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A Taxonomic Odyssey: Evolution, Criticisms, and Future Directions of Driving Automation Taxonomies – The Case of SAE J3016

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ABSTRACT

While the Society of Automotive Engineers (SAE) International's classification system (J3016) has provided a framework for categorising sustained driving automation systems, concerns have arisen about its clarity and ability to incorporate emerging technologies . Therefore, this study explores how various stakeholders, including end users, vehicle manufacturers, and policymakers, use the driving automation taxonomy. The results show that driving automation taxonomy is communicated through media, incorporated into vehicle purchasing decisions for users, and utilised for external and internal communication by vehicle manufacturers and policymakers. The discussion highlights that utilising specialised terminology in automation enhances communication efficiency. However, there is also a discrepancy between the SAE J3016, which is today's prevalent taxonomy, and their audience in terms of both (1) clarity provided by the taxonomy vs. understanding of the stakeholders and (2) topics addressed by the taxonomy vs. needs of the stakeholders. The study also highlights that, while SAE J3016 is being criticised, proposing a clearly better taxonomy is far from straightforward. However, we underscore the importance of revising and updating the current taxonomy to align with stakeholder needs and technological advancements. By enhancing the clarity and relevance of the driving automation taxonomy, stakeholders can make more informed decisions, fostering innovation and improving communication across the industry.

1. Introduction

Automated vehicle technology is rapidly developing, promising increased safety and comfort to drivers. As the deployment of vehicles with automated driving systems becomes increasingly prevalent, systematic approaches for communication are needed. One critical tool in this pursuit is a taxonomy, which classifies and organises a hierarchical framework of various design elements and features (Enghoff, 2009). A taxonomy enhances decision-making and collaboration across domains. Therefore, a well-defined taxonomy serves as an effective communication tool, enabling stakeholders to discuss and understand system designs.

One of the taxonomies for automated vehicles is the SAE J3016 (SAEInternational, 2021) proposed by the Society of Automotive Engineers (SAE) International. It has provided helpful guidance for achieving a broad conceptual consensus on new vehicle technologies that enable sustained driving automation across six levels, ranging from Level 0 (no automation) to Level 5 (full automation). However, it has been criticised for its lack of clarity from specific stakeholder perspectives. Seppelt et al. (2019) pointed out that the standard offers important but complex explanations of the six levels of automation. Its engineering-centric nature can complicate interpretation by the general consumer (Hopkins & Schwanen, 2021). Additionally, consumers tend to attribute greater responsibility for automation solely based on technological nomenclature (Abraham et al., 2017). Using terms such as 'auto' or 'automatic' instead of 'assist' or 'assistant' in system names has been shown to make drivers feel less responsible for driving their cars safely (Harms et al., 2021). Furthermore, perceptions of automated system functionality are further exaggerated by media reports and individuals' tendencies to embrace new technology (Lee et al., 2018), leading to claims that SAE levels exacerbate consumer role ambiguity. This may result from a discrepancy between the targeted audience and the actual audience of SAE J3016. The taxonomy originally targets experts in their field and aims to provide a common language and basis for expert discussion. It does not aim at and is not written for a general audience. However, the topic is not only discussed among experts but also in the media and society. The actual audience of SAE J3016 is therefore not limited to technical experts alone. Yet its language does not account for audiences beyond technical experts in the field.

While the SAE levels are useful for generally categorising the degree

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of human or automation involvement in the vehicle guidance subtask of the driving task (Donges, 2016), the ambiguity in the middle ground of the SAE scale (SAE Levels 1–4) makes it difficult to determine the position of partial automation. Essentially, only the extremes of this continuum (SAE Level 0 and Level 5) provide clarity to consumers (Seppelt et al., 2019). However, among experts, the difference between SAE Level 4 and Level 5 may be a topic of discussion, too, given that "unconditional/not ODD-specific" is also defined in the definition of Level 5 (SAE J3016, p. 32) and not equal to anywhere (on earth). The most critical issue is the substantial ambiguity that can arise regarding the current state of commercially available technology (between SAE Levels 1 and 3), which can confuse (Souders et al., 2022). With the increasing availability of various automation systems, there is a need to further differentiate the positioning of Advanced Driver Assistance System (ADAS) features within the defined SAE levels. For example, according to the current SAE levels, both Adaptive Cruise Control (ACC) and Lane Keeping Assistance (LKA) are considered Level 1. From the users' perspective, however, they behave very differently. While ACC adjusts speed while maintaining a gap with the lead vehicle, LKA assists the driver in keeping the vehicle centred within the lane. However, when both Level 1 systems, ACC and LKA, are switched on simultaneously, the car can be considered to be operating at Level 2, providing both lateral and longitudinal support. The transition from SAE Level 2 to 3, in particular, involves transferring most dynamic driving tasks from the driver to the driving automation system. These ambiguous areas pose a risk that marketing materials may exaggerate the capabilities of driver assistance systems (Levels 1 and 2) to attract consumers. For example, before the first Level-3 System-Equipped car entered the European market, 92 % of European consumers believed they could already buy a self-driving car from a wide variety of car brands (Harms et al., 2021). Consumers' perceptions of their level of responsibility are influenced by marketing decisions such as technical names (Abraham et al., 2017), potentially leading to excessive trust and misuse of the system (Dixon, 2020). This may be even increased by recent discussions and advances in vehicle regulations toward Level 2 systems that can be operated without putting hands on the steering wheel (hands-off) and which may even perform system-initiated lane changes (in vehicle regulations, these systems are referred to as hands-off Driver Control Assistance Systems (DCAS) (UNECE, 2023)). From a user's perspective, these systems may be even more difficult to differentiate from a Level 3 system.

Taxonomies have also been signalled to perpetuate misconceptions about driving autonomy. Stayton and Stilgoe (2020) highlighted a weakness in the SAE J3016, suggesting that it implies automation increases linearly, directly replacing human tasks, and that more automation is inherently better. This results in ambiguity, particularly within the middle range levels, complicating the determination of the benefits of partial automation and potentially leading to misconceptions among taxonomy users. There is a general consensus that the taxonomy inadequately addresses the collaboration between humans and machines, further complicating the understanding and application of driving automation systems. Similarly, Steckhan et al. (2022) argued that the limited consideration of user intervention within the six levels of SAE J3016 implies an "all or nothing" approach to human control, reinforcing misconceptions about complete human replacement in autonomous driving as the ultimate goal (Hopkins & Schwanen, 2021). While the SAE taxonomy (SAEInternational, 2021) recognises constraints in framework usage and explicitly states that the levels are 'nominal rather than ordinal,' the SAE levels continue to be referred to in an ordinal manner. Furthermore, the SAE taxonomy inadequately addresses the potential for collaboration between humans and machines, such as interaction concepts in automated vehicles (e.g., haptic shared control). It also lacks discussion of the environments, infrastructure, and usage contexts that need to be considered in the deployment of automation (Stayton & Stilgoe, 2020; Steckhan et al., 2022).

In summary, while the SAE levels have facilitated a broad conceptual consensus on new vehicle automation technologies, growing concerns are being raised about the current classification system. One concern is that the SAE levels adopt a vehicle-centric, function-oriented perspective that does not sufficiently account for emerging technologies or the diverse perspectives of different stakeholders. Accordingly, this study aims to provide a comprehensive synthesis of the recent evolution of driving automation taxonomies and associated critiques, and to analyse how various stakeholders understand and use these taxonomies, deriving design considerations and critical factors for future driving automation taxonomies. This endeavour is important because taxonomies do more than technically classify systems. For example, taxonomy shapes users' perceptions of responsibility and role, influences trust and misuse, guides regulation and policy, and mediates communication between industry and the wider public. By investigating how current driving automation taxonomies are applied in practice and how stakeholders interpret and rely on them, we identify issues and reflect on how the classification system can be developed to integrate multiple stakeholder perspectives.

2. Taxonomies now and then

Existing taxonomies often fall short in incorporating user perspectives and in meeting regulatory requirements set by governments and regulatory bodies (Yang et al., 2017). This vehicle-centric approach can lead to confusion among researchers, industry experts, and policymakers, thereby misrepresenting the capabilities of automated vehicles (Seppelt et al., 2018; Smith, 2018). For example, Parker et al. (2023) showed that inconsistent descriptions of how automation functions may prevent even researchers from correctly understanding the actual level of automation, thereby making studies more challenging to interpret and replicate.

In response to the limitations of the current SAE levels, several supplementary ideas or alternatives have been proposed. For example, the AmericanAutomobileAssociation (2019) recommended including common names for advanced safety systems on window stickers, owner's manuals, and other supplementary materials to help consumers better understand what technology is present in vehicles. Several alternative taxonomies for driving automation have been suggested. Industry experts have proposed categorising vehicle autonomy into geotonomous (fully automated but restricted to specific geographic areas) and human-assisted systems (requiring human supervision) (Roy, 2018). Taking a consumer perspective, Euro NCAP uses a threefold categorisation, rephrasing 'Levels of Automation' as 'Driving Modes', and distinguishing between assisted driving, automated driving and autonomous driving (Schram, 2019). Seppelt et al. (2019) investigated to suggest alternative terminology for the SAE levels. The results showed that the current terminology "No driving automation" and "Full driving automation" is acceptable, and "assistive driving" leads to better understanding than "driver assistance." However, no optimal terminology was identified for SAE Levels 2, 3, and 4 of driving automation.

In addition, attempts have been made to review a taxonomy comprising 10 levels of human-automation interaction (Sheridan, 1992) for adaptation into a driving automation classification system. This taxonomy has been proposed to encompass various collaborative modes, such as shared control, that the SAE levels cannot accommodate (Steckhan et al., 2022). Additionally, it aims to address the limitations of SAE Level 3 in incorporating actual driver authority and involvement (Inagaki & Sheridan, 2019) and propose a classification system that can accommodate the ADAS (Souders et al., 2022). However, Richardson et al. (2025) showed that the taxonomy also has limitations that can cause confusion during interpretation and application and pose challenges to accessing subsequent research and analysis through systematic literature review.

The Federal Highway Research Institute in Germany (BASt) (BASt, 2021) and results stemming from the MEDIATOR project (Grondelle et al., 2021) proposed a driving automation taxonomy based on a user-centric approach. Following Euro NCAP's Driving Mode categorisation

(Schram, 2019), BASt (2021) published a user-centred communication concept for automated driving that refers to assisted, automated, and autonomous driving modes to enhance understanding and delineate user roles. Assisted driving mode is one in which the driver retains full responsibility, but the system assists with driving. Automated driving mode, on the other hand, assigns full responsibility to the vehicle, granting it complete control, but upon the system's request, drivers must resume their role. Autonomous driving mode is a driving state in which the vehicle controls all functions without driver intervention. To reduce mode confusion, the MEDIATOR project (Grondelle et al., 2021) simplified SAE Levels 1–4 into Manual Driving (SAE Level 0), Assisted Driving (SAE Levels 1 and 2), and Demonstration Driving (SAE Levels 3 and 4).

3. Method

This study combines an expert workshop with supplementary desk research to explore how current driving automation taxonomies address, or fail to address, different stakeholder perspectives. The workshop provides the primary empirical basis for our stakeholder-centric findings, whereas desk research illustrates how taxonomy terminology and classifications are communicated in current practice.

3.1. Expert workshop

To gain insights into how driving automation classification systems are being used in the context and identify the necessary factors for designing such systems, we have organised a workshop (Kim et al., 2023) targeting various stakeholders, including end-users, vehicle manufacturers/technical experts, and policymakers. The workshop was designed to facilitate discussions on the use and understanding of classification in the field, as well as its implications. The workshop also further guided the placement of the key needs of taxonomy into the argument. We wanted to give participants a voice to express their needs and concerns by involving them in the design of the taxonomy for driving automation. The workshop consisted of seven experts, including academics (Universities and research institutes), policymakers (the Vehicle Authority and a Think Tank research and technology organisation), and researchers at vehicle manufacturers (Original Equipment Manufacturers (OEMs) and Tier-1 suppliers). The participants were residing in Germany, the Netherlands, Austria, and the United Kingdom. The host coordinated the workshop by guiding participants through the prepared materials, enabling them to express the stakeholders' perspectives. The workshop was part of the 2023 AutoUI conference, held in person on-site, and all participants volunteered to join and agreed to the collection of data.

The workshop began with a briefing on the participants and an overview of the use of a taxonomy. The main tasks were divided into two sessions. In the first session, participants were focused on identifying the needs and purpose of a taxonomy. Participants were divided into groups representing the different stakeholders: end-users, technology professionals, and policymakers. Participants then discussed each stakeholder's use case scenarios using taxonomies. The results from the different scenarios were documented on a Miro whiteboard. In the second session, participants identified the key factors that differentiate each level of automation in the scenarios they identified in the first session. The discussion was held in groups. Then, all participants discussed the need for a taxonomy. The workshop lasted three hours, with a short break in the middle.

During the workshop, participants generated their own data on digital whiteboards, and group and discussion sessions were documented. Because of the interactive nature of workshops and group work, quantification of the entire code and theme is practically impossible. Instead, we followed best practices in qualitative content analysis and presented the synthesised results. All notes and post-its from the Miro board were exported, and one author independently coded the material using an inductive approach. The authors then jointly discussed and merged codes into themes. These themes were then abstracted into cross-stakeholder critical factors for taxonomy design.

3.2. Supplementary desk research

In addition to the expert workshop, we conducted supplementary desk research to contextualise and illustrate the stakeholder perspectives that emerged from the workshop. This work comprises an analysis of existing driving automation taxonomies and related critical literature, an examination of media that use these taxonomies, and a review of owners' manuals. The aim was not to provide a comprehensive or representative survey, but to offer concrete examples of how automation levels and system capabilities are currently described in practice. Similar combinations of stakeholder engagement and document analysis have been used in prior work on vehicle automation and SAE levels (e.g., (Hopkins & Schwanen, 2021)), and content analyses of automated vehicles-related manuals (e.g.,(Oviedo-Trespalacios et al., 2021)) and media content (e.g., (Dixon, 2020)) have been an established approach to understanding how automation is communicated to users. First, we revisited widely cited driving automation taxonomies (e.g., SAE J3016 and related schemes), focusing on how these taxonomies define categories, position the human driver, and target different audiences. We used these insights to interpret and refine the themes derived from the workshop. Next, for selected systems typically classified as SAE Level 2, we qualitatively examined publicly available media materials and owners' manuals. In doing so, we investigated the contexts in which taxonomy labels were mentioned, how system capabilities and limitations were described, and how driver responsibilities and automation were communicated more broadly. These observations are reported in the Results as illustrative evidence that supports or challenges specific themes from the workshop and are intended as supporting material rather than a separate empirical study.

4. Stakeholder perspectives

4.1. Results on driver perspective

Various media outlets expose driving automation terminology to users. Users may gain access to information about different levels of automated vehicles through news articles detailing potential risks associated with accidents and automation. As shown in Fig. 1, media use SAE J3016 to describe new technologies or steps, which leads the driver to encounter the driving automation taxonomy. In addition, on platforms like X (formerly Twitter), they might encounter expectations set by car manufacturers for the development of highly automated vehicles, such as SAE Level 3, potentially slated for the upcoming year.

When purchasing a vehicle, drivers can use taxonomy to explore potential options and convey their preferences. For example, drivers can express their interest in the vehicle with Level 2 automation and use taxonomy to describe the desired function package, including the Advanced Driver Assistance Systems (ADAS) features such as adaptive cruise control and lane-keeping support. Alternatively, the sales representative provides information about different models, emphasising the driving automation features and their corresponding taxonomy levels. They can utilise these terms to make cars more attractive by highlighting technology level, safety and convenience, particularly those that offer a certain level of automation.

4.2. Results on vehicle manufacturer perspective

For Vehicle Manufacturers, driving automation taxonomy serves both internal and external communication purposes. In external communication, taxonomy is a means of conveying information about technology development to users. One example is through online websites as shown in Fig. 2. For instance, they highlight SAE Level 2 systems,

FORBES > LIFESTYLE > CARS & BIKES

Mercedes-Benz First To Gain U.S. Approval For Level 3 Automated Driving System

Kyle Edward Contributor

I cover the auto industry, from breaking news to car reviews.

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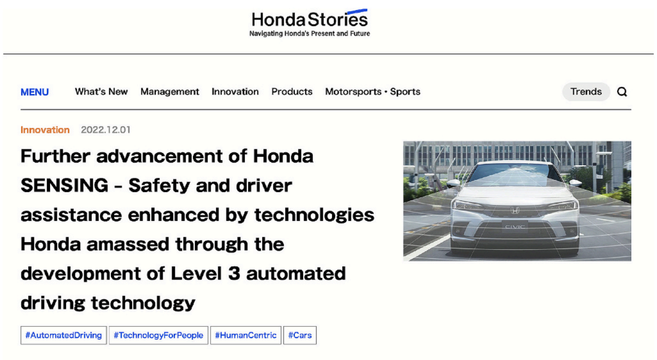
BYD has obtained conditional testing license for level 3 autonomous driving on high-speed roads

Reuters

December 27, 2023 7:19 AM GMT+1 · Updated a month ago

Aa

Fig. 1. An example of taxonomy has been used to introduce the new car era in the media.



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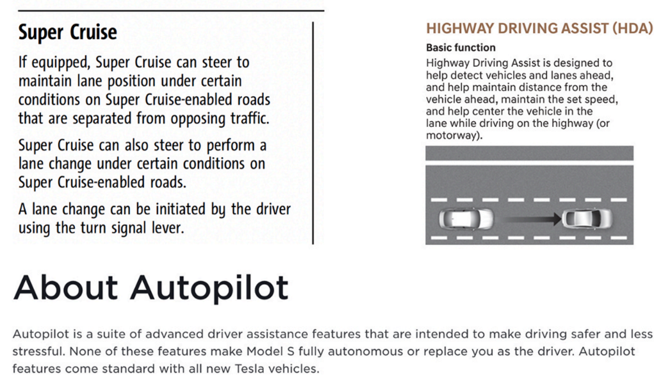
Innovation 2022.12.01

Further advancement of Honda SENSING - Safety and driver assistance enhanced by technologies Honda amassed through the development of Level 3 automated driving technology

#AutomatedDriving #TechnologyForPeople #HumanCentric #Cars

Fig. 2. An article describing the technology of the new vehicle (Screenshot taken from Honda website, 2024).



Super Cruise

If equipped, Super Cruise can steer to maintain lane position under certain conditions on Super Cruise-enabled roads that are separated from opposing traffic.

Super Cruise can also steer to perform a lane change under certain conditions on Super Cruise-enabled roads.

A lane change can be initiated by the driver using the turn signal lever.

HIGHWAY DRIVING ASSIST (HDA)

Basic function

Highway Driving Assist is designed to help detect vehicles and lanes ahead, and help maintain distance from the vehicle ahead, maintain the set speed, and help center the vehicle in the lane while driving on the highway (or motorway).

About Autopilot

Autopilot is a suite of advanced driver assistance features that are intended to make driving safer and less stressful. None of these features make Model S fully autonomous or replace you as the driver. Autopilot features come standard with all new Tesla vehicles.

Fig. 3. Examples of owner manuals: Manual of GMC Sierra (Super Cruise), Genesis G70 (Highway driving assist), and Tesla Model S (Autopilot).

such as adaptive cruise control and lane-keeping assist, clearly conveying the car's automation capabilities to potential buyers. Additionally, they can use the driving automation taxonomy to underscore advancements in driving automation technology. Another set of examples involves press releases and marketing campaigns. When launching new models or introducing updates to existing ones, car manufacturers incorporate driving automation taxonomy into their press releases and marketing campaigns. They communicate advancements in automation technology, emphasising the specific levels of autonomy achieved by their vehicles. This not only raises public awareness but also showcases the manufacturer's commitment to innovation and safety.

However, vehicle manufacturers do not integrate driving automation taxonomy into their owner manuals. One possible reason is that the manual is essentially a legal document, so it may not aim to address every detail or technical aspect of the vehicle. Instead, the owner's manual lists specific names for each manufacturer's driving automation system. This has been the case for owner manuals of various SAE Level 2 systems, all of which are currently available on the market. For this, the following Level 2 systems' owner manuals were investigated: Autopilot (Tesla), Bluecruise (Ford), Traffic Jam Assist (Audi, Acura), Super Cruise (Cadillac), Driving Assistant Plus (BMW), and ProPilot Assist (Nissan). See Fig. 3 for examples. All these systems are considered Level 2 systems, which provide continuous automated control of speed, following distance, and steering. Still, drivers are expected to pay continuous attention and maintain vehicle control should the need arise.

In addition, taxonomy can be used internally to establish new car development goals. For example, during internal product development meetings, engineers, designers, and other team members use a driving automation taxonomy to communicate specific goals for new car models. The taxonomy provides a common language for discussing the desired car image and rough technology expectations. However, during development, they define the features to include in the car and communicate them based on those specific features.

4.3. Results on Policymaker perspective

Policymakers are fostering public understanding and regulatory development concerning automated vehicles. As part of awareness and education campaigns, policymakers utilise a taxonomy of driving automation to communicate effectively with the public. They use the taxonomy to explain different automation levels, their capabilities, and potential implications for road users. Moreover, policymakers are developing regulatory frameworks governing automated vehicles. In this process, the driving automation taxonomy serves as a communication tool for articulating the different levels of automation. It is noteworthy that policymakers often transition from the broader taxonomy to more specific features and requirements when crafting regulatory guidelines. This shift allows policymakers to address nuanced technical and operational considerations within the regulatory framework, ensuring clarity and effectiveness in governing the deployment and operation of automated vehicles.

5. Discussion

5.1. Limitations of current SAE-based classification systems

From differences in the taxonomies used by the three stakeholders, we have identified critical limitations in the current use of classification systems. The first is the ambiguity in interpretation. The problem with using SAE levels is the potential for ambiguity and misunderstanding. While the taxonomy provides a standardised framework for classifying automation levels, variations in interpretation and implementation by various stakeholders can lead to confusion. For instance, Level 2 driving automation, which includes assisted driving functions such as adaptive cruise control and lane-keeping assistance, can cause users to overestimate the system's capabilities and potentially engage in risky behaviour. The second is differences in implementation. Manufacturers may implement automation features differently, even within the same SAE levels. For example, two sustained driving automation systems classified as Level 3 driving automation may have varying degrees of autonomous functions and safety measures. This difference can confuse users about the vehicle's capabilities and limitations, potentially leading to misuse or accidents. This is also apparent in the recent rise of hands-off assisted-driving systems, referred to as Level 2 + systems by some manufacturers (e.g., Fig. 4). Although these assistance systems are still Level 2 systems, the plus implies a higher level of automation, closer to that of Level 3. The third is inconsistency in terminology. Policymakers or vehicle manufacturers often use specific names for driving automation systems rather than SAE levels in practice. Such inconsistency in terminology can inflate the perceived capabilities of functionalities. For example, Schram (2019) showed that four out of ten commercial vehicles included the term "pilot" in SAE Level 2 functionalities, which may erroneously suggest that the system can drive without driver input. Moreover, inconsistent terminology for functionalities across automotive brands makes it challenging to determine whether functionalities are genuinely equivalent. Taken together, these issues reflect a structural tension in SAE J3016: the levels are formally defined as nominal categories, yet they are widely used and interpreted as if they form an ordinal scale, with "higher" levels being more advanced or desirable. This suggests that future taxonomies should either avoid numbered labels that invite ordinal readings or make the nominal nature of their categories much more explicit in both wording and visual representation.

5.2. Towards multidimensional and stakeholder-centred taxonomies

Various taxonomies are being proposed to overcome SAE J3016′s shortcomings. However, at its core, there is a need to critically examine the role and relevance of classification systems. While these systems offer numerous benefits in organising and understanding complex technological landscapes, they also have the potential to foster misconceptions about the capabilities and limitations of driving automation systems. In technology-driven sectors like vehicle manufacturing, the case for a taxonomy to delineate the stages of technological progress is compelling. Nevertheless, existing research has highlighted significant shortcomings in the current taxonomy, noting its nonlinearity and its failure to closely align with the actual stages of technological development (Stayton & Stilgoe, 2020; Steckhan et al., 2022). Our findings indicate that one promising direction is to move away from a single, linear 0–5 scale and towards a more explicitly multidimensional taxonomy that separates at least (i) system capabilities and operational design domain and (ii) human roles and responsibilities, rather than collapsing these aspects into one level. An interesting observation from the workshop was the pragmatic approach of policymakers and vehicle manufacturers, who opt for functional terminology rather than taxonomy to foster clear communication. This emphasis on clarity and precision underscores the limitations of current taxonomies, which fail to accurately reflect the operational capabilities and limitations of automated systems. Furthermore, while drivers understandably value clarity about the capabilities of automated systems, it has been recognised that extensive knowledge of classification systems may not be essential for end-users to operate vehicles, but may still be needed to make an informed choice about using technology and the responsibilities that this entails. As such, a focus on clear, intuitive communication about the functionalities and limitations of automated features is paramount to ensuring user understanding and acceptance.

Another key concern is the varying interpretations of SAE J3016 among stakeholders, leading to inconsistent understanding and implementation. These discrepancies arise because stakeholders, including manufacturers, policymakers, and end users, often have different perspectives and varying levels of technical expertise. As a result, what one group may understand as a specific level of automation might be perceived differently by another group, leading to confusion and misaligned expectations. For example, a manufacturer might design a vehicle feature based on a specific interpretation of an automation level, while policymakers might base regulations on another interpretation, and consumers might expect something entirely different. This fragmentation can hinder the effective deployment of automated driving systems, as consistent, clear communication is crucial to ensuring safety, reliability, and public trust. Therefore, addressing these varying interpretations is essential for creating a unified framework that all stakeholders can rely on for accurate information and guidance. Additionally, it is important to consider knowledge inequities among users and the potential need for different taxonomies tailored to various user groups. Different stakeholders may require distinct levels of detail and clarity to understand and effectively use the taxonomies. For instance, while technical experts may need comprehensive and detailed taxonomies, general consumers might benefit more from simplified versions that highlight key functionalities and limitations. A classification system used to name, define, and categorise biological organisms can serve as an example of a taxonomy that caters to both experts and the public. By organising organisms into domains, kingdoms, phyla, classes, orders, families, genera, and species, the level of detail about a particular organism increases. For instance, for the general public, defining all small cats at the 'genus' level as 'Felis' may suffice, whereas a specialist might require deeper information at the 'species' level to distinguish Felis catus, Felis silvestris, and Felis margarita. Still, they use the same taxonomy, meeting the needs of different stakeholders while avoiding confusion. Analogously, a future automated driving taxonomy could combine an expert-facing layer with more detailed, multidimensional categories and a public-facing layer that clusters these into a small number of clearly distinguishable driving modes (e.g., manual driving, assisted driving, supervised automation, unsupervised automation), thereby addressing different information needs without introducing additional confusion.

5.3. Technological, Policy, and practice implications of taxonomies

Despite the inherent limitations of the aforementioned taxonomy, its positive effects on facilitating communication cannot be denied. What was clear is that taxonomies are not merely simple tools for categorising objects but are instrumental in shaping the technological future. While many stakeholders may be confused or see taxonomy as merely a classification tool, it provides guidelines for technology development. For example, taxonomies influence how new features are integrated into automated driving systems and guide regulatory standards. Our findings

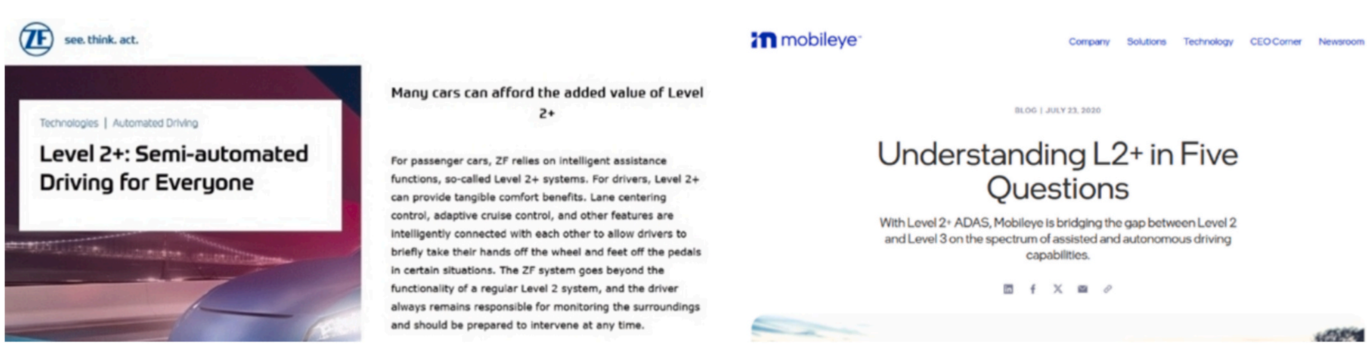


Fig. 4. Example of manufacturers promoting their assisted driving systems as L2+ (screenshots left taken from ZF, 2024, right taken from Mobileye, 2024).

suggest that taxonomies represent a perspective on how technology should evolve and function, making them crucial for guiding development. Therefore, understanding how the structure of the standard shapes technology use is essential to achieving the promised increases in safety and comfort for society and individuals. By critically evaluating the role of classification systems and emphasising clear communication in technology-driven sectors, stakeholders can more effectively navigate the complexities of automation. Moving forward, it is imperative to address the limitations of existing taxonomies and develop frameworks that accurately reflect the capabilities and limitations of automated systems. This approach will help ensure that taxonomies support users effectively, fostering a deeper understanding and more reliable implementation of driving automation technologies.

The policy implications of our research emphasise the need for a critical examination and potential reform of current taxonomies in driving automation. Policymakers should be cautious about adopting and endorsing existing taxonomies, such as the technical-oriented SAE J3016, that may perpetuate misconceptions and ambiguities. Until these issues are resolved, its use should be focused on policy directives to prevent the propagation of misunderstandings about automated systems' capabilities. Additionally, both policymakers and researchers should adopt a critical stance toward existing taxonomies, continually evaluating their effectiveness in accurately reflecting technological capabilities and user needs. Future taxonomies should be developed with a strong emphasis on user-centric design, ensuring technical accuracy and public comprehensibility. This includes reconsidering the use of numbered levels, providing multidimensional descriptors for system capability, operational design domain, and human responsibility, and choosing visual and verbal representations that do not encourage misleading ordinal interpretations (e.g., instead of numbering, manual driving, assisted driving, supervised automation, unsupervised automation). All stakeholders should aim for consistent, clear terminology in automated-driving feature descriptions to bridge the gap between technical descriptions and public understanding. Moreover, existing taxonomies should incorporate elements of human–machine collaboration to emphasise effective cooperation between drivers and automated systems. Finally, taxonomies should be dynamic, with mechanisms for regular updates based on new research findings, technological advancements, and user feedback, ensuring they remain relevant and useful. Addressing these limitations and developing more accurate, user-friendly frameworks will help navigate the complexities of automation, leading to safer and more effective deployment of these technologies. From an ethical perspective, it is crucial to acknowledge that taxonomies, as standards, hold significant power to shape technological adoption and public perception. Misleading or poorly designed taxonomies can lead to misuse, overreliance on automation, and potentially hazardous situations. Therefore, the ethical responsibility of developing and implementing these standards cannot be overstated. By addressing these limitations and developing more accurate, user-friendly frameworks, we can ensure that taxonomies support users effectively, fostering a deeper understanding and more reliable implementation of driving automation technologies.

5.4. Limitations and future studies

This study has several limitations. First, the primary empirical material comes from a single expert workshop with seven highly engaged stakeholders based in Europe. The nature of this study and the expertise of the participants mean that this does not undermine the rigour or quality of the insights. However, the sample is small and geographically constrained, so the findings may not generalise to other regions, regulatory contexts, market conditions, or user groups whose needs and understandings may differ. Second, the work is qualitative and therefore inherently interpretive. Although the analysis of the workshop data followed established qualitative content analysis practices, the themes derived from this process cannot be regarded as statistically representative or as precise indicators of how widely particular views are shared. Third, the supplementary desk research was intended to be illustrative rather than exhaustive. We focused on widely cited taxonomies (notably SAE J3016), selected media materials, and a limited number of owners' manuals for systems typically classified as SAE Level 2. This focus allowed for depth but may bias the account toward SAE-centric and Level-2-centric examples and underrepresent alternative classification schemes or communication practices. Lastly, given the rapid evolution of automated driving technologies and regulations, some examples may quickly become outdated. Future research should therefore combine broader empirical studies with a more diverse and global corpus of taxonomies, regulatory texts, and communication materials.

6. Conclusion

This study aims to examine how current vehicle automation taxonomies are used in practice, identify their shortcomings, and discuss considerations for improving classification systems to support better and more reflective perspectives from diverse stakeholders, including end users, vehicle manufacturers/technical experts, and policymakers. Our findings indicate that driving automation taxonomies are embedded in vehicle purchase decisions and serve as communication tools for both manufacturers and policymakers. However, we also identified critical limitations, including ambiguity, inconsistency, and terminology issues, that contribute to user misconceptions about automation. The main insights of this study can be summarised as follows:

- Current SAE-based taxonomies create confusion due to ambiguous interpretation, divergent implementations across manufacturers, and inconsistent terminology, including labels such as "pilot" and "L2+".
- The linear 0–5 SAE scale is insufficient because it conflates system capabilities and operational design domains with human roles and responsibilities within a single level.
- Because stakeholder needs differ, experts require detailed, multidimensional categories, whereas general users benefit more from a small set of clearly defined driving modes.
- Taxonomies are not merely labels for systems; they actively shape technology and policy by influencing system design, regulation, and public expectations.
- Reforming existing taxonomies is both a policy and ethical imperative, requiring user-centred, updateable frameworks that make human–machine collaboration explicit and support clear, consistent communication.

This study highlights the misalignment between current taxonomies and stakeholder needs and demonstrates the necessity of developing more precise, user-centred taxonomies. At the same time, however, we must acknowledge the gap between such proposals and actual practice. Although current taxonomies (mainly SAE J3016) are actively being critiqued and directions for possible solutions have been proposed, in reality it will be challenging to develop a perfect taxonomy due to the inherent limitations of taxonomic systems themselves. Nevertheless, continually articulating and recognising existing problems, and engaging in ongoing dialogue to address these limitations, can enhance the understanding and use of driving automation systems and, ultimately, contribute to the safer and more efficient deployment of automated vehicles.

CRediT authorship contribution statement

Soyeon Kim: Writing – original draft, Methodology, Formal analysis, Conceptualization, Writing – review & editing. **Fjollë Novakazi:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Elisabeth Shi:** Writing – review & editing, Conceptualization. **Ilse M. Harms:** Writing – review & editing. **Oscar Oviedo-**

Trespalacios: Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Soyeon Kim reports article publishing charges was provided by Delft University of Technology. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.].

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Data availability

The authors are unable or have chosen not to specify which data has been used.

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