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ENHANCING ROAD SAFETY IN ROMANIA THROUGH INTELLIGENT TRANSPORT SYSTEMS (ITS)

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Abstract

Road safety remains a major challenge for Romania's national road network, characterized by high accident rates and increasing traffic demand. In recent years, Intelligent Transport Systems (ITS) have emerged as a key instrument for improving traffic efficiency, safety, and infrastructure management. This paper presents an updated and forward-looking analysis of ITS-based approaches to enhancing road safety in Romania. The article reviews the current state of ITS deployment on Romania's road network, focusing on traffic data collection, incident detection, variable message signs, and integrated traffic management systems. It further proposes a conceptual framework for the future development of ITS solutions aligned with European standards and Cooperative ITS (C-ITS) initiatives, emphasizing data-driven decision-making and interoperability [1]. Particular attention is given to the role of real-time traffic data, automated incident response, and predictive safety analytics in reducing accident risks. The paper also discusses institutional and technical challenges related to large-scale ITS implementation, including system integration, data quality, and governance aspects. By outlining practical directions for future ITS development, this research aims to support national road authorities in designing effective strategies to enhance road safety in Romania and contribute to the broader European objective of safer and smarter transport networks.

Keywords: Intelligent transport systems (ITS), road safety, national recovery and resilience program, pilot projects

1 Introduction

Road safety remains one of the most critical challenges facing road transport systems across Europe, and particularly in countries experiencing rapid growth in traffic demand and vehicle ownership. Despite sustained efforts at national and European levels, road accidents continue to generate significant social and economic costs, with direct impacts on mobility efficiency, public health, and overall quality of life. In Romania, these challenges are amplified by the heterogeneous nature of the national road network, increasing traffic volumes, and the coexistence of modern motorway infrastructure with legacy road sections.

In this context, Intelligent Transport Systems (ITS) have emerged as a key enabler for improving road safety through the integration of advanced sensing technologies, communication networks, and data-driven traffic management tools. By enabling real-time monitoring of traffic conditions, early detection of incidents, and timely information dissemination to road users, ITS enable a transition from predominantly reactive safety measures towards preventive and, increasingly, predictive traffic safety management [2]. At European level, the deployment of ITS is strongly supported by a comprehensive regulatory and strategic framework, aimed at ensuring harmonization, interoperability, and cross-border continuity of services.

The ITS Directive (2010/40/EU) and its associated delegated regulations establish the foundation for coordinated implementation of traffic information services, road safety-related data exchange, and multimodal travel information [3]. These initiatives are closely aligned with broader European objectives such as the Vision Zero approach, which targets a long-term reduction of road fatalities and serious injuries, and the development of a safer, smarter, and more sustainable transport system across the Trans-European Transport Network (TEN-T).

Romania has progressively aligned its national policies and investments with these European objectives, placing increasing emphasis on the deployment of ITS as part of road infrastructure development and modernization. Over the past decade, ITS components have transitioned from pilot applications on selected motorway sections to integral elements of newly constructed and rehabilitated road corridors. This evolution reflects a growing recognition of the role played by real-time data collection, automated traffic monitoring, and integrated traffic management centers in enhancing road safety and operational efficiency.

Against this background, this paper provides an updated and forward-looking analysis of ITS-based approaches to improving road safety in Romania. The study reviews the current status of ITS deployment on the national road network, with a particular focus on safety-oriented applications such as traffic data collection, automated incident detection, and traffic management systems. Furthermore, it discusses how these systems can support data-driven decision-making and contribute to the transition towards more advanced and cooperative ITS solutions, aligned with European standards and C-ITS initiatives.

The main contribution of this paper lies in combining a national-level overview of ITS implementation with a practical case study illustrating the application of ITS solutions on a high-demand road corridor. By identifying both achievements and challenges, the research aims to support road authorities and stakeholders in defining effective strategies for the further development of ITS in Romania, while offering insights that may be relevant for other countries facing similar road safety challenges.

2 ITS architecture and road safety-oriented functionalities

Intelligent Transport Systems deployed on road networks are based on a layered architecture that integrates field equipment, communication infrastructure, data processing platforms, and operational control centers. When road safety is explicitly considered in system design, ITS architectures support continuous monitoring of traffic and infrastructure conditions and facilitate faster detection of hazardous situations, followed by coordinated response measures. At a functional level, ITS architectures typically comprise four main components: (i) data acquisition subsystems, (ii) communication and transmission networks, (iii) data processing and storage platforms, and (iv) traffic management and information dissemination interfaces. The effectiveness of ITS in enhancing road safety depends not only on the performance of individual components, but also on their degree of integration and interoperability within a unified system.

2.1 Data acquisition subsystems for road safety

Data acquisition represents the foundation of any safety-oriented ITS. On the road network, this function is ensured through a distributed set of sensors and monitoring devices installed along critical corridors, junctions, and high-risk locations. These subsystems collect real-time data related to traffic flow, vehicle behavior, environmental conditions, and infrastructure status. Traffic monitoring systems provide essential parameters such as traffic volume, vehicle classification, travel speed, lane occupancy, and congestion levels.

These data allow traffic managers to identify abnormal conditions, detect sudden changes in flow patterns, and assess the risk of incidents. Complementary to traffic data, road weather monitoring systems supply information on meteorological and surface conditions, including temperature, precipitation, visibility, wind, and road surface status, which are directly correlated with accident probability. Video-based monitoring systems further enhance situational awareness by enabling visual confirmation of traffic conditions and supporting advanced functions such as Automatic Incident Detection (AID). Through video analytics, these systems can identify stopped vehicles, wrong-way driving, pedestrian presence, lost cargo, or sudden speed reductions, generating real-time alerts for traffic operators [4]. The general architecture of safety-oriented ITS is illustrated in figure 1.

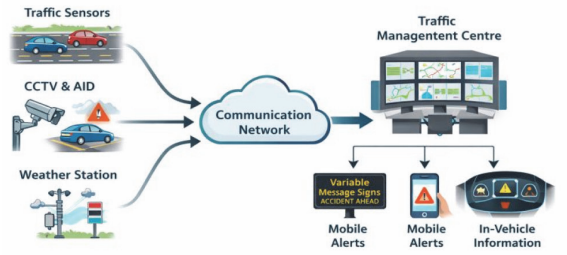

Figure 1 General architecture of safety-oriented ITS

2.2 Communication networks and data transmission

Reliable and secure communication networks are essential for transmitting large volumes of data from the field to Traffic Management Centres (TMCs) with minimal latency. Optical fiber networks, wireless communication links, and hybrid solutions are commonly used to ensure redundancy and resilience of data flows. From a road safety perspective, communication performance directly affects the timeliness of incident detection and response. Delays or interruptions in data transmission can compromise the effectiveness of safety measures, particularly in high-speed environments such as motorways or express roads. Therefore, modern ITS architectures increasingly rely on high-capacity, low-latency networks capable of supporting real-time video streams, sensor data, and control commands. Standardized data exchange protocols, such as DATEX II, play a crucial role in ensuring interoperability between different ITS components and facilitating data sharing between national systems and external stakeholders [5]. This standardization is particularly important in the context of European corridors, where cross-border continuity of safety-related services is required.

2.3 Data processing, storage, and traffic management centers

Once transmitted, data collected from field subsystems are processed and stored within centralized or distributed platforms, typically managed by Traffic Management Centers. These centers act as the operational core of the ITS, providing operators with integrated dashboards, analytical tools, and decision-support functionalities. Data processing functions include filtering, validation, aggregation, and correlation of heterogeneous data sources. By combining traffic, weather, and incident-related data, ITS platforms enable the identification of critical situations and support informed decision-making. Automated alarms and predefined response scenarios allow operators to react rapidly to incidents, deploy intervention teams, and activate traffic control measures. From a road safety perspective, the role of TMCs extends beyond real-time operations to strategic analysis. Historical data stored in ITS databases can be used to identify accident-prone locations, assess the effectiveness of safety measures, and support long-term planning and investment decisions.

2.4 Information dissemination and driver interaction

An essential safety-oriented function of ITS is the timely dissemination of relevant information to road users. Variable Message Signs (VMS), in-vehicle information systems, and digital platforms provide drivers with real-time warnings related to incidents, adverse weather conditions, congestion, or temporary speed limits [6]. Effective information dissemination contributes to accident prevention by enabling drivers to adapt their behavior to prevailing conditions and by reducing unexpected situations. To maintain credibility and driver trust, information must be accurate, concise, and displayed only when relevant. Excessive or non-contextual messages may reduce driver attention and undermine the safety benefits of ITS. The main ITS subsystems and their contribution to road safety are summarized in table 1.

Table 1 Main ITS subsystems and their contribution to road safety

ITS subsystem	Key functions	Contribution to road safety
Traffic monitoring sensors	Volume, speed, classification	Early detection of abnormal traffic conditions
Weather monitoring systems	Surface and meteorological data	Prevention of weather-related accidents
Video surveillance and AID	Incident and hazard detection	Rapid incident identification and response
Communication networks	Data transmission	Reduced response times
Traffic management centres	Data integration and control	Coordinated safety-oriented decision-making
VMS and information systems	Driver information	Improved driver awareness and behavior

2.5 Interoperability and evolution towards cooperative ITS

The effectiveness of ITS architectures in enhancing road safety is increasingly linked to their ability to evolve towards cooperative and connected environments. Cooperative ITS (C-ITS) enable direct communication between infrastructure and vehicles, allowing safety-critical information to be exchanged with minimal delay. In this context, interoperability becomes a key requirement, ensuring that systems developed at different times or by different stakeholders can operate seamlessly together. Aligning national ITS architectures with European standards not only facilitates cross-border data exchange but also prepares road networks for future developments in connected and automated mobility.

3 Current status of ITS deployment in Romania

Over the past two decades, Romania has progressively developed and expanded the deployment of Intelligent Transport Systems as an integral component of road infrastructure management [7]. Initially introduced through pilot projects on selected motorway sections, ITS solutions have gradually evolved into a structured and increasingly standardized framework supporting traffic monitoring, safety management, and information services at national level. The first large-scale ITS implementations were deployed on major motorway corridors, focusing primarily on traffic surveillance, emergency communication, and driver information. These early projects established the technical and institutional foundations for subsequent expansion, demonstrating the operational benefits of centralized traffic monitoring and coordinated incident management.

Following this pilot phase, ITS components became a standard requirement in the construction of new motorways and express roads, ensuring that safety-oriented digital infrastructure was embedded from the early stages of project development.

3.1 ITS Coverage of the national road network

At present, ITS deployment in Romania covers a significant portion of the motorway and express road network, as well as selected high-traffic national roads and European corridors. Priority has been given to sections forming part of the TEN-T network, where traffic volumes, cross-border flows, and safety requirements are particularly demanding. The implemented systems include traffic monitoring sensors, video surveillance equipment, weather monitoring stations, Variable Message Signs, and communication infrastructure interconnected with regional Traffic Management Centers. This approach enables continuous monitoring of traffic conditions and supports coordinated responses to incidents across multiple road sections. The spatial distribution of ITS-equipped road sections in Romania is presented in figure 2.

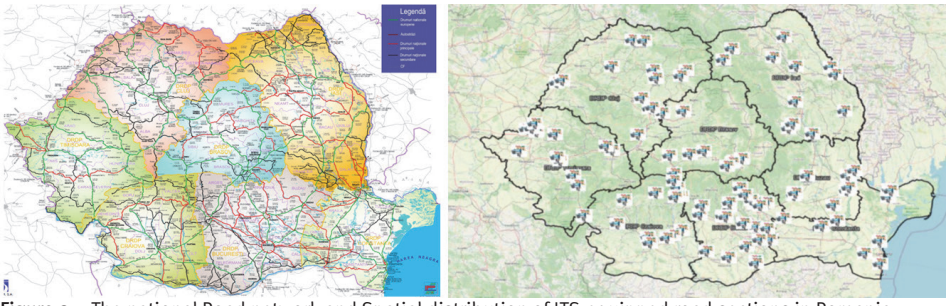

Figure 2 The national Road network and Spatial distribution of ITS-equipped road sections in Romania

3.2 Traffic management centers and institutional framework

Traffic Management Centers represent the operational backbone of ITS deployment in Romania. These centers collect, process, and disseminate traffic-related information, providing operators with real-time situational awareness and decision-support tools. Initially developed at regional level, the network of TMCs has expanded to support coordinated traffic management across multiple corridors. In parallel, Romania is transitioning towards a centralized national-level approach through the development of a National Traffic Management Centre [8]. This center is designed to integrate data from regional systems, ensure harmonized traffic management strategies, and support large-scale safety-oriented interventions, particularly on strategic corridors and during major events or adverse conditions. From an institutional perspective, ITS deployment is supported by a dedicated legal and organizational framework aligned with European requirements. Responsibilities related to system operation, data provision, and enforcement are distributed among road authorities, traffic police, and other stakeholders, emphasizing cooperation and data sharing as key enablers of road safety.

3.3 Safety-oriented ITS applications in operation

Current ITS deployments in Romania support a wide range of safety-oriented applications. Traffic data collection systems provide continuous information on flow conditions, speed patterns, and congestion levels, allowing early identification of potentially hazardous situations.

Weather monitoring systems enhance safety by detecting adverse conditions such as fog, precipitation, or freezing temperatures, enabling timely warnings and preventive measures. Automatic Incident Detection systems play a critical role in identifying accidents and abnormal traffic events, significantly reducing detection times compared to traditional reporting methods. These systems are complemented by video surveillance, which allows operators to visually assess situations and coordinate appropriate responses, including the activation of Variable Message Signs and the dispatch of intervention teams. Speed enforcement and vehicle monitoring systems further contribute to road safety by supporting compliance with traffic regulations and protecting infrastructure integrity. By integrating these systems within the broader ITS architecture, road authorities can adopt a comprehensive and data-driven approach to safety management. An overview of key ITS applications currently deployed on the Romanian road network is provided in table 2.

Table 2 Overview of key ITS applications currently deployed on the Romanian road network

Application area	Main ITS Components	Safety-related benefits
Traffic monitoring	Sensors, cameras, data processing platforms	Early identification of congestion and abnormal flow
Weather monitoring	Road weather stations, visibility sensors	Reduction of weather-related accident risks
Incident detection	Video analytics, AID systems	Faster detection and response to accidents
Driver information	VMS, digital information services	Improved situational awareness for drivers
Enforcement support	Speed and vehicle monitoring systems	Increased compliance with traffic regulations

3.4 Ongoing and planned ITS developments

Beyond the systems already in operation, Romania is actively expanding its ITS capabilities through ongoing and planned investment programs. These initiatives focus on extending ITS coverage to additional road sections, upgrading existing equipment, and enhancing interoperability between systems. Special emphasis is placed on improving data accessibility and integration through national data platforms, supporting real-time traffic information services and cross-border data exchange. Furthermore, the gradual introduction of cooperative and connected ITS elements reflects a strategic shift towards more advanced safety solutions capable of supporting predictive analytics and proactive traffic management. The evolution of ITS deployment in Romania is illustrated in figure 3.

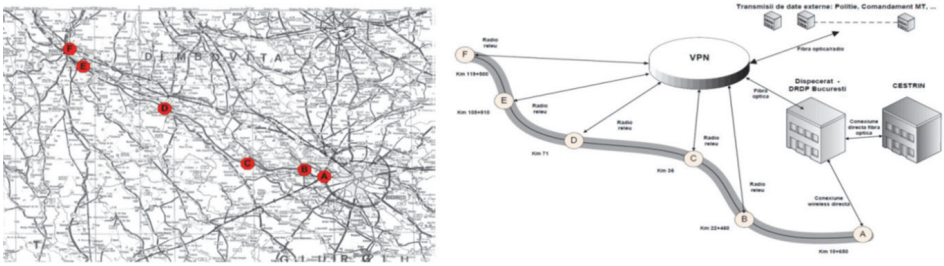

Figure 3 Evolution of ITS deployment in Romania from pilot projects to integrated national systems

4 ITS Applications for road safety: data, incident management, and corridor-level implementation

This chapter focuses on the operational contribution of Intelligent Transport Systems to road safety, with particular emphasis on corridor-level implementation. After a brief overview of the core safety-related ITS functionalities, the chapter presents the DN39 corridor as a representative case study illustrating how integrated ITS solutions can enhance road safety under conditions of high and variable traffic demand.

4.1 Safety-oriented its functionalities: from real-time data to incident management

At operational level, the impact of ITS on road safety is driven by the integration of real-time data collection, automated incident detection, and coordinated traffic management actions. Continuous monitoring of traffic parameters, such as speed, volume, and lane occupancy, enables the early identification of abnormal conditions that may precede accidents, including sudden speed drops or congestion formation. These traffic data are complemented by road weather information and video-based surveillance, allowing a contextual assessment of risk and supporting timely intervention. Automatic Incident Detection systems further enhance safety by identifying critical events, such as stopped vehicles or collisions, and generating immediate alerts for Traffic Management Centre operators. The combination of these functionalities significantly reduces detection and response times, limiting the likelihood of secondary accidents and traffic-related hazards. From a safety management perspective, the integration of multiple data sources within a unified ITS platform represents a shift from isolated monitoring towards a comprehensive, data-driven approach to risk mitigation.

4.2 Corridor-level ITS implementation on DN39 (A4 – Vama Veche)

The DN39 corridor, linking the A4 motorway to the Vama Veche border crossing, represents a critical road section characterized by seasonal traffic peaks, heterogeneous traffic composition, and recurrent congestion [9]. These factors contribute to elevated accident risk, particularly during periods of intensified tourist traffic along the southern Black Sea coast. To address these challenges, an integrated ITS solution was implemented along the DN39 corridor, focusing explicitly on safety enhancement through real-time monitoring and adaptive traffic management. The system combines traffic sensors, video surveillance, Variable Message Signs, and dynamic control of reversible lanes, all interconnected with a centralized Traffic Management Centre. A key element of the DN39 implementation is the automated management of reversible lanes in urban and peri-urban sections with fluctuating directional demand. By adjusting lane allocation in response to real-time traffic conditions, the system reduces conflict points, limits risky overtaking behavior, and improves overall traffic stability. This adaptive approach improves traffic flow stability and contributes to accident prevention by reducing congestion-related conflicts and unpredictable driving maneuvers. In parallel, real-time information provided to drivers through Variable Message Signs increases situational awareness and compliance with traffic control measures. Warnings related to congestion, incidents, or lane configuration changes are delivered in a timely and context-specific manner, supporting safer driving behavior under demanding traffic conditions. The functional layout of the ITS implementation on the DN39 corridor is shown in figure 4.

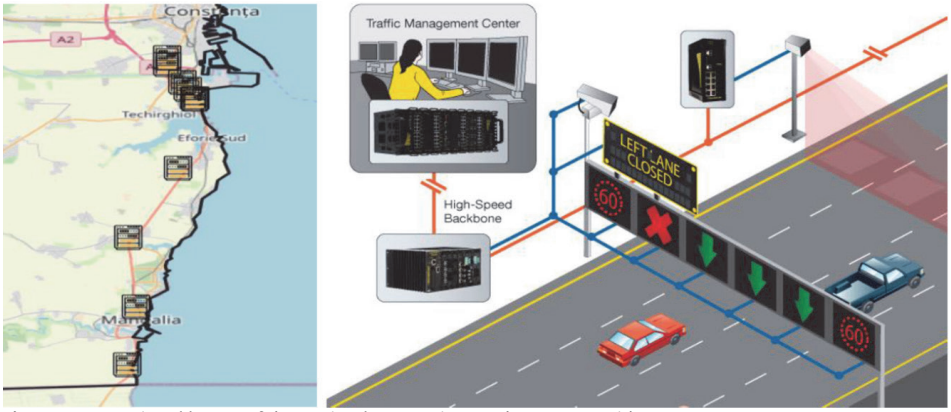

Figure 4 Functional layout of the ITS implementation on the DN39 corridor

4.3 Safety impacts and transferability of the DN39 experience

The DN39 corridor illustrates how corridor-level ITS implementation can effectively address complex safety challenges arising from variable traffic demand and mixed traffic conditions. By integrating monitoring, control, and information dissemination within a unified operational framework, the system enables proactive safety management and rapid response to emerging risks. Beyond local benefits, the experience gained from DN39 provides valuable insights for the deployment of similar solutions on other high-demand road sections in Romania. The combination of real-time data, adaptive lane management, and centralized control demonstrates a scalable model that can be adapted to different corridor characteristics, supporting both safety improvement and traffic efficiency. The main ITS components implemented on the DN39 corridor and their safety contributions are summarized in table 3.

Table 3 Key ITS components implemented on DN39 and their contribution to road safety

ITS component	Operational role	Safety contribution
Traffic sensors	Real-time flow and speed monitoring	Early risk identification
Video surveillance and AID	Incident and hazard detection	Faster response and reduced secondary accidents
Reversible lane control	Adaptive lane allocation	Reduced conflict points and risky maneuvers
Variable message signs	Driver information and warnings	Improved awareness and compliance
Traffic management centre	Integrated control and coordination	Proactive safety-oriented traffic management

5 Discussion, challenges, and future directions

The analysis presented in this paper highlights the growing role of Intelligent Transport Systems as a core instrument for enhancing road safety on Romania's national road network. The progressive integration of ITS functionalities – ranging from real-time traffic monitoring and automated incident detection to adaptive traffic management – demonstrates a clear shift towards data-driven and proactive safety practices.

The corridor-level implementation on DN39 illustrates how integrated ITS solutions can effectively address safety challenges associated with high and variable traffic demand. By combining continuous monitoring, dynamic lane management, and targeted driver information, the system reduces traffic instability and limits conditions that typically lead to accidents, such as congestion-induced conflicts or unpredictable driving behavior. This experience confirms that safety benefits are maximized when ITS solutions are designed and operated at corridor level rather than as isolated technical components. However, the deployment and operation of ITS at large scale also reveal a set of technical and institutional challenges. From a technical perspective, ensuring interoperability between heterogeneous systems remains a critical issue, particularly as ITS infrastructures have been developed incrementally over time. Data quality, system reliability, and cybersecurity represent additional concerns, especially in the context of increasing dependence on real-time information for safety-critical decisions. Institutional challenges are equally significant. Effective ITS-based safety management requires close coordination between road authorities, traffic police, emergency services, and other stakeholders. Clear governance structures, well-defined responsibilities, and standardized operational procedures are essential to ensure that data and system capabilities are translated into timely and effective interventions. Furthermore, the long-term sustainability of ITS solutions depends on adequate resources for maintenance, system upgrades, and staff training.

Looking ahead, the evolution of ITS in Romania is closely linked to the transition towards cooperative and connected transport systems. Building upon existing infrastructure and operational experience, Cooperative ITS (C-ITS) solutions offer the potential to further enhance road safety by enabling direct communication between vehicles and infrastructure. Such systems can support predictive safety analytics, allowing risks to be identified and mitigated before hazardous situations materialize on the road. The gradual integration of advanced data analytics, including predictive and AI-based approaches, represents another important direction for future development [10]. By exploiting historical and real-time data collected through ITS, road authorities can move towards more sophisticated safety management strategies, supporting evidence-based planning and targeted interventions at network level.

In conclusion, the experience gained in Romania indicates that ITS represent an effective instrument for improving road safety when deployed within an integrated and strategically coordinated framework. The lessons learned from corridor-level applications such as DN39 provide a solid foundation for scaling up ITS solutions across the national road network and aligning them with European objectives for safer, smarter, and more resilient transport systems.

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