Critical safety risks for passengers onboard level 4 automated shuttles in Europe: mitigation strategies and public policy implications.

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Research field: ☐ Economics, ■ Technology, ☐ Politics, ■ Social Aspects
Preferred Presentation Type: ■ Oral ☐ Poster

Abstract

A core value proposition of driverless automated vehicles (AVs) is reducing road accidents largely attributed to human errors and increasing traffic safety. Nonetheless, safety remains a foremost concern in the adoption of AVs. This paper enriches the academic and policy debate on driverless (level 4) AV safety for onboard passengers. We conduct semi-structured interviews with 47 Connected Cooperative Automated Mobility (CCAM) experts from diverse sectors and 11 European countries for insights into their views and opinions on the critical safety issues of driverless AV and possible mitigation strategies in Europe. Then, we conduct data analysis using reflexive thematic analysis. We find that the critical safety issues are injury, accident or death of passengers, adverse weather/environmental conditions, cybersecurity issues, perceived safety risks, and AV functional failure. We argue that the safety risks at specific locations in the extant literature are interlinked and are generalisable in the European context. The key mitigation strategies are monitoring in-vehicle conditions, designing AVs for functional safety, increasing road testing to improve AV perception and sensing technologies, user education and communication about AV, support from road infrastructure and V2X technologies. The other mitigation strategies are facilitating stakeholder collaboration, knowledge, and data sharing, enacting/enforcing safety standards and regulations, and separating AVs from human drivers. Then, we analyse the mitigation strategies using five governance policy steering instruments to understand workable public policy approaches to support policymaking on driverless (level 4) automated vehicles in Europe. We argue that a combination of governing by enabling and governing by authority policy steering instruments could support mitigating the critical safety risks of level 4 AVs. We argue that these policy steering instruments could play a key role in supporting driverless AVs' safe integration into transportation systems and the transition to a connected, cooperative, automated mobility future in Europe.

Introduction and Motivation

Automated Vehicle (AV) represents a potentially disruptive yet beneficial change to the transport system with the potential to improve safety (Fagnant and Kockelman, 2015; Xu et al., 2024; Arowolo et al., 2024). AV is primed as a potential solution to reduce road accident deaths and injuries (Liu et al., 2020). However, AV is a complex interconnected system of sensors, processors, and external units to ensure automated driving (Benyahya et al., 2023). Level 4 (driverless) AV could process sensors' inputs and exchange data with other vehicles and intelligent transport systems to achieve real-time assimilation of their surroundings. Nonetheless, technical issues in the AVs' perception, decision-making and control algorithms can undermine the performance of an AV system and cause safety hazards. Therefore, safety remains a foremost concern in adopting automated vehicles (Sohrabi et al., 2021; Tan et al., 2023) and a critical precondition for public trust (Mattas et al., 2022). Before AVs can be widely accepted in urban environments, convincing demonstrations should prove that AV technology can detect and safely respond to VRUs and static objects (Tengilimoglu et al., 2023a). The extant literature, such as Berge et al. (2023), Díaz-Piedra et al. (2023), Tengilimoglu et al. (2023b), Zhang et al. (2023), and others discussed the safety risks of driverless AV. These streams of literature provide insight mostly on the safety risks of driverless AV at a specific location. Notably, Berge et al. (2023) focused on two countries. Moreover, the literature on mitigation strategies is also scant. Therefore, there is a need for

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comprehensive insights into the critical safety risks of driverless (level 4) AV, their inter-relationship and how to mitigate them. Moreover, we propose appropriate policy steering instruments to mitigate the safety risks. A comprehensive study is important as Europe prepares for the future of mobility by integrating driverless AVs in the public transport system. This paper attempts to bridge this important knowledge gap. We attempt to answer the research questions:

- What are the critical safety risks and mitigation strategies of driverless AV in Europe?
- What public policy approach(es) can support mitigating the critical safety risks of driverless AV?

Applied Method

We conduct qualitative data analysis using semi-structured expert interviews to investigate the safety issues of level 4 AV. This methodology is particularly effective for exploring complex phenomena, such as the multifaceted safety considerations specific to level 4 AVs, where quantitative data alone may not capture the depth of expert insights. We conduct interviews with 47 CCAM experts from 11 European countries. The semi-structured expert interviews allow us to better identify underlying issues from the stakeholders' perspective, and uncover and understand the diversity of opinions (Schepis et al., 2023; Suck et al., 2023). We analyse the data from the interviews using NVIVO software. NVIVO is a qualitative data analysis tool that supports thematic coding and categorising recurrent viewpoints and themes (Díaz-Piedra et al., 2023; Tengilimoglu et al., 2023). We use reflexive thematic analysis method (Braun and Clarke, 2006; 2012; 2019). Reflexive thematic analysis is a qualitative data analysis method that facilitates the identification, analysis and reporting patterns or themes within data (Braun and Clarke, 2012; Byrne, 2022). We apply reflective thematic analysis because it allows to conduct data analysis by building upon our disciplinary knowledge of safety issues from the literature and theoretical assumptions to critically and reflexively engage in research on the subject matter (Braun et al., 2016). We follow the six-phase iterative process to facilitate our data analysis (Braun and Clarke, 2006; 2020). Since a crucial concern is the optimal policy approach for AV technology (Singh et al., 2023), we complement our analysis with insights on the steering or policy instruments that a government could use to achieve policy goals and certain societal outcomes (Treib et al., 2007). We analyse the governance approach to address the key mitigation strategy themes using the adapted framework of Audouin and Finger (2019).

Results

We find five interlinked themes from 121 codes for the critical safety risks from the interviews. We find eight themes that encompass a structured view of the strategies to mitigate the critical safety risks for passengers on board driverless AVs from 170 codes from the interviews (see abstract for the critical safety risks and mitigation strategies). We argue that governing by enabling instruments such as initiating public-private partnerships, incentivising private sector actors, funding provision, and leveraging stakeholders to support driverless AVs could be workable policy steering instruments. Also, governing by authority instruments through enacting and enforcing standards and regulations could be workable to support mitigating the critical safety risks of level 4 AVs and play a key role in supporting driverless AVs' safe integration into transportation systems in Europe.

Conclusions and Policy Implications

Driverless AVs could revolutionise urban transportation by enhancing traffic safety and contributing to sustainable mobility solutions in Europe. However, their successful deployment depends on mitigating several critical safety risks with workable public policy approaches. While the extant literature presents different location-specific safety risks. We argue that the safety risks at specific locations in the extant literature are interlinked and are generalisable in the European context. Regarding mitigation strategies, which seem to have scant literature to the best of our knowledge, we provide comprehensive insights to bridge this important knowledge gap. The mitigation strategies are monitoring in-vehicle conditions, designing AVs for functional safety, increasing road testing to improve AV and perception and sensing technologies, user education and communication about AV, and support from road infrastructure and V2X technologies. The other mitigation strategies are facilitating stakeholder collaboration, knowledge, and data sharing, enacting/enforcing safety standards and regulations, and separating AVs from human drivers.

Then, we analyse the mitigation strategies with five governance policy steering instruments to understand public policy approaches to support policymaking on driverless (level 4) automated vehicles in Europe. We argue that a combination of governing by enabling and governing by authority policy steering instruments could support mitigating the critical safety risks of level 4 AVs. Nonetheless, self-governing and governing by doing could be workable in some cases but require overarching government involvement and resources to implement. We offer the following policy recommendations to support public policymaking.

- **Initiate public-private partnerships, incentivise and provide funds.**

The government could initiate PPP to support private-sector investment focused on technological innovations for in-vehicle monitoring services, such as technology and infrastructure, to accelerate state-of-the-art advancements in real-time and remote monitoring, event detection and remote supervision systems, such as intrusion detection systems, and intervention technologies in Europe. The government could have PPP with OEMs, AV technology providers, and AV service providers and provide funds to incentivise OEMs to invest in functional safety design solutions. Moreover, PPP initiatives and funding provisions could support private-sector stakeholders' (infrastructure and complementary service providers) investment in ODD development for road tests. Also, funding provision for awareness, training, and communication activities with public actors (PTOs, PTAs, and government institutions) and non-public actors (OEMs, AV service providers) for public awareness campaigns, training, and communication about AV. The government could collaborate, facilitate, and encourage actions with non-public actors through partnerships and incentive development to educate citizens on the need for data and transparent communication. Government could incentivise research and development in research institutes and universities in the technology and infrastructure investment in sensor technologies, AI models, and algorithms, particularly on solutions to handle critical safety issues triggered by adverse weather and environmental conditions. Moreover, government funding could support the adaptation of road infrastructure and investment in V2X technologies. Government could also incentivise pilot projects that explore the efficacy of V2X in mitigating critical safety issues of driverless level 4 AVs and invest in V2X technologies in areas where environmental condition awareness are most critical. In addition, the government could facilitate stakeholder collaboration, knowledge, and data-sharing activities through investment in data-sharing platforms and PPPs that could support private-sector investment in technology and infrastructure. Moreover, the government could stimulate PPP investment in separate road infrastructure for AV and incentivise research and development in sensing and perception technologies.

- **Leverage stakeholders to support driverless AVs**

The government’s involvement in influencing negotiations in favour of AV could be a nudging strategy to encourage private sector participation. Also, influencing AV opponents through consensus-building, cooperation and collaboration with decentralised power in decision-making could encourage more interest in monitoring in-vehicle conditions and stimulate interest in designing AVs for functional safety. Moreover, influencing negotiations and opponents to support AV could be useful nudging strategies to support AV road testing. The government could influence stakeholder collaboration, knowledge and data-sharing activities, perform more road tests, and facilitate user education and communication about AV. Besides, policymakers could develop public awareness campaigns to inform citizens about AV safety benefits and limitations. Leveraging AV opponents using horizontal network governance could stimulate interest in activities linked to monitoring in-vehicle conditions, performance tests, collaboration, knowledge and data-sharing activities. The government could provide policy support in defining or setting targets and negotiations to influence investment in road infrastructure and V2X technologies.

- **Enact and enforce standards and regulations**

Regulatory interventions and enforcement appear crucial to ensure AVs are designed for functional safety, given the far-reaching implications of any major incident on the entire AV industry. Enacting and enforcing regulations could facilitate monitoring in-vehicle conditions, but should be thoughtfully implemented without hampering market development. Moreover, the government could develop specific legislation/regulations and enforce regulations to design AVs for functional safety, support approval and licensing processes to encourage more private sector participation in AV road testing activities and separate AVs from human drivers. Understandably, the safety of passengers on board driverless AVs should not be entirely committed to the market without some form of government intervention. For example, requirements on the distance covered by the AV during proof of concepts or the minimum distance or required level of tests before driverless AV is deployed could reassure the public and allay perceived safety fears. Also, the government could support approval and licensing processes with regulations to support road testing activities or to separate AVs from human drivers. Enacting and enforcing legislation on user education, communication, and awareness could complement funding provision and public-private partnership initiatives to ensure that private sector entities carry out the activities.

In sum, this paper fosters an understanding of the critical safety risks and mitigation strategies of driverless AVs. With these comprehensive insights and appropriate governance approaches offered in this paper, policymakers can support driverless AVs' safe and effective integration into transportation systems, ensure that the transition to automated mobility aligns with the public interest, and support the transition to a connected, cooperative, automated mobility future in Europe.

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