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Intelligent Transport Systems for Enhanced Road Safety in the Republic of Macedonia

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Abstract. The modern challenges in road traffic and the growing need for enhanced safety, efficiency, and digital connectivity position the implementation of Intelligent Transport Systems (ITS) as a key tool in contemporary transport infrastructure management. The aim of this paper is to explore the possibilities and challenges of their implementation in the Republic of North Macedonia, with a focus on improving safety and preparing for future technological solutions. The methodology is based on an analysis of current ITS technologies and advanced driver assistance systems (ADAS), tcheir integration through cooperative messages (CAM and DENM), as well as the role of RSU units within the C-ITS infrastructure. Through a comparative analysis with European practices, institutional, technological, and regulatory gaps have been identified, and pilot projects are proposed for their gradual enhancement, implementation, and improvement of ITS solutions in order to overcome existing gaps and align with modern European standards. The results indicate that such initiatives, combined with continuous infrastructure development and maintenance, can significantly contribute to a higher level of safety, a more integrated transport system, and greater readiness for the integration of future intelligent technologies.

Keywords: ADAS, C-ITS, CAM/DENM, RSU, V2X

1. INTRODUCTION

Road traffic represents one of the most dynamic and complex infrastructure sectors in modern societies. It provides mobility, economic growth, and social connectivity, but at the same time, it is also a significant source of safety risks. According to the World Health Organization, more than 1.19 million people lose their lives in road traffic accidents globally each year, and millions more are injured [1]. In the European Union, road traffic remains a leading cause of fatal accidents, highlighting the urgent need for innovative approaches to improving road safety and efficiency.Over the past two decades, the digital transformation of the transport sector has led to the development of Intelligent Transport Systems (ITS) integrated solutions that combine information technology, telecommunications, sensors, and automation to enable safer, more efficient, and more sustainable transportation. These systems facilitate real-time data collection and processing, traffic flow optimization, automated decision-making, and improved communication between vehicles and infrastructure. With the emergence of technologies such as ADAS (Advanced Driver Assistance Systems), V2X communication (Vehicle-to-Everything), and cooperative messages (CAM/DENM), road transport is entering a new era of "intelligent mobility." In this context, the European Union and other developed economies have already begun the large-scale deployment of C-ITS infrastructure, installation of RSU (Roadside Units) along highways and urban corridors, and integration of intelligent systems within Smart City concepts [2]. These technologies significantly contribute to reducing incident response time, preventing collisions, and improving the coordination of all traffic participants.

In the Republic of North Macedonia, although there are individual initiatives such as electronic toll collection systems, adaptive traffic lights, and video surveillance, there is still no comprehensive national strategy for the development of ITS and the integration of cooperative technologies into the transport ecosystem. The aim of this research is to analyze the role of Intelligent Transport Systems in enhancing road safety, with a special focus on cooperative communications, the role of RSU infrastructure, and the potential for implementing pilot projects in the Macedonian context.

2. ITS TECHNOLOGIES AND ADAS SYSTEMS

Intelligent Transport Systems (ITS) represent integrated solutions that utilize advanced information and communication technologies to improve the safety, efficiency, flow, and sustainability of transport networks. They operate by collecting, processing, and exchanging real-time data between vehicles, infrastructure, and central management systems, enabling more informed decision-making and proactive risk mitigation. The development of ITS is the result of decades of research and technological progress in telecommunications, sensor systems, automation, and artificial intelligence. Their implementation is crucial in modern smart mobility concepts and “smart city” infrastructures. The key technologies that make up ITS can be divided into several categories:

- Traffic management systems: Intelligent traffic lights with adaptive timing, dynamic road signs, vehicle flow monitoring, and traffic congestion prediction.
- Information and communication systems: Communication networks for vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) interactions, as well as sensor platforms for detecting road conditions.
- User information services: Intelligent navigation, real-time route recommendations, and hazard or congestion notifications..
- Intelligent infrastructure: Roads with embedded sensors, structural monitoring systems for bridges, tunnels, and other critical infrastructure.

One of the most significant segments of ITS technologies is Advanced Driver Assistance Systems (ADAS). These systems are designed to support drivers by increasing situational awareness and autonomously performing certain driving tasks, thereby reducing the likelihood of human error one of the main causes of traffic accidents [3]. ADAS rely on a combination of sensors, cameras, radars, and LiDAR scanners that monitor the vehicle’s surroundings, while data processing algorithms enable real-time hazard recognition and decision-making. Some of the most important ADAS functions include:

- AEB (Autonomous Emergency Braking): Automatic braking in case of collision risk.
- LDW / LKA (Lane Departure Warning / Lane Keeping Assist): Warning and automatic correction when the vehicle unintentionally leaves the lane.
- ACC (Adaptive Cruise Control): Speed adjustment based on the distance to the vehicle ahead.
- ICA (Intersection Collision Avoidance): Collision prevention at intersections through trajectory prediction.
- TSR (Traffic Sign Recognition): Automatic recognition of traffic signs and adaptation of driving behavior.

Modern ADAS solutions do not function in isolation — their effectiveness is directly linked to the quality of infrastructure and the support provided by cooperative technologies such as V2X communication and CAM/DENM messages. For example, automatic braking and collision avoidance systems can react much faster when a vehicle receives a warning from another vehicle or from the road infrastructure. Furthermore, the development of 5G networks and edge computing architectures enables the exchange of large amounts of data with minimal latency, which is critical for implementing autonomous driving functions [4]. In developed countries, ADAS systems and ITS technologies are already integrated into national mobility strategies. Examples include the C-Roads projects in Germany and Austria, where RSU-equipped infrastructure and cooperative messages enhance highway safety and efficiency [5]. Similarly, in the United States, the NHTSA Connected Vehicle Program demonstrates that V2X technologies, combined with ADAS-like systems, have the potential to reduce traffic incidents by 20–30% in certain scenarios, particularly at intersections and highways [6].

3. COOPERATIVE MESSAGES (CAM/DENM) AND THE ROLE OF RSU IN ITS

Cooperative Intelligent Transport Systems (C-ITS) represent an advanced stage in the evolution of ITS, where vehicles, infrastructure, and other road users continuously exchange real-time information with the aim of increasing safety, reducing the number of incidents, and improving the overall flow of the transport network. The fundamental building blocks of C-ITS are cooperative messages, defined by the European Telecommunications Standards Institute (ETSI), which are divided into two main categories: Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Messages (DENM) [7].

3.2. Cooperative Awareness Messages (CAM)

Cooperative Awareness Messages (CAM) are broadcast periodically by all vehicles and serve as a “digital fingerprint” of their current state. They contain information such as the vehicle’s position, speed, direction of movement, size, and unique identifier. This data enables systems to create a situational picture of the traffic environment in real time and to predict potential risks before they occur. For example, if two vehicles are moving toward the same point at an intersection, CAM data can be processed to predict a possible collision and send a warning to the drivers in advance.

3.3. Decentralized Environmental Notification Messages (DENM)

Decentralized Environmental Notification Messages (DENM) are event-driven messages that are transmitted when a specific incident occurs or when a condition affecting road safety is detected. Examples of such messages include notifications about a traffic accident, road obstacle, slippery surface, fog, reduced visibility, or the presence of an emergency vehicle. These messages enable other road users to take timely actions, such as slowing down, changing lanes, or choosing an alternative route. Research on C-ITS, including systems based on CAM and DENM messages, indicates significant potential for improving driver response and reducing traffic incidents by providing real-time safety information [8].

3.4. RSU in C-ITS eco system

A central role in the C-ITS network is played by the RSU (Roadside Units) — stationary communication devices installed along roads that act as intermediaries between vehicles and the transport infrastructure. RSUs can be considered as “intelligent nodes” that collect, analyze, and forward data received from vehicles through V2X communication channels. n essence, RSUs perform the following key functions:

- Reception and processing of CAM messages.
  RSUs collect periodic data from surrounding vehicles, creating a local traffic map and monitoring potential risk situations, such as possible collisions or vehicles moving in the wrong direction.
- Forwarding and generation of DENM messages.
  In the event of an incident, RSUs can transmit received messages to other vehicles within range or generate new ones based on their own sensor data (e.g., fog detection, pedestrian on the roadway, hazardous zone).
- Edge computing analysis.

RSUs perform real-time data analysis directly at the network edge, reducing latency and enabling faster decision-making for safety-critical applications without the need to send all data to a central server.

One of the most significant examples of the practical application of RSU in cooperative networks is the C-Roads project in Germany and Austria, where CAM and DENM messages are used to warn drivers about potential collisions at intersections, road obstacles, or the presence of emergency vehicles [9]. Similarly, in the United States, the Connected Vehicle Pilot Program has demonstrated that RSU infrastructure can enable significant improvements in traffic management, reduced travel times, and enhanced safety on critical road segments [10].

Table 1. Examples of Typical DENM Messages and Their Purpose

DENM Event Type	Description	Purpose / Action Enabled
Accident	Notification about a collision or accident ahead	Notification about a collision or accident ahead
ObstacleOnRoad	Detection of debris, fallen objects, or broken-down vehicles	Detection of debris, fallen objects, or broken-down vehicles
VehicleBrokenDown	Vehicle malfunction or stopped on the road	Vehicle malfunction or stopped on the road
AnimalOnRoad	Presence of an animal on the roadway	Presence of an animal on the roadway
SlipperyRoad	Slippery road due to ice or rain	Slippery road due to ice or rain
HeavyRain / Fog / StrongWinds / PoorVisibility	Adverse weather conditions reducing road safety	Adverse weather conditions reducing road safety
RoadWork / LaneClosure	Roadworks or lane closure	Roadworks or lane closure

4. CURRENT SITUATION AND CHALLENGES IN THE REPUBLIC OF MACEDONIA

The development and implementation of Intelligent Transport Systems (ITS) in the Republic of North Macedonia are still in their early stages and are progressing in a fragmented manner, without a comprehensive national strategy or a coordinated plan for the digital transformation of the transport sector.Although certain initiatives have been undertaken in recent years to modernize road infrastructure and improve traffic management, their implementation remains limited to individual projects and does not form part of a broader ITS framework.

4.1. Existing ITS Elements

In the Republic of North Macedonia, several basic components can be considered the first steps toward the development of an ITS ecosystem:

- Electronic Toll Collection System (TAG):

  Enables automated payment of road tolls, improving vehicle flow and reducing congestion at toll stations.

- Vehicle Counting Systems:

  Inductive loops installed on certain highway sections monitor traffic intensity, but they currently operate without integration into centralized databases.

- Adaptive Traffic Light Control:

  Implemented on a limited scale in parts of Skopje, this system allows for dynamic adjustment of signal timing based on real-time traffic density.

- Video Surveillance and Enforcement Systems (in implementation phase):

  Part of the Safe City initiative, which includes the installation of cameras for traffic violation detection and vehicle flow analysis..

These solutions represent an important foundation, but their effectiveness is limited due to the lack of standardization, absence of connectivity with national databases, and insufficient integration with other ITS technologies [22].

4.2. Main Challenges

The main obstacles to the development of modern ITS solutions in the Republic of North Macedonia can be classified into four key categories, each addressing a critical aspect necessary for building an advanced and interoperable transport ecosystem:

- Maintenance and Inspection of Road Signage.

  The high level of retroreflectivity and the quality of horizontal road markings are crucial for the proper functioning of ADAS systems, especially those responsible for lane detection and traffic sign recognition. In North Macedonia, road markings often do not meet the requirements of the EN 1436 standard, and regular inspection mechanisms for measuring retroreflectivity and assessing visibility under various weather conditions are lacking.Additionally, the condition of vertical signage poses a significant challenge: many traffic signs suffer from reduced visibility, faded retroreflective surfaces, or insufficient contrast, which makes it difficult for cameras and sensors to detect them accurately.Introducing regulations for systematic measurement, periodic inspections, and defined maintenance criteria for both markings and signage is a prerequisite for the safe integration of modern ITS solutions.

- Institutional Challenges.

  There is a lack of a national strategy and legal framework for the development and governance of ITS. Responsibilities for transport infrastructure are divided among multiple institutions without a central coordinating body, which complicates planning, implementation, and monitoring of ITS projects. A centralized approach is essential for ensuring interoperability, standardization, and efficient allocation of resources.

- Technological Challenges.

  The deployment of ITS is limited by insufficient digital infrastructure, inadequate coverage of next-generation communication networks (5G), and the absence of RSU units, which are essential for the development of C-ITS solutions. Without these components, real-time communication between vehicles and infrastructure remains limited, hindering the implementation of cooperative safety and traffic management applications.

- Standards and Regulations.

  There are currently no adopted technical standards — such as EN 1436 for retroreflectivity of road markings — which are critical for the proper operation of ADAS systems. Standardization is a key enabler for interoperability, certification, and future cross-border integration of ITS technologies.

- Financial and Human Resources.

  The implementation of ITS requires significant financial investment, yet budgetary limitations remain a major obstacle. In addition, there is a shortage of technically trained personnel capable of planning, implementing, and maintaining ITS infrastructure. Capacity building through specialized training programs, academic curricula, and international cooperation is essential to overcome this barrier

4.3. Comparison with European Practices

In most European Union member states, the development of ITS is regulated by national strategies, clear legal frameworks, and long-term investments in digital infrastructure. For example, in Germany and Austria, there are more than 1,200 active RSU units integrated with CAM/DENM communication within the C-Roads project. The Netherlands and Slovenia have implemented national programs for the introduction of “smart intersections,” where local RSU units perform predictive calculations to prevent collisions at intersections. Compared to these countries, Macedonia lags behind in all four key aspects: strategy, infrastructure, standardization, and institutional coordination. This gap limits the country’s ability to join European initiatives for connected and autonomous transport and delays the process of adopting new technologies..

4.4. Comparison with European Practices

To reduce the technological gap and create the conditions for integrating cooperative transport systems, the following priority measures need to be undertaken:

- Development of a national ITS strategy:

  Define objectives, priorities, the institutional framework, and a timeline for implementation.

- Standardization and regulatory changes

  Adopt European technical standards and introduce a legal framework for C-ITS communications and data management.

- Infrastructure investments:

  Install RSU units at critical locations, develop a 5G communication network, and integrate local systems into a centralized platform.

- International cooperation:

  Join European initiatives such as C-Roads, NeMo, or TN-ITS (Transport Network Intelligent Transport Systems) to facilitate knowledge exchange and access to financial resources.

By implementing these steps, Macedonia can significantly accelerate the development of intelligent transport infrastructure and lay the foundation for the integration of advanced cooperative mobility systems and autonomous driving.

5. PROPOSALS FOR PILOT PROJECTS AND IMPLEMENTATION

Pilot projects represent an essential step in the process of introducing intelligent transport systems, as they allow technologies to be tested under real conditions, their effectiveness to be analyzed, and technical, institutional, and regulatory barriers to be identified before broader implementation. In most European countries, the development of C-ITS began precisely with such initiatives, which later evolved into national programs. For this reason, the approach to implementation in the Republic of North Macedonia should be based on gradual deployment through carefully selected pilot projects that will lay the foundation for the complete digital transformation of the road infrastructure.

5.1. Full Integration of the eCall System within the 112 Emergency Number Framework

This system allows the vehicle, in the event of an accident, to automatically send its location and data to emergency services via the 112 number. Such solutions have been a standard in the EU since 2018 and significantly reduce response times, which directly increases the chances of saving lives. In the context of North Macedonia, this project could begin as a pilot on several key highway corridors.

5.2. Installation of RSU Units for V2I Communication

RSU devices are essential for the operation of CAM and DENM messages and for supporting V2X communication. The pilot project could include the installation of RSUs at critical sections of the road network — such as city entrances, tunnels, and segments with a high frequency of accidents — thereby creating the first C-ITS communication network in the country. Additionally, these devices could be connected to Smart City platforms for data analysis and visualization.

5.3. Smart Intersections with Cooperative Coordination

As part of the pilot project, several high-traffic intersections in Skopje could be selected where sensors, cameras, and RSU devices would be installed to collect CAM messages and calculate the risk of collision in real time. Based on this data, the system could send warnings to drivers or adjust traffic light signals to prevent incidents. Similar projects have been implemented in Ljubljana and Vienna, resulting in a reduction in the number of collisions by more than 20% [11].

5.4. Introduction of Dynamic Warning Signs and VMS Panels

Dynamic warning signs can display information about weather conditions, obstacles, traffic congestion, or the presence of emergency vehicles on the road. They will be based on data received from RSU devices and will enable proactive driving adjustments, which significantly increases road safety.

5.5. Centralized National Platform for ITS Management

The platform will enable the processing of CAM and DENM messages, traffic flow analysis, traffic light management, and coordination of emergency services. Such solutions are standard practice in developed countries and represent a prerequisite for the implementation of autonomous vehicles and predictive transport system management.

5.6. Expected Benefits

The implementation of these pilot projects will create a foundation for the gradual digital transformation of road infrastructure and will enable:

- Reduction of traffic accidents through proactive prevention.
- Preparation of infrastructure for the future introduction of autonomous vehicles.
- Optimization of traffic flow and reduction of congestion.
- Improved emergency response times.

6. PROTECTION OF PERSONAL DATA IN INTELLIGENT TRANSPORT SYSTEMS – CHALLENGES AND NECESSARY MEASURES

The implementation of intelligent transport systems (ITS) in the Republic of North Macedonia brings significant benefits to road traffic safety and efficiency. However, since these systems process large amounts of sensitive data — including location, movement, driver, and passenger information — there is a strong need to establish strict mechanisms for personal data protection and to prevent their misuse or manipulation. ITS solutions such as automatic number plate recognition (ANPR) systems, smart traffic lights, traffic cameras, and vehicle tracking systems involve the processing of identifiers that can directly or indirectly identify individuals. Therefore, these technologies fall under data protection regulations, including the Law on Personal Data Protection of the Republic of North Macedonia and the EU General Data Protection Regulation (GDPR) [12]. A critical aspect is the prevention of unauthorized access, modification, or incomplete processing of data, which requires the integration of the principles of "privacy by design" and "privacy by default" already in the design phase of ITS solutions [13]. These principles mandate that systems be designed to minimize privacy risks and ensure that the processing of personal data is limited only to what is necessary to achieve specific objectives.In addition, it is necessary to establish technical and organizational protection measures, such as:

- Encryption and pseudonymization of personal data during transmission and storage.
- Access control mechanisms to ensure that only authorized personnel have access to the data.
- Logging and audit trails to monitor every access and activity related to data processing.
- Regular audits and security testing of protection mechanisms.

Manipulation of data in ITS contexts such as the intentional modification of traffic frequency information or the display of false real-time data can have a direct impact on the safety of road users and may also lead to a loss of public trust in institutions. Therefore, it is essential to establish monitoring and anomaly detection systems that can signal potential data misuse in real time [14].

6.1. Ethical Aspects of Data Processing in ITS

In addition to legal obligations, ethical issues related to the processing of personal data are becoming increasingly prominent. Systems that involve tracking movement, facial or license plate recognition, or the analysis of driving behavior raise questions about proportionality, awareness, and voluntariness. In this regard, the European Forum for Transport and Transport Technologies (ERTICO) points out that when implementing ITS technologies, it must be ensured that every citizen has the right to informed participation — meaning they should know when and why their data is being processed and have the option to object to or opt out of certain functions (4). Furthermore, the principle of minimization must be respected, which requires collecting and processing data only to the extent that is absolutely necessary for the specific purpose. From an ethical perspective, excessive automation without clear human responsibility and control can lead to discrimination or inappropriate profiling of certain groups of road users, which violates the principles of equality and fairness [15].

6.2. International Examples: Ethical and Regulatory Practicese

In Germany, the implementation of ANPR systems is subject to strict oversight by the Federal Data Protection Commissioner. Data from these systems is stored for only a few seconds if no violation is detected, thereby avoiding unnecessary retention of personal data [16]. In the Netherlands, the traffic police use ITS in combination with the Dutch Data Protection Act, where all installations are accompanied by informational notices for citizens and the possibility for individuals to access their own data through a portal provided by the competent authority [17]. In France, the National Commission on Informatics and Liberties (CNIL) halted the use of certain video analytics systems in public transport precisely due to a lack of transparency and an inadequate privacy impact assessment [18].

7. CONCLUSION

The development and implementation of intelligent transport systems (ITS) represent a key strategic direction for enhancing the safety, efficiency, and sustainability of road traffic. The results of this research confirm that combining cooperative technologies such as CAM and

DENM messages with advanced driver assistance systems (ADAS) and infrastructure elements like RSU units can significantly reduce the number of traffic incidents and increase the level of proactive prevention. The analysis shows that the Republic of North Macedonia possesses some fundamental ITS components, but they are isolated and not connected into an integrated system. The main obstacles are institutional, technological, and regulatory, as well as the absence of a national strategy and technical standardization. It is necessary to establish a clear legal framework, invest in digital infrastructure, and create a coordinated approach to ITS development through active cooperation between the public and private sector. The pilot projects proposed in this paper represent realistic and achievable steps toward the practical implementation of ITS under Macedonian conditions. The introduction of a fully implemented eCall system, the installation of RSU units, the development of smart intersections, and the establishment of a centralized ITS platform will enable the gradual construction of a national ecosystem that supports future technological solutions. In the future, ITS development is expected to be closely linked to emerging technologies such as 5G communications, artificial intelligence (AI), machine learning, and autonomous vehicles. These technologies will enable more advanced real-time data analysis, predictive transport system management, and more efficient decision-making. Furthermore, integration with smart city concepts will create opportunities for better coordination between transportation, energy, and urban infrastructure. As a final conclusion, the development of ITS should not be viewed merely as a technological issue but as a key part of the national strategy for sustainable transport and digital transformation. With a well-defined vision, institutional support, and gradual implementation, the Republic of North Macedonia can successfully follow European trends and ensure a safer, smarter, and more efficient transport network. Additionally, ITS development must be accompanied by continuous maintenance and inspection of road infrastructure. High retroreflectivity of horizontal road markings, proper visibility and coloring of traffic signs, and their regular renewal are crucial prerequisites for the precise operation of ADAS sensors, lane and signal recognition, and the overall efficiency of cooperative systems..

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