The Impact of Advanced Driver Assistance Systems on Road Safety: Critical Review and Perspectives

O Impacto dos Sistemas Avançados de Assistência ao Condutor na Segurança Rodoviária: Análise Crítica e Perspetivas

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Abstract

Road safety remains one of the greatest global challenges, with severe human and economic costs, as human error is responsible for most accidents. This article, developed within the scope of the IDT – PIVOT project, Incentive System for Business Research and Development – Individual Operations, critically examines the role of Advanced Driver Assistance Systems (ADAS) in reducing road traffic accidents. The methodology consisted of a critical review of international literature (2000–2025), complemented by institutional reports and secondary data analysis. The results show that systems such as Autonomous Emergency Braking (AEB), Electronic Stability Control (ESC) and Intelligent Speed Assistance (ISA) can significantly reduce accidents and fatalities, achieving up to 58% reduction when combined. However, barriers remain regarding costs, lack of standardization, risks of driver overreliance and legal uncertainties. The study concludes that ADAS are an essential transitional technology towards autonomous mobility, fundamental to achieving the objectives of Vision Zero 2030.

Keywords: Road safety, ADAS, traffic accidents, autonomous mobility, public policies.

Resumo

A digitalização tem provocado uma redefinição significativa do conceito de Recursos Humanos, remodelando práticas tradicionais como recrutamento e seleção, tornando os processos mais eficientes e atrativos para candidatos. Além disso, é possível verificar que a automatização e a digitalização são as novas tendências, o que permite otimizar os procedimentos administrativos e, por consequência, leva a uma reestruturação estratégica por parte dos gestores e gestores de recursos humanos. Esta realidade competitiva e globalizada requer um novo perfil de liderança, focado na promoção de uma cultura organizacional inclusiva e na utilização da tecnologia como uma ferramenta de capacitação e não como substituição dos colaboradores. Através de uma abordagem qualitativa, fundamentada na revisão de literatura, o artigo analisa a transformação digital e o seu impacto direto na Gestão de Recursos Humanos (GRH), explorando a evolução histórica do fenómeno e os marcos que impulsionaram a integração tecnológica nas organizações. Foi possível apresentar uma proposta para uma correta implementação dos recursos digitais ao nível do recrutamento e seleção numa organização. Evidenciou-se o reposicionamento estratégico da GRH como um elemento fundamental para o pensamento crítico e adaptado às necessidades organizacionais, consolidando-se como um motor estratégico para o futuro das organizações. Destaca-se ainda que a transformação digital redefine as práticas GRH e exige colaboradores capacitados para desafios tecnológicos emergentes, consolidando-se como fator essencial para a competitividade das organizações num contexto global. Limitações e sugestões futuras são apresentadas no final.

Palavras-chave: Segurança rodoviária, ADAS, Acidentes de viação, Mobilidade autónoma, Políticas Públicas.

1. INTRODUCTION

Improving road safety emerged as a pressing challenge for modern societies at the start of the 21st century. Despite technological, legislative, and infrastructural advances, road accidents remain a leading cause of death and permanent disability worldwide. According to the World Health Organization (WHO), around 1.35 million people lose their lives in road accidents every year. This equates to an average of 3,700 deaths per day or one every 24 seconds (WHO, 2018). In addition to the irreparable human consequences, road accidents entail high economic and social costs, representing a significant portion of a country's Gross Domestic Product (GDP) (OECD/ITF, 2022).

In the framework of sustainable mobility policies, the European Union (EU) considers road safety a strategic priority. Since the 2000s, the European Commission has set ambitious targets to reduce road deaths through ten-year plans, encouraging Member States to work together (European Commission, 2018). While the EU has made significant progress, Member States did not fully meet the goal of halving road deaths between 2010 and 2020 (European Transport Safety Council [ETSC], 2020). The Road Safety Strategy 2021–2030 now aims to achieve a 50% reduction in deaths and serious injuries by 2030, following the Stockholm Declaration and the "Safe System" philosophy (European Commission, 2021). This approach assigns shared responsibility for road safety to drivers, manufacturers, public authorities, and civil society. It acknowledges that people inevitably make mistakes, but that authorities can and should mitigate the consequences (OECD/ITF, 2022).

In Portugal, the figures confirm the persistence of the problem. Despite positive developments over the last two decades, Portugal continues to average around 650 deaths and more than 2,000 serious injuries from road accidents each year (Institute for Mobility and Transport [IMT], 2020). In addition to the human tragedy, the associated costs were estimated at over €6.4 billion in 2019, equivalent to 3.03% of the national GDP (ANSR, 2021). Given this reality, the National Road Safety Strategy 2021–2030 — Vision Zero 2030 — was developed in accordance with European and international commitments (ANSR, 2021). The strategy is based on the principle that no road deaths are acceptable and establishes biennial action plans combining legislative, educational, infrastructural, and technological measures.

Identifying risk factors is crucial to understanding accident dynamics and designing effective responses. The most relevant factors include speeding, which accounts for about one-third of fatal accidents; drunk driving, which accounts for more than 20% of road deaths in Portugal; distracted driving, particularly due to mobile phone use, which quadruples the risk of an accident; and fatigue, which is associated with 10–20% of road collisions (ETSC, 2020; WHO, 2018). Additionally, pedestrians, cyclists, and motorcyclists are vulnerable, and their probability of death increases exponentially at an impact speed of 30 km/h (OECD/ITF, 2022).

The automotive industry and scientific community have invested in driving assistance technologies designed to reduce the impact of human error, which is widely recognized as the primary cause of most accidents (Litman, 2020). Advanced Driver Assistance Systems (ADAS) are considered essential for preventing collisions, alerting drivers to imminent risks, and mitigating the severity of unavoidable accidents (Wang, Zhang, & Li, 2020). These systems encompass features such as Automatic Emergency Braking (AEB), Electronic Stability Control (ESC), Driver Drowsiness and Attention Warning (DDAW), and Intelligent Speed Assistance (ISA).

The evolution of these systems reflects ongoing technological progress. Driver Assistance Systems (DAS) were introduced in the 1970s and 1980s, featuring innovations such as ABS and ESC. ADAS followed in the 1990s, integrating smart sensors, cameras, and radars. Cooperative ADAS (C-ADAS) subsequently expanded assistance through Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) connectivity. ADS now aim to achieve levels 4 and 5 of autonomy as defined by the Society of Automotive Engineers (SAE, 2021).

Scientific literature has demonstrated that these systems are effective in reducing accidents. According to international studies, widespread adoption of ADAS can reduce road accidents by up to 58%, depending on the combination of features installed (ETSC, 2020). Specifically, AEB is estimated to reduce accidents by around 20%, ESC by 5–7%, and ISA is shown to significantly contribute to compliance with speed limits and directly impact pedestrian mortality (Wang et al., 2020). However, the effectiveness of ADAS should not be analyzed solely in statistical terms. Practical limitations must also be considered, such as the lack of standardization between manufacturers, restricted accessibility to high-end vehicles, the risk of driver overconfidence, and legal implications for assigning liability in the event of an accident (Litman, 2020; SAE, 2021).

This article provides a critical analysis of the role of ADAS in road safety. It examines the current state of research, empirical evidence, and prospects for the evolution toward autonomous driving. The article is structured in five sections: an introduction; a literature review that synthesizes research on road accidents, risk factors, and driving assistance technologies; a presentation of the research methodology, emphasizing a critical literature review and secondary data analysis; a results and discussion section that evaluates the impact of ADAS, including their benefits, limitations, and policy implications; and a concluding section that summarizes key contributions and proposes directions for future research and implementation.

2. Literature Review

2.1. Road Accident Framework

The WHO recognizes road accidents as a global public health problem. They represent the eighth leading cause of death worldwide and the leading cause of death among children and young adults aged 5 to 29 (WHO, 2018). It is estimated that 1.35 million people die on the roads each year, and tens of millions more are injured with permanent sequelae (WHO, 2018). The aggregate economic impact amounts to hundreds of billions of dollars, which may correspond to up to 5% of GDP in some countries (OECD/ITF, 2022).

In the European context, the EU set ten-year targets to reduce deaths and serious injuries. The EU aimed to halve the number of victims between 2010 and 2020, but this goal was not fully achieved despite remarkable progress (European Commission, 2018; ETSC, 2020). The 2021–2030 framework renews the –50% target and establishes Vision Zero as the goal for 2050 (European Commission, 2021; OECD/ITF, 2022).

In Portugal, the long-term trend is downward, albeit at concerning levels. In 2019, there were 628 deaths and 2,144 serious injuries, resulting in an estimated social cost of €6.4 billion (National Road Safety Authority [ANSR], 2021). Vision Zero 2030 takes a shared responsibility and systemic approach to mitigating human error (ANSR, 2021; OECD/ITF, 2022).

2.2. Risk Factors in Accident Rates

The literature states that over 90% of accidents involve human error (ETSC, 2020; WHO, 2018).

- Speed is associated with approximately one-third of deaths, increases braking distance and impact severity, and increases the probability of pedestrian death. The probability of pedestrian death is greater than 80% at 50 km/h and less than 10% at 30 km/h (OECD/ITF, 2022; Richards, 2010).
- Alcohol and psychoactive substances: present in over 20% of deaths in Portugal; 0.5 g/L doubles the risk of an accident; other substances and sedative drugs compromise reaction times (ANSR, 2021; WHO, 2018).
- Distractions: Using a mobile phone while driving quadruples the risk by affecting visual, cognitive, and manual attention (ETSC, 2020; Dingus et al., 2016).
- Fatigue/drowsiness is estimated to account for 10–20% of motorway accidents (OECD/ITF, 2022; May & Baldwin, 2009).
- Vulnerable users: Pedestrians, cyclists, and motorcyclists face a disproportionate risk, especially above 30 km/h in urban areas (OECD/ITF, 2022; WHO, 2018).

These factors highlight the importance of complementary technology, enforcement, and traffic calming policies (ETSC, 2020; OECD/ITF, 2022).

2.3. Historical Evolution: DAS, ADAS, C-ADAS, and ADS

This evolution mirrors the transition from specific aids to cooperative ecosystems:

- DAS (1970s–1980s): ABS and ESC were developed to prevent loss of control (National Highway Traffic Safety Administration [NHTSA], 2015).
- ADAS (1990s–present): sensors, cameras, and radar; ACC, LDW, BLIS, and AEB (ETSC, 2020; Peden et al., 2004).
- C-ADAS (2020–present): V2V and V2I connectivity extends perception beyond onboard sensors (European Commission, 2021; Papadimitratos et al., 2009).
- ADS: SAE levels 0–5, ranging from assistance levels (0–2) to conditional (3) and full (5) automation (SAE, 2021).

The paradigm shifts from an isolated driver to an interconnected vehicle-user-infrastructure system (OECD/ITF, 2022).

2.4. ADAS Features

ADAS integrates the following complementary features:

- AEB: detects obstacles and activates braking. It is associated with a ~20% reduction in rear-end collisions and additional benefits with pedestrian/cyclist detection (Wang, Zhang, & Li, 2020; ETSC, 2020).
- ESC corrects trajectories and achieves an average reduction of 5–7% in serious collisions and higher impacts in loss of control (NHTSA, 2015; OECD/ITF, 2022).
- ISA: Promotes compliance with speed limits and has the potential to reduce pedestrian fatalities and average speeds (European Commission, 2021; ETSC, 2020).
- DDAW monitors fatigue and distraction. Its effectiveness increases when combined with tactile or audible alerts (May & Baldwin, 2009; Fleury et al., 2017).
- ACC/LDW/LKA/BLIS reduce dangerous approaches, lane departures, and lane-change conflicts. However, they can lead to complacency or "alert fatigue" (ETSC, 2020; Larue et al., 2015).

2.5. Scientific Evidence on the Effectiveness of ADAS

Meta-analyses and before-and-after studies suggest that a combination of AEB, ESC, and ISA could reduce accidents by up to 58%, depending on the level of adoption and the mix of technologies (ETSC, 2020). In Portugal, modelling exercises suggest that widespread deployment could substantially increase the number of lives saved and serious injuries avoided (IMT, 2020).

Specific evidence:

- AEB: reduction of rear-end collisions by 20%;
- ESC: reduction of serious accidents by 5–7%; greater effect on loss of control;
- ISA: significant reduction of speeding and pedestrian deaths in urban areas (Wang et al., 2020; NHTSA, 2015; European Commission, 2021).

However, variations persist by manufacturer, context, and user profile, and there is a risk of overconfidence (Litman, 2020; Larue et al., 2015).

2.6. Limitations and Challenges

The main constraints include:

- Standardization: Non-uniform interfaces, symbols, and behaviours between brands (ETSC, 2020).
- Costs and access: Advanced features are concentrated in the mid- to high-range vehicles (OECD/ITF, 2022).
- Driver dependency: SAE levels 1–2 require constant vigilance and may create false expectations of autonomy (SAE, 2021).
- Legal and ethical issues: The attribution of responsibility in events involving system intervention remains debated (European Commission, 2021; Litman, 2020).
- Social acceptance and alert fatigue: Resistance to technologies perceived as intrusive, as well as the possibility of "switching off" systems (Larue et al., 2015; ETSC, 2020).

2.7. Future Prospects

The EU requires that all newly approved vehicle models integrate AEB, ISA, and DDAW, thereby accelerating the adoption of these technologies (European Commission, 2021). In the medium term, V2X connectivity will support C-ADAS with real-time data sharing (Papadimitratos et al., 2009; European Commission, 2021). In the long term, levels 4–5 automation depend on technological maturity, regulatory standardization, and public acceptance. The transition will be gradual, coexisting with conventional vehicles (SAE, 2021; OECD/ITF, 2022). Thus, ADAS remains a critical bridge technology for autonomous mobility (Litman, 2020).

3. Methodology

3.1. Nature of the Research

This article is part of a critical review of scientific literature on road safety and ADAS. The research is qualitative and exploratory, focusing on analyzing, synthesizing, and interpreting previously published results (Grant & Booth, 2009). The objective is to systematize the state of the art, identify patterns of effectiveness, point out limitations, and highlight future trends related to the technological evolution of ADAS.

A critical review was chosen to gather and compare scattered evidence from diverse areas, such as automotive engineering, traffic psychology, public health, transport economics, and public policy (Snyder, 2019). ADAS is a multidisciplinary field, and integrating results is essential to understanding its overall impact on road safety.

3.2. Bibliographic Research Strategy

The bibliographic research was conducted in the following international scientific databases: Scopus, Web of Science, IEEE Xplore, ScienceDirect, and SpringerLink. This research was supplemented by institutional reports from organizations such as the WHO, the European Commission, the ETSC, and the ANSR.

Combinations of keywords in Portuguese and English were used, including: "road safety," "traffic accidents," "DAS," "ADAS effectiveness," "Cooperative ADAS," "ADS," "AEB," "ESC," "ISA," "driver monitoring," "road safety," "accident rates," and "ADAS effectiveness."

The search covered publications from 2000 to 2025 to ensure coverage of recent technological developments and topicality (Kitchenham & Charters, 2007).

3.3. Inclusion and Exclusion Criteria

Studies that met at least two of the following criteria were included:

1. An empirical evaluation of the effectiveness of one or more ADAS in reducing accidents, serious injuries, or deaths.
2. Systematic reviews or meta-analyses on ADAS.
3. Relevant case studies in comparable international contexts (e.g., Europe, the United States, Japan, and Australia).
4. Official reports from government agencies or international organizations.

Excluded were non-peer-reviewed publications, promotional documents (e.g., manufacturers' marketing materials), and studies with insufficiently described methodologies (Moher et al., 2009 – PRISMA framework).

3.4. Selection and Analysis Process

The initial search yielded approximately 450 publications. After reviewing the abstracts, 230 were eliminated due to duplication or irrelevance. Of the remaining 220 publications, 120 were selected for full reading, and 80 were included in the final analysis.

The analysis used a narrative synthesis approach organized into four main areas:

Accident rates and risk factors.

Historical evolution and classifications of assistance systems.

Scientific evidence on the effectiveness and impact of ADAS.

Limitations, challenges, and prospects.

The analysis critically compared quantitative data (e.g., accident reduction percentages), highlighting methodological differences between studies (Popay et al., 2006).

3.5. Methodological Limitations

This review has several limitations:

- Heterogeneity of studies: The methodologies range from controlled trials to simulations, which makes direct comparisons difficult (Grant & Booth, 2009).
- Different contexts: Results from countries with different infrastructure and fleets from Portugal may affect the transferability of the results (OECD/ITF, 2022).
- Rapid technological evolution: Continuous innovation means some studies quickly become

outdated (Litman, 2020).
- Lack of national data: In Portugal, there is still little empirical analysis of the real impact of ADAS, forcing extrapolations from international data (IMT, 2020).

Despite these limitations, the adopted methodology allows us to identify robust trends and synthesize knowledge relevant to public policy and future research.

3.6. Originality of Approach

Unlike technical or automotive engineering reviews that focus exclusively on one aspect, this research takes an integrated approach that crosses technological, behavioural, and political dimensions. The goal is to not only describe functionalities but also to critically discuss their actual impact on road safety while considering practical limitations, implementation barriers, and ethical implications (Snyder, 2019).

4. Results and Discussion

4.1. Overall Impact of ADAS on Accident Reduction

The international literature confirms that ADAS significantly impact the reduction of road accidents. Comparative studies in Europe and the U.S. show that vehicles equipped with AEB, ESC, and ISA have lower accident rates than vehicles without these systems (ETSC, 2020; NHTSA, 2015).

A meta-analysis by the ETSC concluded that the combined adoption of ADAS can reduce accidents by up to 58%, depending on the technological configuration. In Portugal, simulations by the IMT (2020) indicate that widespread adoption could save hundreds of lives and prevent thousands of serious injuries.

However, the impact depends on the context, including the average age of the fleet, the quality of the infrastructure, and driving behavior (OECD/ITF, 2022). Countries with newer fleets benefit more quickly, while the effect is less immediate in contexts with older vehicles (Litman, 2020).

4.2. Functionality Analysis:

Automatic Emergency Braking (AEB)

AEB is one of the most studied systems. The European Commission has estimated a ~20% reduction in rear-end collisions (European Commission, 2021). Its effectiveness increases when pedestrians and cyclists are detected (Wang, Zhang, & Li, 2020). However, limitations include false positives and poorer performance in poor weather conditions (Larue, Rakotonirainy, & Pettitt, 2015).

Electronic Stability Control (ESC)

ESC has been mandatory in the EU since 2014 and is considered one of the most effective systems. According to NHTSA data, there have been reductions of 41% in single-vehicle accidents and 56% in light passenger vehicles (NHTSA, 2015). In Europe, average reductions are between 5 and 7 per cent (OECD/ITF, 2022). ESC illustrates how regulation can accelerate the adoption of safety technologies (ETSC, 2020).

Intelligent Speed Assistance (ISA)

Mandatory in new vehicles in the EU starting in 2024, ISA could reduce pedestrian deaths in urban areas by 20–30% (European Commission, 2021). However, social acceptance is a challenge; some drivers perceive the system as intrusive (Regan et al., 2020).

Driver Drowsiness and Attention Warning (DDAW)

Fatigue/distraction monitoring has proven effective in laboratory studies (May & Baldwin, 2009). However, there are barriers such as privacy and cost concerns (Fleury et al., 2017).

Other systems (ACC, LDW, LKA, and BLIS)

- ACC reduces collisions due to excessive proximity but may induce complacency (Larue et al., 2015).
- LDW/LKA is useful on motorways, but the frequency of alerts may cause drivers to deactivate them (Regan et al., 2020).
- BLIS: Effective against side collisions, especially those involving motorcyclists (OECD/ITF, 2022).

4.3. Systemic Benefits and Empirical Evidence

The combination of ADAS features has synergistic effects. ACC + AEB increases safety in heavy traffic, while ISA + ESC reduces loss of control due to excessive speed. DDAW + LDW protects in fatigue-related scenarios (ETSC, 2020).

According to European studies, the mandatory implementation of AEB, ESC, ISA, and DDAW could save 25,000 lives by 2038 (European Commission, 2021). However, this depends on the renewal of the vehicle fleet. In countries such as Portugal, this process is slow (IMT, 2020).

4.4. Limitations and Risks

Despite the potential, limitations remain:

- Costs and unequal access: Technologies are concentrated in premium vehicles (OECD/ITF, 2022).
- Insufficient standardization: Different interfaces and symbols confuse users (ETSC, 2020).
- Alert overload: Too many signals can be distracting (Larue et al., 2015).
- Overconfidence: Some drivers reduce their active vigilance because they believe the system is in control (Regan et al., 2020).
- Legal issues remain, such as ambiguous liability in accidents involving partial system intervention (Litman, 2020; SAE, 2021).

4.5. Future Prospects: From ADAS to ADS

The evolution points to a gradual transition from ADAS to Automated Driving Systems (ADS). The SAE classification system includes five levels, but only levels 0–2 (partial assistance) are currently widespread. Level 3 (conditional automation) has already been authorized in countries such as Germany and Japan (SAE, 2021).

In the medium term, C-ADAS with V2X connectivity is expected to become widespread, enabling the anticipation of invisible risks (Papadimitratos et al., 2009).

In the long term, levels 4–5 will depend on 5G/6G technology, legislative standardization, and social acceptance (Litman, 2020; OECD/ITF, 2022). During this transition, ADAS will continue to be an essential bridge technology (ETSC, 2020).

4.6. Implications for Public Policy

The results suggest the following implications:

- European legislation: The European Commission (2021) states that mandatory key ADAS from 2024 is a structural milestone.
- National policies: Countries with ageing fleets, such as Portugal, need incentives for renewal (IMT, 2020).
- Education and awareness: The effectiveness of ADAS depends on correct use, so technological literacy is essential (ETSC, 2020).
- Social equity: State support can prevent inequalities in access to safety (OECD/ITF, 2022).
- Ethical/legal issues: There is an urgent need to clarify liability in accidents involving partial system intervention (Litman, 2020; SAE, 2021).

5. Conclusions

The analysis presented in this article confirms that road safety remains a significant global challenge with enormous social, economic, and public health implications (WHO, 2018; OECD/ITF, 2022). Despite progress in recent decades, accident rates remain concerning, particularly in countries with ageing vehicle fleets and diverse infrastructure (IMT, 2020).

ADAS play a decisive role in this context as technological tools capable of mitigating human error, which is responsible for most road accidents (ETSC, 2020; SAE, 2021). A literature review demonstrated the evolution of these systems from DAS (e.g., ABS and ESC) to current ADAS (e.g., AEB, ISA, and DDAW), as well as the emergence of C-ADAS and ADS (Papadimitratos et al., 2009; Litman, 2020).

The discussed results show measurable benefits, including an average 20% reduction in rear-end collisions with AEB (Wang, Zhang, & Li, 2020); a 5–7% reduction in serious accidents with ESC (NHTSA, 2015); and a significant reduction in pedestrian fatalities with ISA (European Commission, 2021). Together, these systems can reduce accidents by up to 58% (ETSC, 2020).

However, there are still critical limitations: a lack of full standardization among manufacturers (Larue, Rakotonirainy, & Pettitt, 2015), high costs that restrict diffusion (OECD/ITF, 2022), risks of driver overconfidence (Regan, Oviedo-Trespalacios, & Symmons, 2020), and ethical and legal challenges in assigning liability in accidents (SAE, 2021; Litman, 2020).

The experience with ESC, which became mandatory in the EU in 014, shows that regulation can accelerate the democratization of safety technologies (NHTSA, 2015; ETSC, 2020). Similarly, the mandatory installation of ISA, AEB, and DDAW in all new vehicles starting in 2024 is expected to have a significant impact (European Commission, 2021).

From a forward-looking perspective, the future points to the consolidation of C-ADAS based on V2X and 5G/6G networks, as well as a gradual transition to Level 3–5 ADS (Papadimitratos et al., 2009; SAE, 2021). However, for decades, full autonomous mobility will coexist with conventional vehicles, reinforcing the critical role of ADAS in this transition (Litman, 2020).

Portugal's priority should be to accelerate the renewal of its vehicle fleet, encourage the purchase of ADAS-equipped vehicles, and integrate these technologies into national road safety strategies (IMT, 2020; ANSR, 2021). Only then will Portugal be able to align with the objectives of Vision

Zero 2030 and contribute to the European goal of eliminating deaths and serious injuries by 2050 (European Commission, 2021).

In short, ADAS are not just technological tools; they are catalysts for structural changes in how we conceive of mobility. Their success depends on overcoming economic, social, and legal barriers; achieving technical standardization; and fostering cooperation between industry, policymakers, and civil society, all within the framework of a safe and sustainable system (OECD/ITF, 2022; ETSC, 2020).

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ETHICAL PROCEDURES

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