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Assensing the Impact of Advanced Driver Assistance Systems (ADAS) on Road Safety an Empirical Study Using Factor Analysis

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Abstract. Road traffic accidents remain a critical global concern, especially in low- and middle-income countries. Advanced Driver Assistance Systems (ADAS) are introduced as proactive safety technologies in the industry 4.0 era. This study aims to assess the impact of ADAS on road safety through an empirical approach. A quantitative survey involving 260 licensed drivers was conducted, followed by qualitative interviews to provide contextual insights. The dataset was confirmed reliable (KMO = 0.82; Cronbach's α = 0.87), and factor analysis identified four latent constructs: Collision Avoidance, Driver Behavior and Acceptance, System Reliability, and Road Safety Impact, explaining 68.5% of variance. Results indicate that collision avoidance and system reliability are the strongest predictors of user trust, while road safety impact emerges as an independent factor emphasizing societal benefits. The findings highlight that ADAS adoption should be framed not only as technological acceptance but also as a contribution to sustainable mobility and SDG 3.

Keywords: ADAS, factor analysis, industry 4.0, road safety, sensor integration.

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1. Introduction

Road traffic accidents are a significant global public health concern, causing nearly 1.35 million deaths or disabilities each year and millions of additional injuries worldwide [1,2]. In 2019, about 93% of traffic-related deaths occurred in low- and middle-income countries, reflecting a disproportionate burden of approximately 1.3 million fatalities [1,2]. Projections indicate that road traffic injuries will become the seventh leading cause of death globally by 2030 [3]. Although traditional passive safety measures, such as airbags and seatbelts, have helped reduce the severity of crashes, they remain inherently limited because they function only after an accident has occurred [1,4]. There is a critical need for proactive technologies that can prevent accidents before they occur [4–6].

In the era of Industry 4.0, Advanced Driver Assistance Systems (ADAS) have become central to this effort [5,7,8]. By monitoring vehicle and environmental parameters, features such as Adaptive Cruise Control, Automatic Emergency Braking, and Lane Keeping Systems enhance road safety and address the demand for proactive measures in modern transportation [5,8,9]. ADAS contributes to smoother traffic flow, minimizing congestion and delays [10,11]. Vehicles equipped with ADAS often receive higher safety ratings from insurance companies, potentially leading to lower premiums for drivers [6,12]. ADAS serves as a stepping stone towards autonomous vehicles, gradually introducing drivers to the concept and capabilities of self-driving technology [13,14].

ADAS combines sensors, cameras, radar, and software to support drivers in real time, improving hazard detection, decision-making, and vehicle control [12,15]. These systems encompass a wide range of functionalities, including Adaptive Cruise Control (ACC), Lane Departure Warning (LDW), Blind Spot Monitoring (BSM), and Automatic Emergency Braking (AEB), all of which are designed to reduce driver error and improve safety outcomes [12,16]. Empirical studies consistently demonstrate that ADAS can substantially reduce accident risk. For instance, research shows that ADAS technologies can lower accident probability by up to 50% and prevent as much as 80% of frontal collisions [16]. They also contribute to safer driving behavior by encouraging compliance with safe distances, lane discipline, and speed management [17,18]. Beyond safety, ADAS supports broader societal objectives. By reducing road accidents and fatalities, ADAS directly advances the United Nations Sustainable Development Goal (SDG) 3, which seeks to halve global road traffic deaths and injuries by 2030 [12].

Despite its promise, widespread adoption of ADAS faces important technical and non-technical challenges. Sensors may perform poorly under adverse weather or complex traffic environments, while driver overreliance can undermine attentiveness [17,19]. Furthermore, regulatory frameworks governing ADAS usage and liability remain under development, particularly in emerging economies where accident rates are disproportionately high. These barriers highlight the importance of empirical research to evaluate the actual effectiveness of ADAS in improving road safety.

While prior studies have emphasized the technical architecture of ADAS [16,17,19], or demonstrated its safety benefits in experimental or simulation contexts there is limited empirical evidence based on user perceptions and factor-based analysis. This gap is critical, as driver acceptance and behavioral responses determine the real-world effectiveness of ADAS. Furthermore, most existing literature has focused on developed countries, leaving a paucity of insights from contexts where road safety challenges are more severe.

To address these gaps, this study aims to empirically assess the impact of ADAS on road safety using a quantitative survey analyzed through factor analysis. Specifically, it evaluates how ADAS influences accident reduction, driver behavior, and collision avoidance, while also exploring the challenges to its implementation. By integrating perspectives from Industry 4.0 and sustainability frameworks, the study contributes to both theoretical understanding and policy discussions on the role of intelligent transport technologies in achieving safer and more sustainable mobility.

The contributions of this research are threefold: (1) It provides empirical validation of ADAS benefits through factor analysis, advancing beyond descriptive or conceptual accounts. (2) It highlights context-specific challenges that may hinder adoption, particularly in developing economies. (3) It situates ADAS within the broader discourse of SDG 3 and Industry 4.0, underscoring its relevance to global health and sustainability goals. Through this approach, the study seeks to offer novel insights into the effectiveness of ADAS and its implications for the future trajectory of intelligent transportation systems.

2. Methods

Advanced Driver Assistance Systems (ADAS) are increasingly integrated into modern vehicles to enhance safety and reduce accidents. However, empirical evidence on their effectiveness, usability, and reliability in real-world driving remains limited. To address this gap, this study employed a mixed-method design consisting of a quantitative phase supported by factor analysis, complemented by a qualitative phase to deepen interpretation.

2.1. Research Design

The research was conducted sequentially in two phases:

1. Quantitative Phase.
    - Survey Development**.** A structured questionnaire was designed based on prior ADAS studies and validated through a pilot test with 20 respondents to ensure clarity and reliability.
    - Sampling and Administration**.** The final survey was distributed to 260 licensed drivers with direct experience using ADAS features. Respondents were selected using purposive sampling to ensure exposure to technologies such as Adaptive Cruise Control (ACC), Lane Departure Warning (LDW), and Automatic Emergency Braking (AEB).
    - Measurement**.** Items were measured using a 5-point Likert scale (1 = strongly disagree; 5 = strongly agree), covering constructs such as safety performance, usability, trust, and system reliability.
    - Statistical Analysis**.** Data suitability was tested using *Kaiser Meyer Olkin* (KMO) and Bartlett's Test of Sphericity. Exploratory Factor Analysis (Principal Component Analysis with Varimax rotation) was applied to extract latent factors. Reliability was assessed using Cronbach's alpha (threshold $\alpha > 0.7$).
2. Qualitative Phase.
    - Participant Selection**.** A subset of 20 respondents from the survey sample was invited for follow-up interviews and focus group discussions. Selection ensured variation in age, driving experience, and ADAS usage frequency.
    - Data Collection**.** Semi-structured interviews and focus groups explored user experiences, perceived benefits, limitations, and behavioral adaptation to ADAS.
    - Analysis**.** Transcripts were coded thematically using NVivo to identify recurring patterns, challenges, and contextual factors influencing perceptions.

2.2. Data Collection

Data were collected in three forms:

1. Questionnaire responses (Likert scale 1–5) covering constructs such as safety performance, usability, trust, and system reliability. Example items include: *"ADAS features make me feel safer while driving"* and *"I find it easy to interact with ADAS systems."*
2. Demographic information including age, driving experience, and frequency of ADAS use.
3. Qualitative narratives from interviews and focus groups providing contextual understanding of driver experiences.

2.3. Data Analysis

The data analysis process was designed to systematically examine the information obtained from both quantitative and qualitative phases. This step aims to ensure that the collected data can be transformed into meaningful insights that address the research objectives. Quantitative data were processed through statistical techniques to identify patterns and relationships, while qualitative data were analyzed to capture deeper perspectives and contextual understanding. By integrating both approaches, the analysis provides a comprehensive foundation for evaluating the effectiveness of Advanced Driver Assistance Systems (ADAS) and their implications for sustainable transportation development.

1. Quantitative analysis was conducted using IBM SPSS and AMOS. Factor analysis (Principal Component Analysis with Varimax rotation) was applied to identify latent factors representing ADAS effectiveness. Criteria such as Kaiser-Meyer-Olkin (KMO > 0.7) and Bartlett's Test of Sphericity ($p < 0.05$) ensured sampling adequacy. Items with factor loadings < 0.5 were removed to refine constructs.

2. Qualitative data were coded thematically to highlight user perceptions and challenges.
3. A mixed-method interpretation integrated both phases, providing a holistic assessment.

2.4. Validation

Several strategies were employed to ensure methodological rigor:

1. Pilot testing was conducted with 20 respondents to refine questionnaire clarity.
2. Reliability testing applied Cronbach's Alpha ($\alpha > 0.7$) to ensure internal consistency of constructs.
3. Triangulation was achieved by integrating survey findings with interview and focus group results.
4. Peer review and expert feedback from transportation safety researchers strengthened the validity of factor interpretation.

2.5. Research Frame Work

To provide a clear overview of the methodological flow, a research framework was developed. This framework illustrates the sequential process undertaken in the study, beginning with the quantitative phase and survey data collection, followed by factor analysis, and continuing with the qualitative phase through interviews and focus groups. The integration of both quantitative and qualitative findings enables a comprehensive sustainability assessment, which ultimately informs the formulation of results and recommendations. By outlining these stages, the framework ensures transparency, coherence, and a systematic approach to achieving the research objectives.

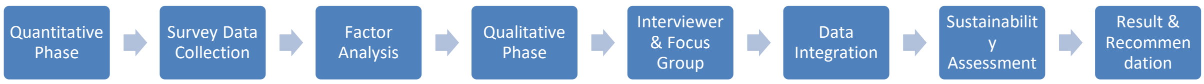

Figure 1. Framework Research

3. **Results and Discussion**

3.1. Demographic and Inferential Analysis

The demographic profile shows that respondents had diverse driving experience levels (Figure 1). Approximately 7.69% had less than one year of driving experience, 30.77% had 1–5 years, 23.08% had 6–10 years, 23.08% had 11–20 years, and 15.38% had more than 20 years. These percentages purely describe the distribution of respondents and ensure that the sample represents a wide range of driving backgrounds. These percentages purely describe the distribution of respondents and ensure that the sample represents a wide range of driving backgrounds. Such diversity is crucial because it reflects heterogeneous exposure to road conditions, accident risks, and prior interactions with vehicle technologies. According to Samaila et al. [20], heterogeneity in driving experience strongly influences the way drivers perceive both the usefulness and trustworthiness of Advanced Driver Assistance Systems (ADAS). Drivers with shorter experience tend to rely more on external aids due to limited confidence in their own skills, whereas experienced drivers may appreciate ADAS for its ability to complement their situational awareness.

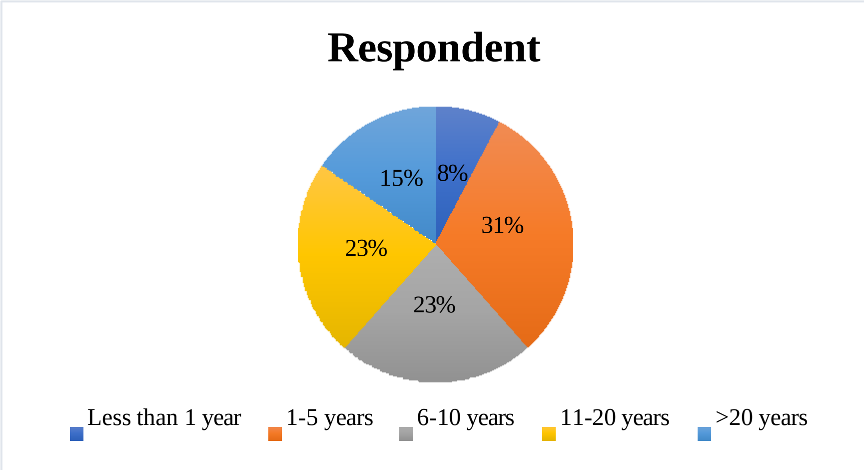

Figure 2. Respondent's data-based Driver Experience

However, descriptive data alone cannot explain how driving experience affects perceptions of ADAS (Table 1). Therefore, a Chi-square test was conducted to examine whether driving experience was associated with ADAS acceptance levels. Table 1 presents the demographic profile of respondents. To examine whether demographic variables influenced ADAS perceptions, *Chi-square* and ANOVA tests were applied.

Table 1. *Chi-Square* Test Between Driving Experience and ADAS Acceptance

Driving Experience (Years)	Acceptance Level (%)	X2	p-value
<1	55.0		
1-5	60.6		
6-10	68.3		
11-20	74.1	18.24	0.032*
>20	76.8		

*Note: *Significant at p < 0.05*

The difference between Figure 1 and Table 1 must be clarified. Figure 1 illustrates how respondents were distributed demographically (i.e., how many people fell into each experience category). In contrast, Table 1 presents the inferential test, showing the percentage of respondents within each category who expressed acceptance of ADAS technology. Thus, while Figure 1 shows who they are, Table 1 shows how their driving experience influenced their acceptance. The *Chi-square* result (χ^2 = 18.24, $p < 0.05$) indicates a statistically significant association between driving experience and ADAS acceptance. Respondents with more years of driving experience were more likely to accept ADAS technology. This suggests that exposure to diverse road conditions and accumulated driving risk awareness shape greater trust in safety-support systems, consistent with findings [21].

3.2 Reliability and Factor Analysis

The reliability test using Cronbach's Alpha produced a coefficient of 0.87, indicating strong internal consistency of the survey items. The Kaiser-Meyer-Olkin (KMO) measure was 0.82 and Bartlett's test of sphericity was significant ($p < 0.001$), confirming the suitability of the data for factor analysis. An exploratory factor analysis (EFA) was then conducted using Principal Component Extraction with Varimax rotation. Four latent factors with eigenvalues greater than 1.0 were extracted, jointly explaining 68.5% of the total variance. The scree plot confirmed this four-factor solution.

The first factor, Collision Avoidance Capability, included variables such as Adaptive Cruise Control (ACC), Lane Departure Warning (LDW), Blind Spot Detection (BSD), and Automatic Emergency Braking (AEB), with loadings ranging from 0.74 to 0.84. The second factor, Driver Behavior and Acceptance, reflected aspects of trust in ADAS, compliance with system alerts, and the impact of ADAS on distraction, with loadings between 0.65 and 0.80. The third factor, System Performance and Reliability, was characterized by responsiveness, consistency, and emergency braking effectiveness, with loadings from 0.68 to 0.81. Finally, the fourth factor, Road Safety Impact, included indicators such as accident reduction, pedestrian/cyclist detection, and overall improvements in road safety, with loadings ranging from 0.70 to 0.83.

These findings indicate that perceptions of ADAS are multidimensional, with collision avoidance and system reliability emerging as the strongest determinants of user trust. The results are consistent with previous studies, which emphasized that effective collision-avoidance and reliable system performance are the most critical aspects shaping driver confidence in ADAS [22]. Moreover, the emergence of Road Safety Impact as an independent factor supports the view that ADAS adoption should not only be framed in terms of individual technology acceptance but also in relation to broader societal benefits such as reducing fatalities, aligning with SDG 3 [6].

3.3 Integrated Discussion

The integration of inferential analysis and factor structure provides nuanced insights into how ADAS is perceived across different user groups [23,24]. The demographic findings highlight a paradox: while younger drivers are more eager adopters, it is the experienced drivers who display higher trust levels [24,25]. This suggests that successful ADAS deployment strategies must not adopt a one-size-fits all approach. Instead, policymakers and industry stakeholders should design differentiated interventions: education and awareness campaigns for younger drivers to channel enthusiasm into responsible usage, and reliability-focused technical improvements to sustain the trust of experienced drivers [25–27].

The factor analysis deepens this perspective by showing that trust is multidimensional. Trust is built not only through technical attributes (reliability, responsiveness) but also through behavioral aspects (compliance with warnings, reduced distraction) [23,28,29]. This resonates with the extended TAM framework, which posits that psychological variables moderate technology adoption [30]. Importantly, the identification of Road Safety Impact as a distinct latent construct signals that ADAS adoption cannot only be studied at the micro-level of user acceptance but also at the macro-level of societal benefit. From a theoretical standpoint, these findings bridge two discourses: human machine trust models and public health frameworks (SDG 3). The combination suggests that ADAS should not merely be evaluated as a driver aid but as a public safety intervention. This provides a richer conceptual lens for future research.

4. **Conclusion**

This study empirically assessed the impact of Advanced Driver Assistance Systems (ADAS) on road safety by combining a quantitative survey of 260 drivers with qualitative interviews and focus groups. Factor analysis revealed four latent constructs, Collision Avoidance, Driver Behavior and Acceptance, System Reliability, and Road Safety Impact explaining 68.5% of the variance. Among these, collision avoidance and system reliability emerged as the strongest predictors of user trust, while road safety impact was identified as a distinct dimension highlighting societal benefits. The findings provide clear evidence that ADAS adoption should be understood not only as a matter of individual technology acceptance but also as a public safety intervention that contributes to broader goals such as Sustainable Development Goal 3 (SDG 3). This answers the research question by confirming that ADAS influences driver trust and safety both at the individual and societal levels. From a theoretical perspective, the results extend existing technology adoption models by integrating dimensions of human–machine trust and sustainability. Practically, the findings suggest that policymakers and automotive stakeholders should prioritize reliability improvements, driver education, and context-specific deployment strategies to strengthen trust and maximize safety outcomes. Despite these contributions, the study has limitations. First, the sample was limited to drivers with prior exposure to ADAS in a specific national context, which may not fully represent global user diversity. Second, self-reported measures may introduce bias, while qualitative insights, though valuable, were restricted to a small subset of respondents. Future research should address these limitations by incorporating longitudinal data to capture behavioral adaptation over time, expanding samples across different regions and driving cultures, and employing experimental or real-world driving simulations to validate survey-based findings. Moreover, comparative studies between advanced and developing economies could provide deeper insights into how socioeconomic and infrastructural contexts shape ADAS adoption and impact.

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