The automotive industry is not new to accounting for possible driver mistakes (e.g. beeping sound when the seat belt remains unfastened), but they become more important as vehicle capabilities increase. Figure 4 illustrates this logic on some of the key safety tasks.

FIGURE 3 **Move towards "safe-by-design"**



	Current state	Target state
Responsibility shift examples	Driver can lose attention during a long drive with ADAS/AD engaged	System ensures the driver is ready to take over via smart DMS and notification logic
	Drivers can be overwhelmed with different types of notifications when takeover is required	Key notifications are designed for immediate comprehension by the driver
	Some non-driving related tasks can lead to increased takeover time	The available takeover time is sufficient to ensure safe takeover in all conditions
	Not always clear for the driver which ADAS/AD mode is engaged	Simple and unified mode indications making drivers always aware about the engaged ADAS/AD mode

4. Define a shared approach for human-machine interaction

Many aspects of existing vehicle-driver interaction elements are already standardized (e.g. dashboard warning lights for adaptive cruise control, lane keep assist, etc.). The emergence of L2+/L2++ and L3 functionalities leads to additional basic standardization requirements to avoid driver confusion and maximize safety when faced with a critical situation. This is especially so given the strong division of tasks between both driver and vehicle for these vehicle autonomy levels.

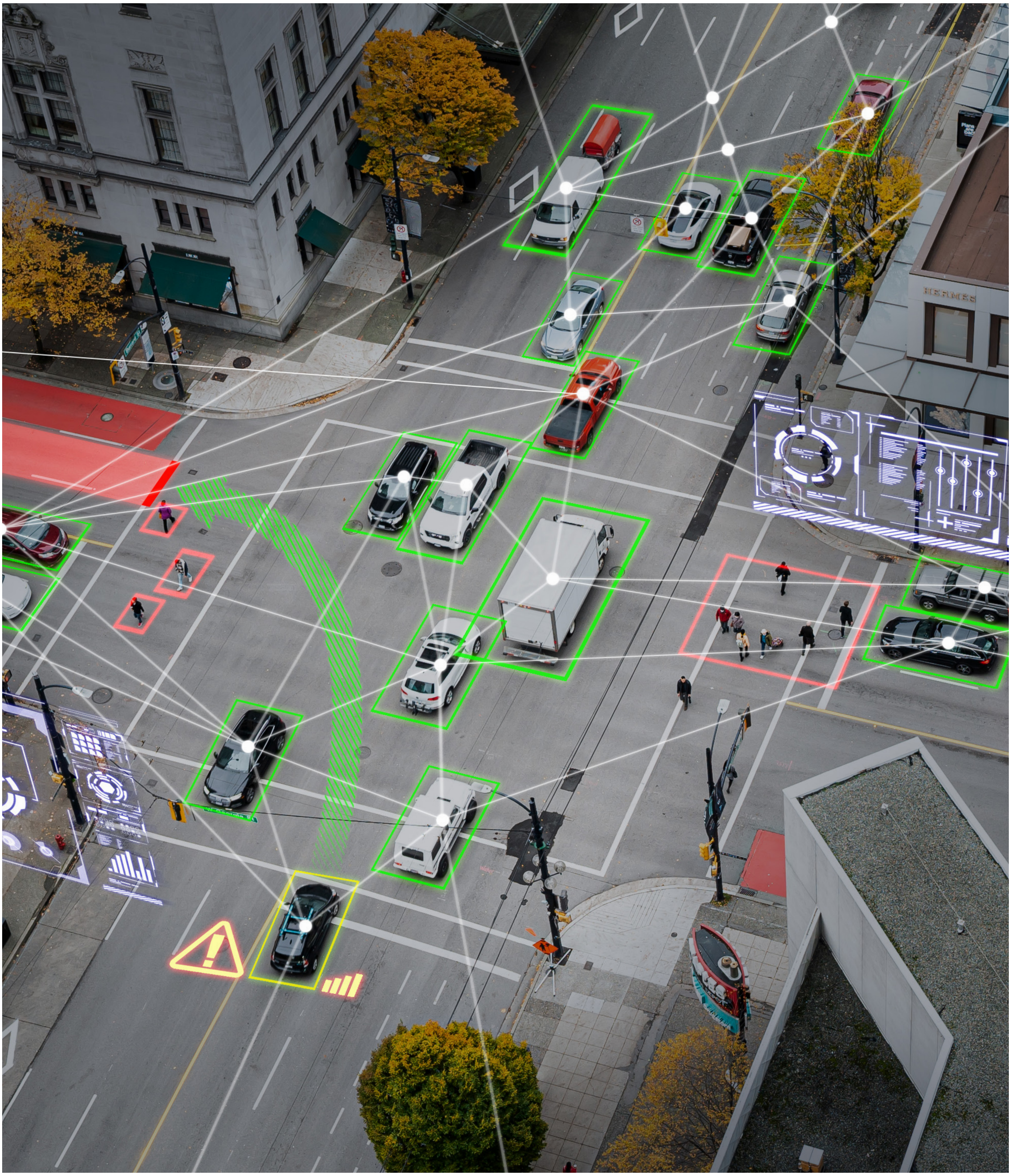
The need for a seamless human-machine interaction is twofold. First, the driver should have clarity about the system engagement mode and their expected contribution to the driving tasks. The human-machine interface (HMI) plays an important role here. Second, the vehicle should understand the attentiveness and engagement state of the driver, which the vehicle learns via the driver monitoring system (DMS).

One particular case where the industry needs to collaborate to ensure safety is in its effort to avoid mode confusion, especially when changing between autonomy levels. For example, when the vehicle is operating in L3 mode and asks the driver to regain control, which level does the vehicle go back to? An aligned industry approach for user notification and the systems that should remain engaged after the control takeover can avoid confusion and, as a result, avoid unnecessary safety risks.

5. Ensure a minimum level of software development and testing unification

Industry collaboration on the advancement of system accuracy in different ODDs (operating design domains) is crucial to avoid system glitches, which would deteriorate users' trust and decrease safety.

Industry players can ensure a minimum level of system unification in non-competing areas, following suggestions made in industry consortia such as ECLIPSE SDV or The Autonomous. Some of these areas include the standardization of testing use cases and the joint development of common software non-differentiating elements. Such collaborations can lead to reductions in the cost of software development and testing, and enable increased safety and a faster rollout across the industry.



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Endnotes

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