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THE TRANSITION TO THE NEXT-GENERATION (NG) ARCHITECTURE OF ECALL SYSTEM IN THE X_HeERO PROJECT

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Abstract: *Road safety, in particular the protection of vulnerable users (VRU), remains a major challenge in the European Union. The pan-European eCall system was a fundamental step in reducing the response time to accidents. This paper analyzes the imperative technological transition from the conventional eCall system, based on circuit-switched networks, to the new generation architecture (NG eCall), based on IP technologies. At the heart of this transition is the European project X_HeERO, whose contributions are essential for the modernisation of the infrastructure of the Emergency Call Answering Points (PSAPs). The paper demonstrates the technical superiority of NG eCall and determines the component elements of the cost-benefit analysis, highlighting the role of the new architecture in creating an advanced paradigm for road incident management.*
Keywords: *NG eCall, X_HeERO, road safety, vulnerable users (VRU), VoIP, IMS, PSAP.*

1. INTRODUCTION

Road safety is a key strategic priority in the Union's policies, aligned with the long-term objective of Vision Zero [1], which aims to completely eliminate road deaths and serious injuries. Despite significant progress in recent decades, the number of victims remains unacceptably high. Statistical data at the EU level indicate that by 2023, there were 20,640 deaths caused by road accidents, underlining the persistence of a public safety crisis [2].

A detailed analysis of these statistics revealed the disproportionate vulnerability of certain categories of road users. Vulnerable Road Users (VRUs), a heterogeneous group that includes pedestrians, cyclists, and motorcyclists, are particularly severely affected. In 2021, they will account for 48% of all road deaths in the EU, with a distribution of 20% for pedestrians, 18% for motorcyclists, and 10% for cyclists. In urban areas, where the interaction between vehicles and VRUs is most intense, pedestrians make up 37% of all victims.1 These alarming figures demonstrate the pressing need to develop and implement dedicated technological measures capable of providing a higher level of protection for the most exposed segments of the population.

In this context, the mandatory implementation of the pan-European eCall system, starting on March 31, 2018, was a milestone in efforts to improve road safety. Designed to dramatically reduce the time it takes to notify emergency services in the event of a serious accident, eCall has demonstrated the ability to shorten the critical time to medical intervention, known as the 'golden hour,' a determinant of victims' survival.

The central thesis of this study is that the transition from the conventional system to the next-generation architecture (Next-Generation eCall - NG eCall) is a major step forward in the emergency communications paradigm. The core initiative of this Europe-wide transformation effort is the X_HeERO project (project number 101175713), which acts as the main vector for implementation and standardization of the new architecture. The persistence of high mortality rates among VRUs has created a political and social imperative that has led to the funding and prioritization of advanced technology projects. Thus, X_HeERO is not just a technological upgrade project but a direct and targeted

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response to a specific humanitarian problem, transforming a social challenge into a large-scale technical mission.

This study provides a multi-faceted analysis of the transition to NG eCall, moving beyond a purely technical comparison. It aims to demonstrate that this transition is not only a technological imperative but also a socio-economically justified and manageable undertaking. To achieve this, the paper analyzes the historical evolution and technical superiority of the NG architecture, highlights the specific contributions of the X_HeERO project, and provides a structured assessment of the critical implementation risks and mitigation strategies as defined within the project's official framework. Furthermore, it presents preliminary empirical findings from the project's socio-economic cost-benefit analysis, with a particular focus on quantifying the system's life-saving impact for Vulnerable Road Users (VRUs). This holistic approach provides a comprehensive assessment of the NG eCall transition, aligning technological innovation with policy, safety, and economic considerations.

2. DEVELOPMENT AND IMPLEMENTATION OF THE CONVENTIONAL ECALL SYSTEM

The foundations of the eCall system, as is known today, have been strengthened through a series of precursor projects co-financed by the European Union. Initiatives such as HeERO1 [3], HeERO2, and later I_HeERO [4], carried out between 2012 and 2018, played a key role in testing feasibility, developing technical standards, and ensuring the initial modernization of the Public Safety Answering Points (PSAP) infrastructure in the participating Member States.

The technical architecture of the conventional eCall system, which has been mandatory for all new cars sold in the EU since 2018, has been designed in a different technological era. Its operation is based on circuit-switching technology, specific to second- and third-generation mobile networks (2G - GSM and 3G - UMTS, respectively). In the event of an accident, the system initiates a voice call for 112 emergency numbers and, in parallel, uses an in-band modem to transmit a Minimum Set of Data (MSD). This data package, with a fixed size of 140 bytes, contains critical information for locating and identifying the incident: precise GPS coordinates, the direction of travel of the vehicle before the impact, and the vehicle identification number (VIN).

Although it represents a major advance, this “legacy” architecture suffers from fundamental limitations that compromise its efficiency and long-term viability, fully justifying the need for technological evolution [5]:

- Restricted bandwidth: MSD's 140-byte MSD is insufficient to transmit complex data such as images, video recordings, or detailed logs from vehicle sensors. This limitation significantly reduces the ability of PSAP operators to achieve full and immediate situational awareness.
- Dependence on obsolete networks: The operation of the system is intrinsically linked to 2G and 3G networks. At the European level, telecommunications operators have already started the process of decommissioning these networks to free up the radio spectrum for newer and more efficient technologies, such as 5G. This trend directly threatens the continuity of the eCall service, rendering the systems installed on millions of vehicles unusable.
- Voice channel interference: Using an in-band modem to transmit the MSD can result in muting the voice channel. In an emergency, in which every second of verbal communication with victims can be vital, this interruption represents a significant operational disadvantage.
- Incompatibility with modern architecture: The conventional eCall system is fundamentally incompatible with the fully Internet Protocol (all-IP) architecture of 4G/LTE and 5G networks.

3. NG eCALL AND CONVENTIONAL eCALL

The transition to Next-Generation eCall (NG eCall) should not be seen as an incremental evolution but as a fundamental technological leap that aligns emergency communications

with the modern architecture of telecommunications networks. NG eCall abandons the circuit-switching-based model in favor of an IP native architecture built on three key technology pillars:

- IP Multimedia Subsystem (IMS): This represents a standardized architectural framework, essential for the provision of advanced multimedia services, such as Voice over LTE (VoLTE), over IP-based networks. The IMS is the backbone of modern communications, enabling seamless integration of different types of media.
- Voice over IP (VoIP): This technology allows voice communication to be transmitted in the form of data packets, eliminating the need for a dedicated circuit. Through VoIP, voice and data can coexist and be transmitted simultaneously over the same network connection, without interference.
- Session Initiation Protocol (SIP): This is a signaling protocol used to initiate, maintain, and terminate communication sessions in real-time. In the NG eCall architecture, SIP plays a crucial role because the Minimum Data Set (MSD) is no longer transmitted through a slow modem but is incorporated directly into the session initiation message (SIP INVITE), reaching the PSAP instantly once the call is established.

This robust architecture is governed by a set of European standards that ensure technical rigor and interoperability across the union. Among the most relevant are ETSI TS 103 683, which defines communication protocols [6]; EN 15722, which standardizes the content of MSD; and CEN TS 17240, which establishes procedures for conformity testing.

The differences between the two systems are fundamental and highlight the superiority of next-generation architectures. Table 1 provides a direct comparison of the most important technical characteristics, summarizing the complex information in a clear and concise format, which fully justifies the efforts and investments directed through the X_HeERO project.

The comparative analysis demonstrates that NG eCall not only solves the critical deficiencies of the conventional system but also paves the way for a new generation of emergency services, capable of handling a much larger volume and a much wider variety of data, essential for an effective response in the event of an accident.

Table 1

Technical Comparison of Conventional eCall vs. NG eCall.

Feature	Conventional eCall (GSM/UMTS)	NG eCall (4G/5G/IMS)	Feature
Core Network	Circuit Switching (2G/3G)	Packet Switching (All-IP 4G/5G)	Core Network
Data Transmission Method	In-band modem	Protocol Internet (IP) via SIP INVITE	Data Transmission Method
Data Volume (MSD)	Fixed, 140 bytes	Expandable, significantly larger	Data Volume (MSD)
Impact on the Voice Channel	Possible interruption/muting during MSD transmission	No impact; Data and voice are on separate paths	Impact on the Voice Channel
Scalability (Video, Sensors)	Existent	Native, supports multimedia and bidirectional data	Scalability (Video, Sensors,)

4. CHALLENGES AND OBJECTIVES OF PROJECT X_HeERO

Project X_HeERO – eCall Next Generation (23-EU-TG eCall NG) [7] (is a large-scale initiative, coordinated by ITS MOBILITY GMBH from Germany, which brings together a consortium of 45 partners (38 beneficiaries and seven associated partners) from 11 European countries. It is positioned as the European Commission's main strategic tool for orchestrating and supporting Member States in the complex and mandatory transition to NG eCall. Given the deadline of January 1, 2026, for implementation at the level of all PSAPs in the EU, the project's role is critical. Its main objectives include the creation of detailed deployment plans ("blueprints") for the modernization of the PSAP infrastructure, rigorous testing of the entire communication chain, and ensuring cross-border

interoperability, a key aspect of a trans-European transport network.

4.1 The Romanian consortium and pilot site

Within the X_HeERO project, Romania is represented by a robust consortium of six key partners from the public and private sectors: the Special Telecommunications Service (RO_STS), the Romanian-American University (RO_RAU), Orange Romania (RO_ORO), Telekom Romania Mobile Communications (RO_TRM), Greensoft (RO_GS) and Radcom (RO_RADCOM).

The tasks of the Romanian consortium are diverse and cover the entire spectrum of NG eCall implementation:

- Modernization of the 112 Infrastructure: The partners collaborate to modernize the national eCall platform, ensuring compatibility with NG technical specifications based on IMS packet-switched technologies while maintaining the ability to handle conventional calls.
- Mobile network upgrade: Mobile network operators (ORO and TRM) are upgrading their infrastructure to support NG eCall functionalities and to ensure compliance with new signaling and data transmission requirements.
- Software development and integration: Software companies (GS and RADCOM) developed and integrated NG eCall-specific data into the software platforms used by 112 centers and emergency agency dispatches.
- Cost-Benefit Analysis and dissemination: The Romanian-American University (RAU) has a strategic role in conducting a two-stage Cost-Benefit Analysis (CBA) to assess the feasibility and economic impact of implementing NG eCall at the European level. This analysis uses the methodology approved by the European Commission and includes the application of the Technology Acceptance Model (TAM) to understand the factors of acceptance by users. The results of this analysis are essential for informing investment decisions and public policies at the EU level.

4.2 Project risks and mitigation strategies

The successful pan-European deployment of NG eCall, orchestrated by a large consortium of 45 partners across 11 countries under a strict deadline, is contingent upon the effective management of several critical risks.

The X_HeERO project framework explicitly identifies these challenges and outlines corresponding mitigation strategies to ensure a smooth and secure transition. Key risk categories include:

- Technical and Interoperability Risks: A primary challenge lies in ensuring seamless end-to-end communication and interoperability between the diverse national PSAP systems, mobile network operator (MNO) infrastructures, and in-vehicle systems across the EU. Mitigation involves the creation of detailed deployment blueprints, rigorous cross-border testing of the entire communication chain, and adherence to harmonized European standards such as ETSI TS 103 683.1
- Cybersecurity and Data Privacy Risks: The transition to an all-IP architecture exposes the emergency communication system to new cybersecurity threats, such as denial-of-service attacks or data interception. Furthermore, the handling of sensitive MSD and potentially richer datasets requires strict compliance with data protection regulations like GDPR. The project's mitigation strategy includes conducting thorough security analyses, implementing robust encryption and authentication protocols, and developing clear guidelines for PSAPs on secure data handling and privacy compliance.1
- Stakeholder Engagement and Adoption Risks: The mandatory nature of the transition does not automatically guarantee timely adoption. Delays can arise from administrative hurdles, insufficient resource allocation at the national level, or lack of coordination between PSAPs, MNOs, and regulatory bodies. X_HeERO mitigates this risk by acting as a central coordination platform, providing technical guidance, fostering collaboration through workshops and webinars, and engaging with national

authorities to support their deployment roadmaps.

- Dependence on Third-Party Vendors: Many PSAPs rely on a limited number of specialized vendors for their core software and hardware. Any delays or issues from these vendors could create significant bottlenecks. The project addresses this by performing thorough vendor assessments, encouraging the use of standardized and certified components, and defining clear service level agreements (SLAs) in procurement contracts to ensure accountability and timely delivery.

By systematically addressing these risks, the X_HeERO project aims to de-risk the complex transition and provide a clear, replicable path for all Member States to achieve NG eCall readiness.

4.3 Identifying the socio-economic benefits and costs

One of the most important contributions of the X_HeERO project is the rigorous quantification of the socioeconomic benefits generated by the implementation of NG eCall.

The calculation assumptions, according to the project's grant agreement, stipulate that the implementation of eCall can reduce fatalities by approximately 5% and serious injuries by 10% among the VRUs. These percentages are based on the acceleration of emergency medical response. The associated societal costs are assessed using standardized values: the Value of a Statistical Life (VSL) [8] is estimated at €2.5 million in EU27, and the Value of a Critical Injury Avoided (VCIS) [9] at €300,000. The benefits and costs are summarized in Table 2. This assessment is ongoing, and the first results are presented in section 5.

Table 2

Summary of Estimated Benefits and Costs for the Implementation of NG eCall for VRU.

Estimated Benefits	Estimated Costs
Directly Monetizable Benefits	*Technology and Implementation Costs*
Reducing Deaths (Lives Saved)	Software development (mobile application scenario)
Reducing the severity of injuries	Device acquisition ('wearable' scenario)
Reduction of direct medical costs	Infrastructure equipment (beacon scenario)
Reducing productivity losses	Marketing, logistics, and support costs
Qualitative Benefits (Secondary)	*Operation and Maintenance Costs*
Reducing traffic congestion post-crash	Maintenance of servers, software and data costs
Increasing the sense of public safety	Service subscriptions ('wearable' scenario)
Increased efficiency for emergency services	Hardware and power maintenance (beacon scenario)
	Societal costs
	The cost of interventions to false alarms
	Privacy Risk Mitigation Measures

4.4 X_HeERO innovation and scope expansion

The X_HeERO project is not limited to the modernisation of the existing system, but acts as a catalyst for extending eCall's functionalities to new technological frontiers, transforming it into an integrated safety ecosystem, the following items being inquired:

- Integration with Autonomous Vehicles (AV): The NG eCall architecture with its superior bandwidth unlocks the potential of autonomous vehicles to act as high-fidelity data sources in the event of an accident. Instead of a 140-byte MSD, an autonomous vehicle can transmit a “comprehensive incident-data packet. This can include multimodal data that provide unprecedented situational awareness for PSAP operators, such as point clouds from LiDAR sensors for an accurate 3D reconstruction of the collision scene; video recordings from inside and outside the vehicle captured before, during, and after impact; and data from RADAR sensors regarding the speed and trajectory of other objects involved.
- Integration with Wearable Devices: Another innovative direction explored within the project is synergy with wearable devices such as smartwatches. They can add a vital layer of medical information to emergency calls. By transmitting vital signs, such as heart rate

and blood oxygen saturation (SpO2), directly to the PSAP in real time, the system can provide critical indications of the victim's medical condition (e.g., shock, internal bleeding, or cardiac arrest). This information allows for superior medical triage during the dispatching phase and adequate training of the intervention crews. Preliminary estimates suggest that this integration could increase the efficiency of the system, leading to a reduction in mortality by up to 20% and serious injuries by up to 28%.

By defining the technical requirements for integrating data from AVs and wearables, X_HeERO not only implements a standard, but also de facto sets the agenda for the future of road safety. The project creates a market for new safety technologies and services, generating a positive feedback loop, which makes NG eCall more valuable, and the existence of NG eCall as a standardized communication platform stimulates the development of safety functionalities in these technologies.

5. SOCIO-ECONOMIC IMPACT AND USER-CENTERED PERSPECTIVES

Beyond the technical imperatives, the transition to NG eCall is fundamentally driven by its potential to enhance humanitarian outcomes. The X_HeERO project places a strong emphasis on this dimension, operationalizing its commitment to road safety through a user-centered design philosophy and a rigorous socio-economic evaluation framework.

This user-centered approach is operationalized through a particularized Cost-Benefit Analysis (CBA) methodology, which develops specific models for different VRU categories, including pedestrians, cyclists, and motorcyclists. Rather than applying a generic evaluation, the project's framework considers the unique accident scenarios, risk factors, and potential benefits of NG eCall for each group. This ensures that the socio-economic assessment is grounded in the lived reality of the most exposed road users, making the analysis both more accurate and more relevant to its humanitarian goals.

The rigor of this framework is further established by its adherence to standardized European Commission guidelines for monetizing societal benefits. The analysis employs key indicators such as the Value of Avoiding a Fatality (VAF) and the Value of Avoiding a Severe Injury (VASI), derived from the authoritative Handbook on the external costs of transport.

5.1 Reinforcing User-Centered Perspectives for VRUs

The central humanitarian goal of the eCall initiative, protecting human life, is most critical for Vulnerable Road Users (VRUs), who account for a disproportionate share of road fatalities. The X_HeERO project institutionalizes its focus on this group through its formal structure and analytical methodologies. Work Package 2 of the project, titled "eCall for vulnerable road users and autonomous vehicles," is explicitly dedicated to studying and developing solutions tailored to the needs of pedestrians, cyclists, and motorcyclists.

This user-centered approach extends to the project's analytical framework. Rather than treating road users as a monolithic group, the project's Cost-Benefit Analysis (CBA) develops particularized methodologies for different VRU categories. This granular analysis acknowledges that the risks, accident scenarios, and technological solutions (e.g., smartphone applications versus wearable devices) differ significantly between a pedestrian and a motorcyclist. By developing distinct models, the project ensures that the evaluation of NG eCall's benefits is grounded in the real-world contexts of the most exposed populations, reinforcing the principle that technological advancement must be directly tied to tangible improvements in human safety.

5.2 Preliminary Cost-Benefit Analysis findings

To provide a robust economic rationale for the significant investments required for the NG eCall transition, the X_HeERO project includes a comprehensive CBA. This analysis monetizes the societal benefits of preventing fatalities and severe injuries, allowing for a direct comparison against implementation costs. The methodology is based on established European Commission

guidelines and uses standardized values for the human cost of accidents.1 The key valuation metrics are:

- Value of Avoiding Fatality (VAF): Calculated at €2,443,077, this represents the economic benefit of an intervention that reduces fatality to a severe injury.
- Value of Avoiding a Severe Injury (VASI): Calculated at €429,087, this represents the benefit of reducing a severe injury to a slight one.

Preliminary results from the CBA for pedestrians, based on a forecast period of 2026-2035, highlight the profound economic and social impact of deploying NG eCall solutions for VRUs. The analysis compares three distinct scenarios: (1) Do nothing, which relies only on the gradual fleet renewal with legacy eCall; (2) Do minimum, which involves deploying an NG eCall mobile application for pedestrians; and (3) Do something, a comprehensive approach combining the mobile application with dedicated wearable devices for users without smartphones. The findings, summarized in Table 3, demonstrate a compelling case for proactive investment.

Table 3

Summary of CBA results.

Scenario	Cumulative Benefit-Cost Ratio (BCR)	Net Present Value (NPV)
Do nothing	0.85	€1,134,855,484
Do minimum	1.48	€3,564,789,898
Do something	1.67	€8,874,585,636

6. CONCLUSION

The mandatory transition from conventional eCall to the Next-Generation (NG) architecture marks a decisive moment for road safety in the European Union. This study shows that change is not only a technological necessity but also a socio-economic and humanitarian imperative. The decommissioning of 2G/3G networks makes migration to an IP-based 4G/5G system unavoidable. NG eCall removes the limits of the legacy system, enabling richer and faster data essential for effective emergency response.

Although this pan-European deployment is complex, the X_HeERO project provides a structured framework to address interoperability, cybersecurity, and coordination risks, ensuring harmonized implementation across Member States.

Importantly, NG eCall promises significant societal benefits, particularly for Vulnerable Road Users. Preliminary Cost-Benefit Analysis findings confirm that proactive investment yields strong net benefits, turning a technical upgrade into a humanitarian mission aligned with the Union's Vision Zero objective.

The study has certain limitations, based on preliminary findings of the X_HeERO project and aggregated EU-level data. The cost-benefit estimates remain indicative until further validated through extended pilot studies and national-level implementations. Future work should integrate longitudinal evidence and operational feedback from PSAPs to refine and strengthen the conclusions.

Beyond these findings, the transition also highlights the importance of international collaboration, knowledge transfer, and continuous stakeholder engagement, which are crucial for building resilience and ensuring long-term sustainability of NG eCall across Europe.

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Tranziția la arhitectura de Nouă Generație (NG) a sistemului eCall în cadrul proiectului X_HeERO

Siguranța rutieră, în special protecția utilizatorilor vulnerabili (VRU), rămâne o provocare majoră în Uniunea Europeană. Sistemul pan-european eCall a reprezentat un pas fundamental în reducerea timpului de răspuns la accidente. Această lucrare analizează tranziția tehnologică imperativă de la sistemul eCall convențional, bazat pe rețele cu comutare de circuite, la arhitectura de nouă generație (NG eCall), fundamentată pe tehnologii IP. În centrul acestei tranziții se află proiectul european X_HeERO, ale cărui contribuții sunt esențiale pentru modernizarea infrastructurii Punctelor de Preluare a Apelurilor de Urgență (PSAP). Lucrarea demonstrează superioritatea tehnică a NG eCall și determină elementele componente ale analizei cost-beneficiu, evidențiind rolul noii arhitecturi în crearea unei paradigme avansate pentru managementul incidentelor rutiere.

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