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Integrating Artificial Intelligence into Automotive Functional Safety: Transitioning from Quality Management to ASIL-D for Safer Future Mobility

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Abstract

The advancement of vehicle automation and electrification requires a new generation of functional-safety strategies that extend beyond conventional quality-management (QM) approaches. This paper presents a comprehensive study on the transition from QM to Automotive Safety Integrity Level D (ASIL-D) within the ISO 26262 framework and examines how artificial intelligence (AI) technologies enhance safety, reliability, and fault tolerance in modern vehicles. Using secondary data analysis combined with thematic evaluation of ADAS, lighting, and battery management systems, the research investigates practical applications across Advanced Driver Assistance Systems (ADAS), lighting control, and battery-management systems. The findings reveal that AI improves fault-detection accuracy, predictive diagnostics, and adaptive risk mitigation, supporting more reliable safety-critical operations. However, challenges such as algorithm explainability, validation under uncertainty, and long-term assurance remain barriers to certification. The study concludes by proposing a hybrid validation model that combines deterministic FuSa principles with AI-driven verification, enabling data-centric compliance for next-generation mobility. These insights contribute to safer, smarter, and more sustainable automotive engineering practices

Keywords: *Automotive Functional Safety; ISO 26262; ASIL-D; Artificial Intelligence; ADAS; Battery Management System; Predictive Diagnostics; Future Mobility.*

1. Introduction:

1.1 Background:

The advancement of automotive functional safety (FuSa) is central and significant to the transformation of mobility (Xu *et al.,* 2024). FuSa also affects the growing reliance on Advanced Driver Assistance Systems (ADAS) and autonomous industry technologies (Ayyasamy, 2022). Functional safety provides vehicle safety even in the presence of faults, mitigating risks that could lead to accidents or any technical issues. In this context, transitioning traditional Quality Management (QM) processes into the Automotive Safety Integrity Level D (ASIL-D) frameworks represents a critical step in safeguarding high-stakes automotive systems. ADAS spans from the 20th century to the present time with its roots in technological variables like cruise control (1950s), anti-lock brakes (1970s) and evolving crucially in the 1980s-1990s with computer vision (Caradas, 2022).

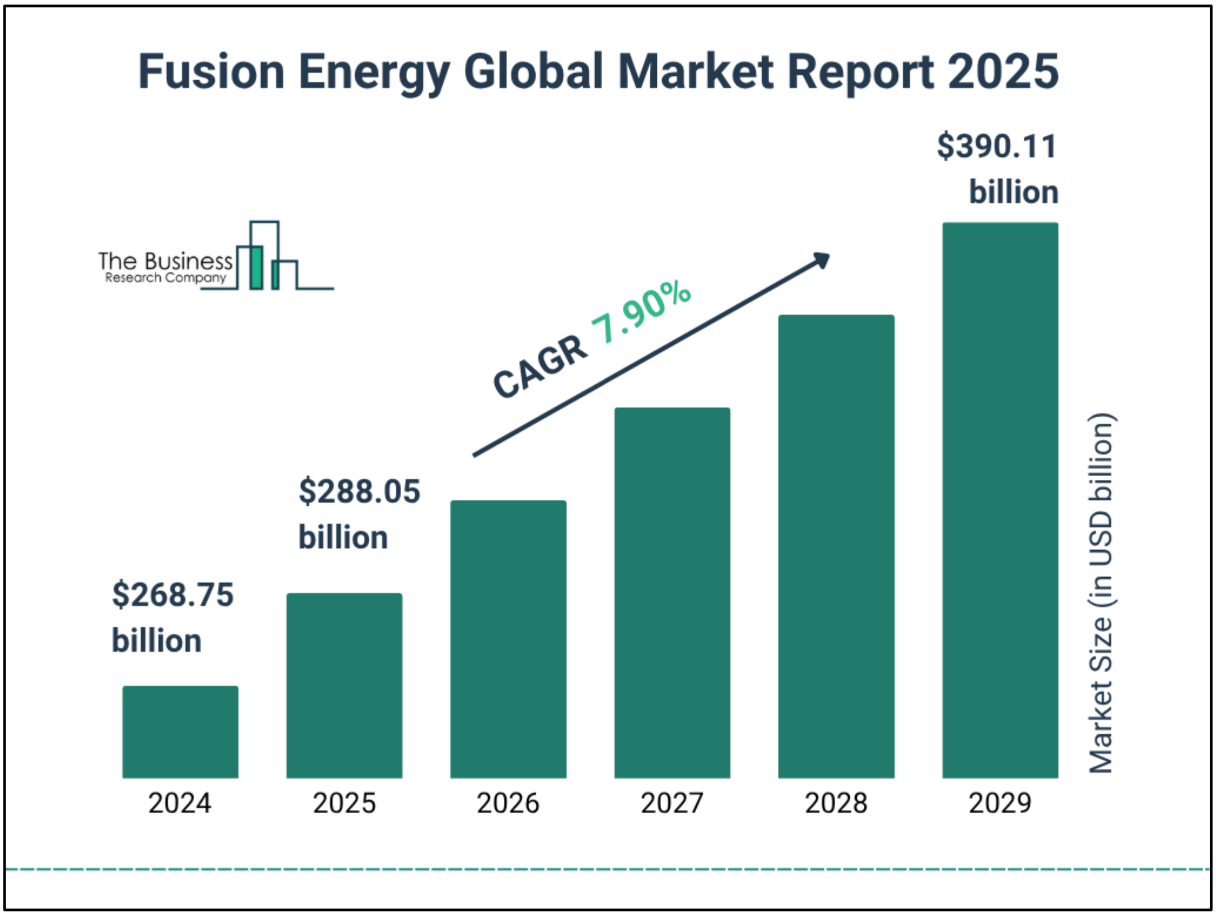

Figure 1: Fusion energy in the global market

The fusion energy market is projected to grow from $268.75B (2024) to $390.11B (2029), with a strong CAGR of 7.90%, indicating accelerating global adoption and investment. In the modern ADAS era, Volvo introduced a crucial development in Automatic Emergency Braking (AEB). Advanced AI and machine learning technologies allow high-accuracy interpretation of vehicles' surroundings for the next generation of autonomous driving features. As of 2024, AI introduced both benefits and challenges in this evolving technological landscape. AI enables advanced fault detection, predictive maintenance and specific decision making within ADAS (Oviedo-Trespalacios, Tichon and Briant, 2021). Practical implementation of FuSa observed across domains like ADAS, lighting systems, and battery management systems (BMS) that are targets of fault tolerance and reliability affecting driver and their safety. Additionally, HARA (Hazard Analysis and Risk Assessment), setting safety goals and implementing redundancy mechanisms, translates theory into applied safety practices (Haupt and Liggesmeyer, 2024). However, AI difficulties in this technological landscape raise questions about explainability, validation and long-term assurance against failure. Thus, the tension between innovation and assurance underlines the need for evolving standards that accommodate AI within functional safety frameworks (ISO TC22/SC32 Working Draft ISO/PAS 21448:2024). FuSa also influences future generations through its innovations in learning and adaptive safety mechanisms to handle the safety of drivers and passengers in vehicles with different technologies. Building road maps that must handle regulatory requirements, technical innovations and focusing on methodological rigour & solutions, this research contributes to the safer mobility systems of the future.

1.2 Aim:

This research aims to explore the advancement of automotive functional safety from Quality Management (QM) to Automotive Safety Integrity Level D (ASIL-D), emphasising real-world applications and the integration of Artificial Intelligence to enhance fault detection, risk management, and the development of safer future mobility systems.

RO-1: To analyse the transition from QM to ASIL-D and its implications for functional safety in the automation industry.

1.3 Objectives:

RO-2: To examine real-world applications of the safety of driving in addressing risk across different vehicle domains.

RO-3: To evaluate the role of AI in developing fault detection, prediction, safety and in ADAS.

RO-4: To propose an integrated strategy supporting future mobility solutions within ASIL-D frameworks.

1.4 Questions:

RQ-1: Why is the transition from QM to ASIL-D significant for functional safety in the automation industry?

RQ-2: Where can real-world safety applications in driving best address risks across different vehicle domains?

RQ-3: How can AI support fault detection, prediction, safety, and ADAS development?

RQ-4: How can integrated strategies be proposed to enhance future mobility solutions?

1.5 Problem Statement:

Automotive systems face many critical safety challenges as vehicles advance toward autonomy. Current quality management (QM) has a lack of robustness against complex risk, while achieving ASIL-D remains more difficult due to hardware, software and AI systems as a gap. These problems are most critical for reliable fault detection, risk management and safe future life on mobility deployment.

1.6 Research Significance:

This research has significance as it bridges the transition from quality management (QM) to the highest automotive safety integrity level (ASIL-D). This research also includes stronger compliance with functional safety standards. By integrating specific artificial intelligence technologies, criteria would highlight AI's potential to develop fault detection, risk detection and future life safety in advanced mobility systems. Through specific case studies, this research includes theoretical principles about FuSa and ADAS creativity and effects on the driving vehicles, especially in autonomous and connected vehicles. Ultimately, this research contributes to shaping safer, more reliable and sustainable automotive systems for future mobility.

2. Literature Review:

Automotive functional safety (FuSa) has become the most important aspect of autonomous and connected vehicles. The International Organisation for Standardisation (ISO) introduced ISO 26262 which defines Automotive Safety Integrity Levels (ASIL) up to ASIL-D (Kilian *et al.,* 2022). Quality management (QM) approaches to ASIL-D compliance highlight a fundamental shift from process efficiency to system-level risk prevention. This transition ensures that critical components like banking, steering and advanced driving assistance systems operate reliably under all conditions.

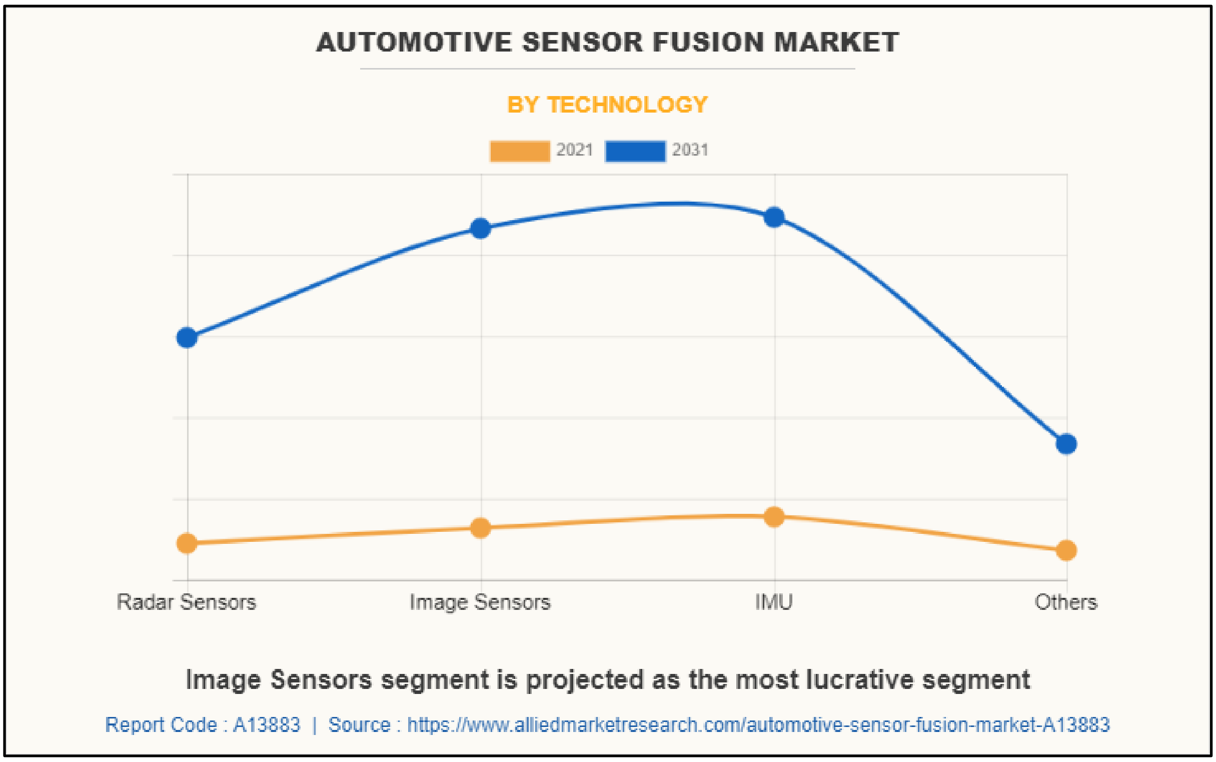

Figure 2: Automotive sensor fusion market

Source: (Market, 2021)

HAAR is a systematic process defined by the ISO 26262 standard to investigate potential hazards, exposure and controllability and integrity levels (ASILs) to mitigate those risks (Fiorucci, 2023). HARA is mainly focused on identifying the manufacturers that could possibly lead to E/E systems hazards and assessing the risk associated with them. A lane departure warning assistant (LDW) in a car is designed to alert the driver to potential safety issues if the vehicle attempts to switch lanes without the turn indicator in the same direction (Mascoli *et al.*, 2021). The LSW gets activated automatically even when the car has no changing lanes that cause the driver to lose control of the car (Augmentor, 2024). In addition, the complexity between sensors, actuators, and decision-making software in ADAS and autonomous driving often exceeds the verification scope envisioned by ISO 262262, which creates uncertainty in meeting ASIL-D requirements. In ADAS, redundancy mechanisms like dual braking systems help meet ASIL-D standards, while battery management systems (BMS) face risks such as fraud detection issues (Ayoub *et al.,* 2022). The journey from QM to ASIL-D represents a structured evolution from process quality to life-critical system reliability from quality assurance to life-critical system reliability. AI also helps advanced driver assistance systems by improving its obstacle detection, adaptive functions through explainability challenges and mobility systems. Thus, mobility systems such as connected, electric and autonomous vehicles are reshaping transportation with enhanced resilience on electric and AI-driven functions (Rana and Hossain, 2021). This research uniquely contributes by proposing an AI–FuSa framework, identifying ISO 26262 gaps, and outlining validation roadmaps addressing explainability, black-box limitations, and SOTIF challenges in safety-critical automotive systems. ISO 26262 gaps include limited AI integration, weak black-box validation, inadequate explainability methods, and insufficient coverage of emerging autonomous safety scenarios.

Thus, this section explores AI integration and the QM-to-ASIL transition, emphasizing validation gaps across ADAS, BMS, and mobility safety requirements and connecting AI-based safety validation with real-world applications across ADAS, BMS and mobility functional safety requirements.

Literature gap:

The literature reveals significant gaps in AI explainability and unresolved black-box validation issues, which conflict with deterministic assumptions in FuSA. SOTIF's limited scope further complicates achieving reliable ASIL-D compliance, creating inconsistencies between traditional safety frameworks and AI-enabled systems. These unresolved challenges emphasize the urgent need for integrating AI-based validation methods with real-world automotive safety applications, while critically assessing how autonomous decision-making may undermine conventional safety guarantees. These literature gaps form the basis for the methodological framework discussed in the following section.

This study employs secondary data collection guided by peer-reviewed sources, industry reports, and academic literature to ensure that its main aim and objectives are systematically addressed (Baldwin *et al.*, 2022). This data collection is based on secondary data that is guided by specific secondary sources like newspapers, articles, documents, annual reports, websites, and scholarly articles (Antoniadis *et al*., 2023). This research will utilise secondary data to examine the advancement of automotive functional safety from Quality Management (QM) to ASIL-D and artificial intelligence, real-world applications. Here, this research utilizes secondary data as it accesses a broad range of reliable and peer-reviewed materials without the need for direct fieldwork. This research goes beyond summarizing secondary sources by thematically analyzing how Artificial Intelligence strengthens the transition from QM to ASIL-D, thereby offering a novel synthesis that links functional safety standards with real-world AI applications.

3. Method:

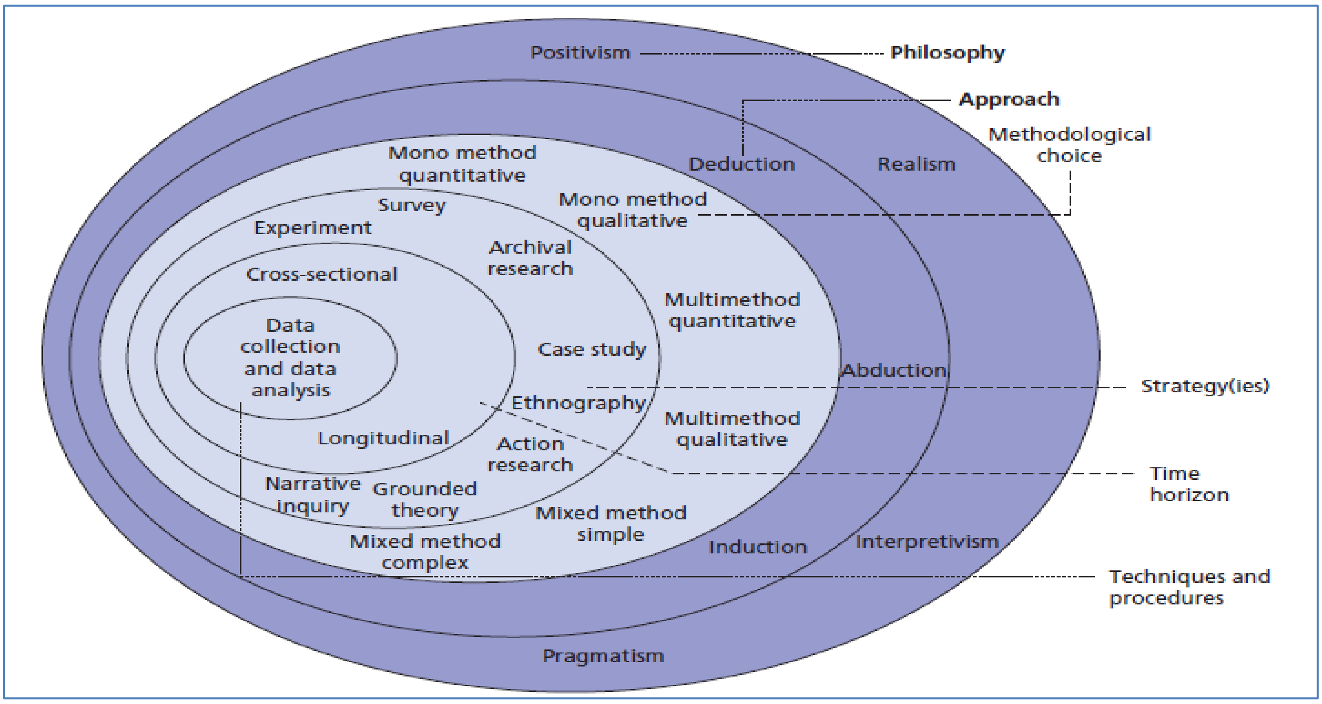

Figure 3: Research methods

Source: (Chetty, 2016)

This study chose an interpretivist research philosophy to emphasise understanding the meanings and perspectives embedded in data rather than merely relaying only measurable facts (Dewi, 2022). Interpretivism research philosophy also helps this research to examine how stakeholders in the automotive sector perceive and apply safety practices and the process of giving safety life to well as vehicle users (Pervin and Mokhtar, 2022). Interpretivism philosophy allows this research to contextualise industry practices and human decision-making with highly relevant data. Moreover, interpretivist philosophy captures transitioning from QM to ASIL-D, allowing us to understand not just technical measures but also contextual understandings (Pimentel, 2024).

This research uses an inductive approach to improve its main aim and identify patterns within the collected data and gradually form theoretical insights (Ward *et al.,* 2022). An inductive approach helps this research analyse field functional safety-related information and AI integration in mobility and their effects on the future. Thus, inductive approaches uncover emerging insights into functional safety, compliance strategies and complex domains related to ADAS (Khay Wai See *et al*., 2022). An inductive research approach ensures flexibility and deeper insights into this research allowing for shorter style and future mobility solutions.

However, this research employs a quantitative design to analysing measurable data on safety integrity levels, fault detection rates, and accident reduction processes from existing reports (Shital Thekdi and Aven, 2023). Therefore, quantitative design helps this research to ensure the practices of artificial intelligence and safety standards across the real-world automotive industry's effects on the present and next generations as well as sustainbility in the environment. Here, this research employs a quantitative design to analyse technological roles and mobility on the vehicle's runway and accident reduction to ASIL-D measurable effects. (Daniela and Mavroudi, 2022).

Moreover, this research uses thematic analysis to analyse the research's most important data and information about ASIL-D measurable effects (Braun, 2022). AI-driven fault detection, real-world application challenges, and future mobility impacts are also analysed by thematic data analysis. Additionally, thematic data analysis is chosen to bridge between critical issues and the benefits of AI integration in vehicle safety-related information explanations (Naeem *et al.,* 2023). This analysis helps explain case studies related to ADAS, BMS, and lighting. Also, thematic analysis highlights safety standards and OM and ASIL-D.

Research Ethics:

Overall, this research maintained all of the data analysis and collection by presenting both the systematic and limitations of existing criteria. This research followed strict ethical standards to ensure integrity and reliability. Thus, this research provides academic articles and industry reports, which are properly cited from specific sources to avoid plagiarism and acknowledge intellectual property. Additionally, this research crucially highlights authentic data and information for advancing knowledge in functional safety and artificial intelligence.

4. Result Discussion:

4.1 Functional Safety Impact In Modern Vehicles

Functional safety (FuSa) provides modern vehicles' electrical and electronic systems to operate reliably under fault conditions (Kane *et al.*, 2022). The ISO 26262 standard includes safety management that guides manufacturers in addressing technological risks and developing system reliability. Also known that advanced driver assistance systems (ADAS) reduce single vehicle crashes by 30% and prevent 43% of rear-end collisions in urban environments.

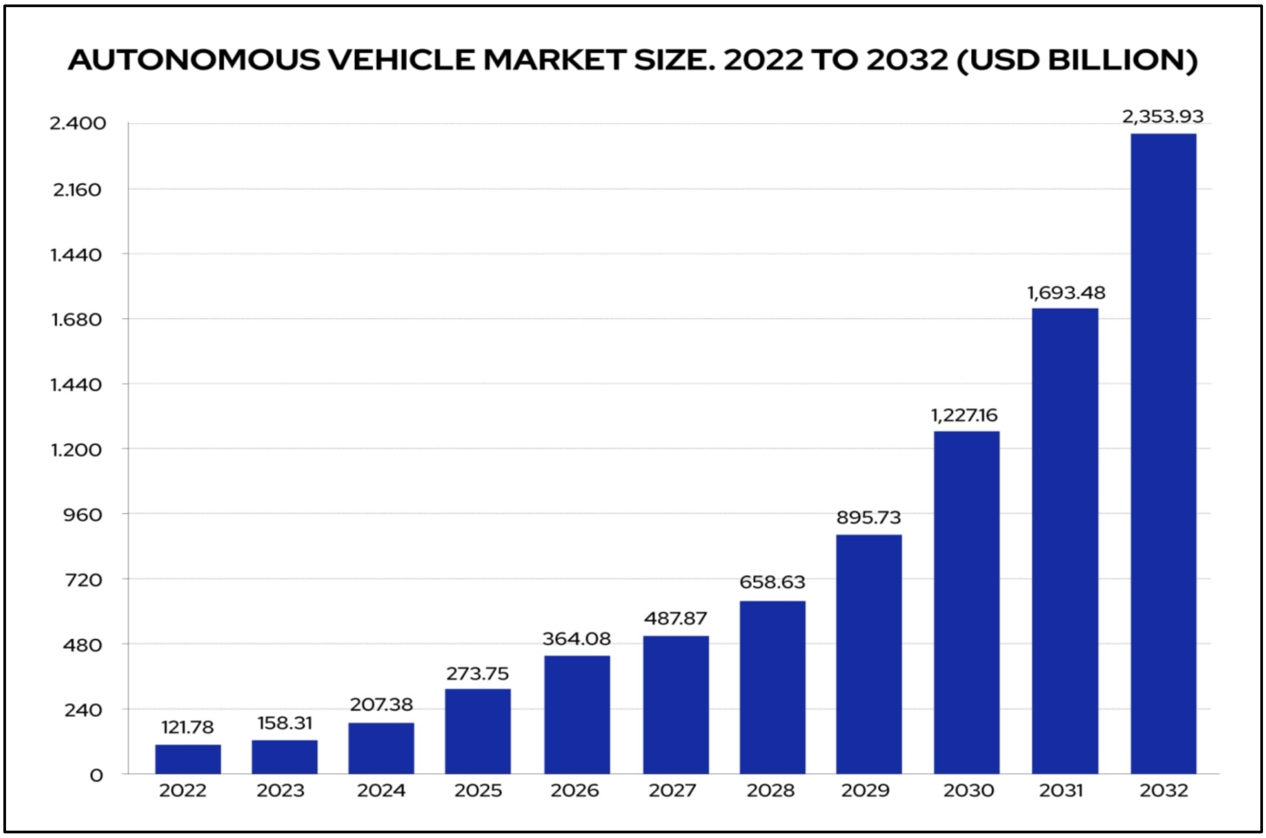

Figure 4: Global Autonomous Vehicle Market Forecast (2022–2032)

Source:(Ailabs, 2024)

ADAS technologies are projected to prevent approximately 250,000 fatalities and 14 million injuries globally over the next three decades (estimate based on 2024 data). Battery management systems in electric vehicles prevent 95% of thermal runaway incidents through specific FuSa designs which increase lithium-ion cell safety by 40%. Thus, lighting systems are enhancing visibility and reducing pedestrian accidents by 28% and lowering roadway fatalities by 12%. Thus, FuSa, combined with ISO compliance and artificial intelligence-driven systems, improves safety, reliability, and public trust for autonomous and connected vehicles (Pérez-Cerrolaza *et al.,* 2023).

4.2 Qm To Asil-D Transition

QM to ASIL-D provides implementing stringent, system-level safety mechanisms and detailed justification to compensate for the lack of intrinsic safety in QM components. Thus, QM has no hazardous consequences, and no specific requirements from ISO 26262 apply (Bramley *et al.,* 2023). On the other hand, ASIL has the highest automotive safety integrity, which indicates extreme hazards and crucial requirements to prevent failures and threatening situations (Letizia Tasselli, 2022). QM for consistency moves through ASIL-B and ASIL-C for moderate and high-risk functions and curricula related to technological performances in the driving sense, and ASIL-D for life-critical systems. Among those, QM and ASIL, Hazard compliance with ISO and ensure maximum safety and fault tolerance in the driving sense.

4.3 Case Studies and Real-World Applications

Real-world applications of functional safety (FuSa) demonstrate its critical role in modern vehicles (He *et al*., 2022). Battery management systems (BMS) apply FuSa principles to mitigate thermal runaway incidents in electric vehicles in electric cars. Real-world data on ADAS develops road safety, consistency and traffic flow by specific traffic roles, which help drivers to save their lives. Lane Keeping Assist prevents accidents in blind spots, but it also reduces the likelihood of lane changes. ACC (adaptive cruise control) maintains a set speed and a safe following distance from the vehicle ahead, reducing dangerous accidents.

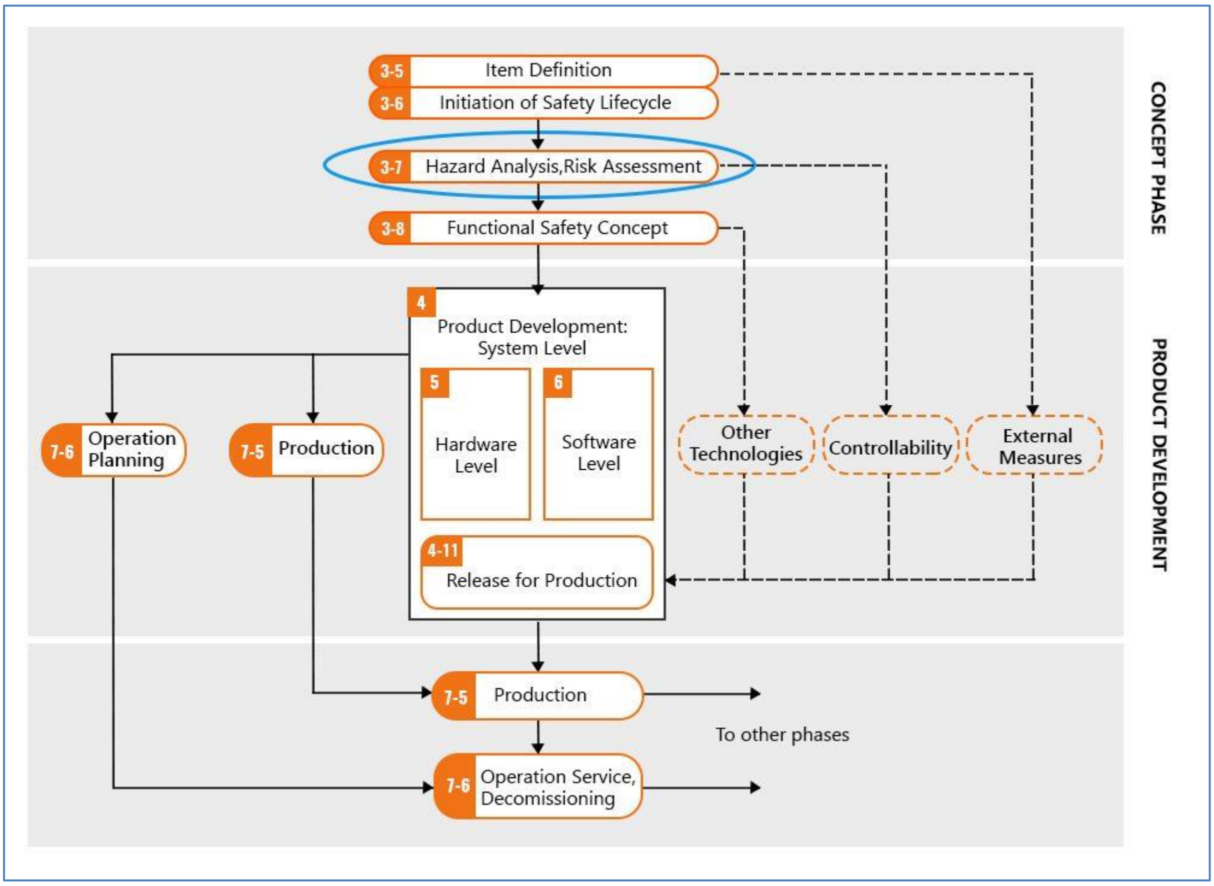

Figure 5: HARA Helps Functional Safety (ISO 26262) Consultants to Determine ASIL Values

Source: (Vaibhav, 2019)

ISO certified that vehicle lighting systems help the driving sense of security, which helps drivers to stop before any environmental and weather-related hazards (Pimentel, 2024). Improving roadway facilities shows that FuSa not only develops technical performances but also builds public safety more than before the use of artificial intelligence in its every specific system. It is also known that in 2024, 68.6% of new vehicles globally incorporated advanced ADAS features, which confirmed FuSa's practical impacts on safety and reliability. Despite AI’s promise in FuSa, Tesla Autopilot incidents reveal ongoing validation gaps, raising concerns for safety-critical deployment.

4.4 Ai’s Role In Enhancing Adas Safety

Artificial Intelligence is proving to be a vital enabler in the advancement of Advanced Driver Assistance Systems (ADAS) safety, closing the gap between the algorithms traditionally used (which are often rule-based) and dynamic and real-world driving conditions (Aleksa et al., 2024). Perception models powered by CNNs or RNNs are examples of AI algorithms enabling accurate detection of pedestrians, cyclists, and obstacles under varied environmental conditions These algorithms enable perception models that detect pedestrians, cyclists, and obstacles under diverse conditions that allow detecting the presence of pedestrian, cyclists, and unexpected obstacles in various environmental conditions (e.g. low-level, rainy with a lot of rain, snowy). For example, AI-enabled sensor fusion uses data from LiDAR, radar, and cameras to boost object recognition and lane-keeping capabilities for more advanced object perception than a human (Javier, 2022). While ISO 26262 establishes the foundation for FuSa, integrating AI within this framework introduces both opportunities and challenges, illustrated by case studies.

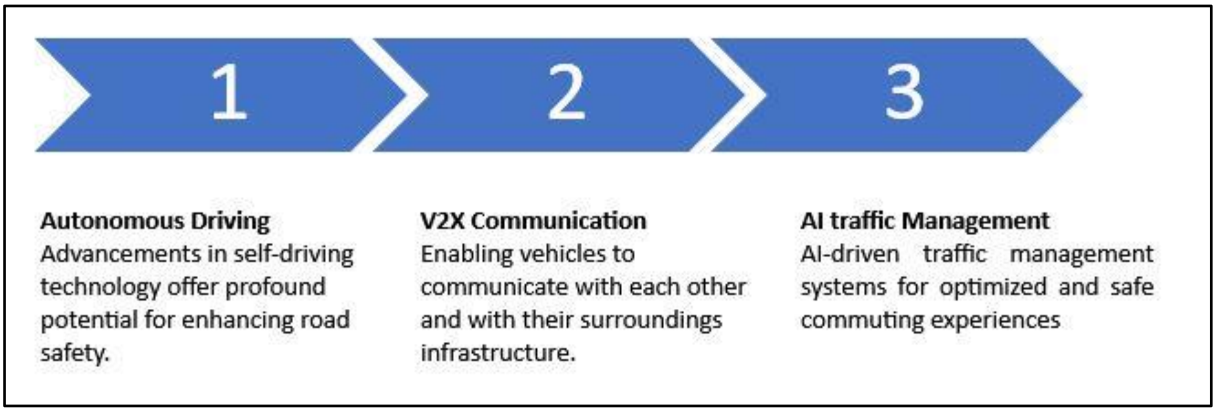

Figure 6: ADAS Functionality Enabled by AI

Source: (Iiechdrive, 2024)

Evidence from real-world testing, such as Tesla's Autopilot and the Driver AI of Waymo, shows a significant drop in probabilities of collisions in cases when AI-enhanced ADAS modules can actively track blind spots, cross traffic alerts, and perform emergency braking functions (Jatavallabha, 2024).

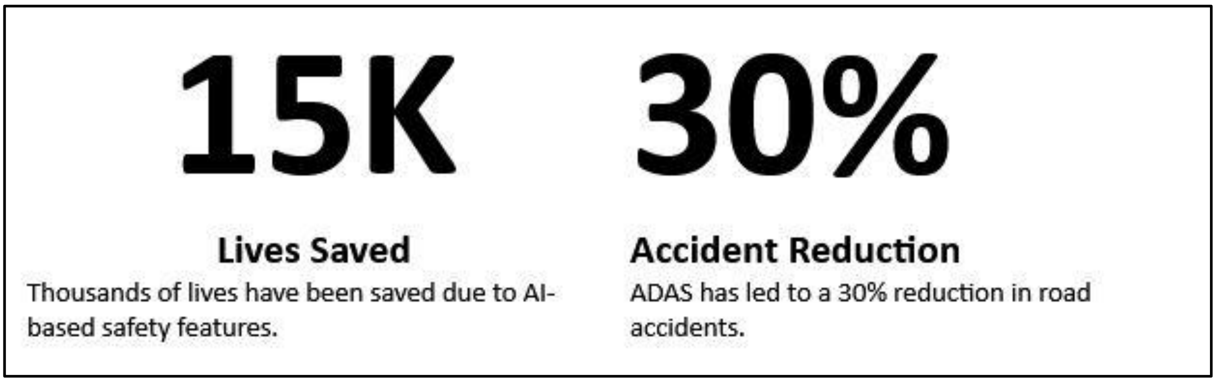

Figure 7: AI in Road Safety

Source: (Iiechdrive, 2024)

Additionally, machine learning models dynamically update the decision-making frameworks by analysing millions of driving scenarios, reducing the false positives for emergency braking and adaptive cruise control. The black-box nature of AI models introduces unpredictability, necessitating explainability and traceability for ISO 26262 validation, making explainability and transparency essential for ISO 26262-compliant validation under ISO 26262. Importantly, AI plays a part in achieving compliance with functional safety (FuSa) compliance, in terms of possible real-time risk assessment according to Automotive Safety Integrity Level (ASIL) compliance, and especially ASIL-C and ASIL-D systems. The ability of AI with continuous learning ensures ADAS evolves with complex traffic patterns, making it an indispensable technology to ensure higher robustness, predictive decision-making and finally safer mobility both in automated and human-driven vehicles.

4.5 Future Of Standards And Next-Gen Fusa

The future of functional safety standards is trending beyond ISO 26262 to accommodate AI-driven systems, autonomous driving, and more complex electronic architectures. Current FuSA standards, dealing in particular with deterministic hardware and software, are being supplemented by ISO/PAS 21448 (SOTIF - Safety of the Intended Functionality), extending safety considerations to non-deterministic AI-based perception systems (Maier and Mottok, 2022). Evidence from industry consortia such as UNECE WP.29 highlights how next-generation FuSA will place emphasis on integration of cyber security, as industry recognises

that functional safety and security are interdependent in connected mobility ecosystems (Ji, Wang and Su, 2024). Standards will also evolve in life-cycle thinking validation such that continuous monitoring and over-the-air (OTA) updates is the norm, where mate safety compliance continues not only at the manufacturing point, but also during vehicle operation. Validation challenges in AI-driven ADAS highlight unresolved issues where system decisions lack auditability, complicating trustworthiness in life-critical automotive functions.

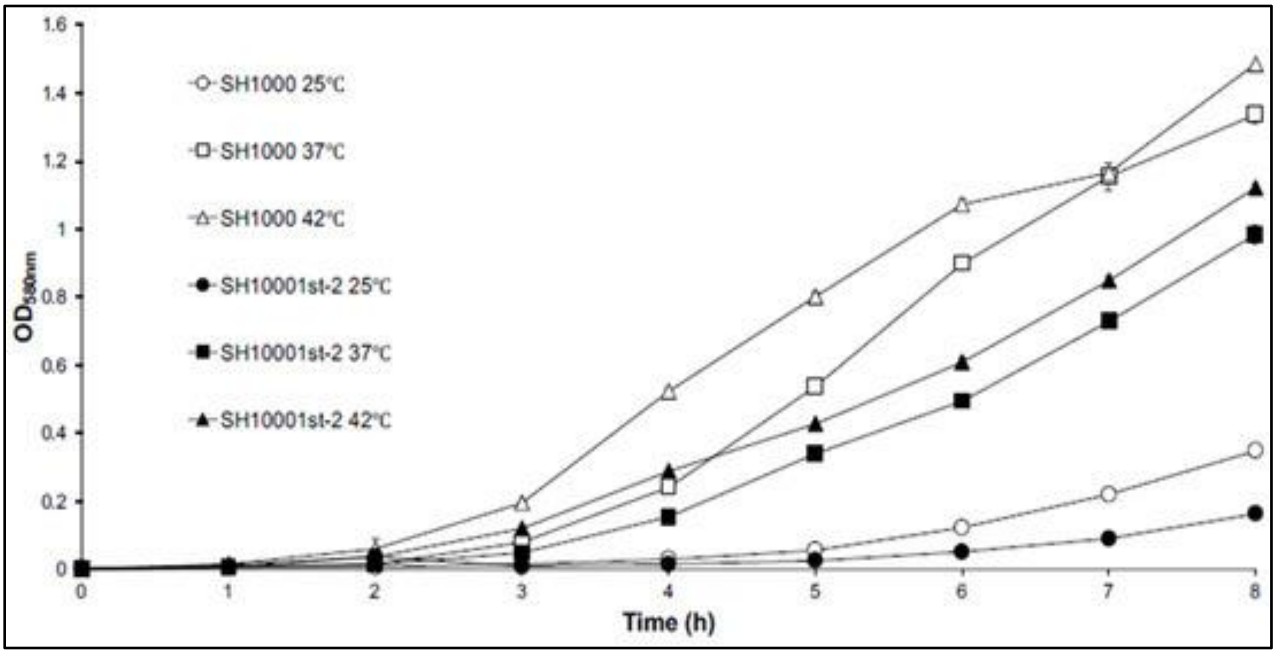

Figure 8: AI Validation Workflow for Functional Safety Integration

Source: (Haupt & Liggesmeyer, 2024)

In real-world applications, organisations such as BMW and Audi are already rolling out their centralised domain controllers based on ASIL-D compliance, which can ensure fault containment across multiple ADAS features (Pimentel, 2024). Furthermore, future FuSA frameworks will probably use models of probabilistic risk assessments to reflect the uncertainty of AI and ensure redundancy (safety islands and fail operational architectures). By the combination of deterministic safety guarantees and adaptive AI-driven validation, next-gen FuSA should be able to tackle previously unpredictable scenarios such as the occlusion of sensors or new traffic behaviours. This evolution represents a paradigm change from static compliance testing to a data-driven, dynamic assurance framework in the future of safe mobility.

4.6 Challenges and Future Considerations

Despite startling accomplishments, there remain some significant challenges that pose limitations to end-to-end automotive functional safety in AI-powered systems. One of the foremost challenges is the explainability of AI models, which makes it complex for relevant, ISO 26262 certified, because black box decision making cannot be easily verified with ASIL-D technologies (Iyenghar, Gracic and Pawelke, 2024). Reproducibility – Ensuring that AI-driven outcomes remain consistent across diverse datasets and environments of datasets is another limitation, especially as a model may have been trained in one geography and may not care for unfamiliar traffic. AI-based automotive systems, including explainability issues, SoC complexity, and scalability, while expanding cybersecurity discussion to address ISO/SAE 21434 and UNECE WP.29 standards and their interaction with FuSA. Tesla Autopilot incidents, alongside strong statistics on ADAS crash reduction and BMS fire prevention, to enhance academic rigor and provide balanced, insightful analysis.

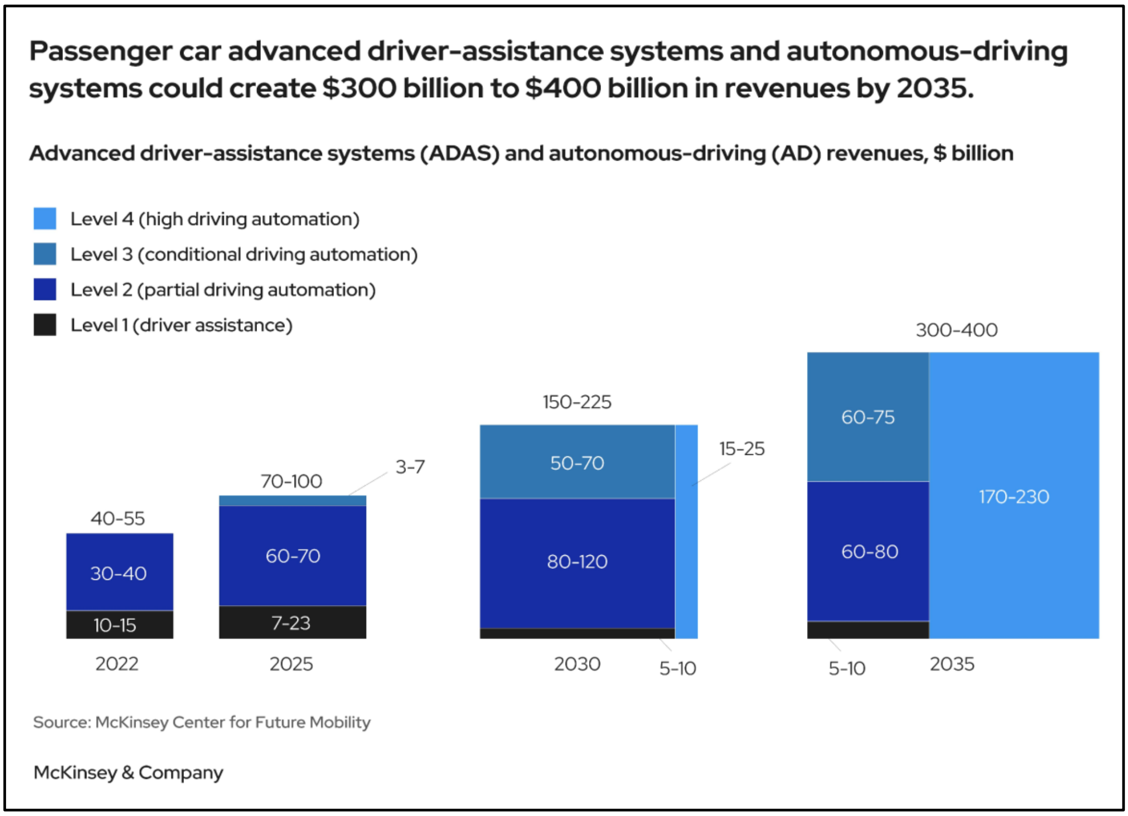

Figure 9: Multi-Sensor Fusion and the Role of Explainable AI (XAI) in Autonomous Vehicles

Source: (Ailabs, 2024)

Hardware complexity is also increasing; in system-on-chip (SoC) architectures, fault-tolerant mechanisms, including lockstep processors and error-correcting codes, have been developed to prevent a single point of failure. Furthermore, there are issues of scalability in safety validation stages, where it would take billions of driving scenarios to statistically demonstrate AI reliability against all edge cases. Future considerations also need to address human factors to ensure a safe hand-off to the drivers when Level 3 automation is employed (alternating no human supervision and human supervision). Cybersecurity vulnerabilities also pose risks as malicious interference with ADAS functions remains possible. Looking toward the future, the need will arise to combine hybrid verification approaches that combine simulation, digital twin and real-world testing to accelerate validation (Pimentel, 2024). Industry-wide standardization on AI explainability, combined with robust datasets that represent rare but important scenarios, will be imperative (Alsharif, Mishra and AlShehri, 2022). Only by working through these multi-faceted challenges should the industry be able to fulfil the vision of AI-enabled, functionally safe and reinsurable self-driving mobility. Failures in autonomous systems underscore the gap between theoretical AI capabilities and practical reliability, emphasizing risks in large-scale FuSa integration.Thus, Ethical AI in automotive safety requires addressing bias, ensuring transparency, and maintaining accountability to build societal trust while enhancing fairness, reliability, and responsible adoption of autonomous driving technologies.

5. Conclusion:

In conclusion, this research highlights the evolution of functional safety (FuSa) toward enhanced automotive reliability, tracing the transition from QM to ASIL-D and the incorporation of AI. By integrating secondary data, the study demonstrates how ISO 26262 frameworks, ADAS systems, and battery management mechanisms reduce accidents, fatalities, and thermal incidents significantly. Real-world applications such as lane-keeping assist, adaptive cruise control, and enhanced lighting systems underscore FuSa's tangible contributions to public safety. Moreover, AI emerges as a transformative enabler, powering perception models, sensor fusion, and adaptive decision-making for complex driving environments, thereby reinforcing ASIL-C and ASIL-D compliance. Evidence from Tesla, Waymo, and industry consortia illustrates AI's role in shaping safer autonomous mobility. Finally, the evolution of FuSa standards beyond ISO 26262, towards SOTIF and cybersecurity integration, ensures resilience in future connected ecosystems. Collectively, the study concludes that FuSa, empowered by AI, establishes the foundation for adaptive, data-driven, and trustworthy next-generation mobility as of November 2024.

Recommendation:

Recommendations include enhancing figure clarity, refining methodology focus, adding critical synthesis in literature, linking conclusions to ADAS reliability and FuSa standards, and highlighting regulatory and industry implications, streamlining the methodology by focusing on a primary approach while using others as support, adding critical synthesis in the literature to highlight conflicts, gaps, and unresolved issues, sharpening the conclusion to explicitly link findings to ADAS reliability, functional safety, and Ethernet standardization, and emphasizing practical implications such as ROI, stakeholder trust, and regulatory compliance.

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