Integration of Intelligent Transportation Systems for Optimizing Sustainability and Efficiency in Commercial Vehicle Operations

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***Abstract*— Intelligent Transportation Systems (ITS) utilize computers, electronics, and telecommunications to enhance the safety and efficiency of surface transportation networks. This research aims to comprehensively analyze the impact of incorporating ITS technologies into the commercial transportation ecosystem. The study assesses the benefits and challenges posed by technologies in two main areas: Intelligent Infrastructure Systems and Intelligent Vehicle Systems. Key technologies include safety information exchange, electronic screening, and credentialing, which automate fleet operations and enhance regulatory enforcement. The findings underscore the pivotal roles of ITS within the commercial vehicle sector, evaluating their effectiveness in terms of safety, efficiency, sustainability, and socio-economic factors.**

Keywords*— *Intelligent transportation systems (ITS), Commercial Vehicle Operations (CVO), Sustainability

I. INTRODUCTION

As per the 2023 report by the European Automobile Manufacturers' Association (ACEA), the EU roads witness the presence of over 6.4 million medium and heavy commercial vehicles, depicting a 3.2% increase from the statistics of 2020 [1]. Additionally, the report outlines that 714,008 buses operate in the European Union, with Poland, Italy, and France collectively hosting almost half of this number [1]. Despite these recent upswings, electrically chargeable vehicles constitute a mere 1.5% of the total EU car fleet, with only three countries surpassing a 2% share in battery electric cars [1]. Diesel-powered vehicles, especially in the light commercial and truck categories, continue to dominate the EU roads, underscoring the prevailing reliance on traditional fuels [1]. The data unequivocally highlights that the surge in demand for expanded transportation capacity is exerting significant pressure on current infrastructure, ushering in a myriad of challenges in the social, political, and economic spheres. Addressing these contemporary road transport challenges and the pressing need for sustainable solutions, the integration of Intelligent Transport Systems (ITS) emerged out as an essential element in the modern transportation strategy [2]. Intelligent Transportation Systems leverage established electronics and telecommunication technologies to enhance surface transportation performance, aiming for a well-managed, integrated, universally accessible, customer-centric, and cost-effective system, thereby ensuring fast and safe movement of people and goods [2]. These systems entail a focus on intelligent vehicle and infrastructure systems to enhance road safety, efficiency, and environmental sustainability through collaborative efforts. The implementation of ITS involves integrating information processing, data communication, sensor technology, control engineering, internet of things, and cloud-based services [2]. Additionally, it encompasses a range of telematics systems, consists of mobile, wireless, and satellite communication [8]. It relies on sensors, cameras, image analysis, and real-time information gathering, along with powerful computers linked to large databases to provide the necessary insights [8].

As outlined by the Horizon 2020 project 'CAPITAL', the EU's research and innovation funding program spanning from 2014 to 2020, with a budget of nearly €80 billion, various typologies of ITS can be identified [8]. These encompass three main categories. Firstly, there are infrastructure-based systems, often referred to as Intelligent Infrastructure Systems, which utilize both short-range and long-range communication technologies [8]. These systems significantly contribute to enhanced sustainability and network management, as exemplified by applications like variable message signs (VMS), highway management, and tolling systems [8]. Secondly, on-board vehicle systems, known as Intelligent Vehicle Systems, employ telematics and in-vehicle safety technologies to offer safety-focused services to drivers [8]. Examples of these services include blind-spot monitoring, navigation systems, safety technologies under Advanced Driver Assistance Systems (ADAS) and eco-driving features [8]. Lastly, there are Co-operative ITS (C-ITS) systems which include systems relying on nomadic devices such as smartphones and tablets [8]. These systems use vehicle-to-vehicle (V2V) and vehicle-to-everything (V2X) communication technologies to enhance information services for public transportation, benefiting both passengers and service-providers [8]. This enhancement is manifested through services like journey planning, smart ticketing, and smart cards [8].

Researchers have identified six primary advantages and aims of ITS, encompassing safety, mobility, performance, productivity, energy, and environmental considerations [3]. The field of ITS is vast, owing to advancements in communication technologies that enable the emergence of diverse structures for implementing ITS in unique ways [3]. Consequently, numerous frameworks have surfaced to elucidate the applications and their services. As per [3], the latest framework, aligned with the US National ITS Program Plan, is illustrated in Table I, which highlights ITS user services and their features. Comprising eight main applications, it includes 28 sub-system user services for seamless information exchange among various applications. The applicability and effectiveness of these user services depends on the latest advancements in communication technologies within a given country [3]. The fourth application in Table I showcases the existing and most commonly available ITS user services tailored for

Commercial Vehicle Operations. These user services primarily aim to enhance fleet management and optimize freight mobility within the private sector [3]. Additionally, their implementation seeks to streamline government and regulatory functions for increased efficiency [3].

TABLE I [3, Table 3]

The National ITS Program Plan

Application	Sub-system services
Travel and Traffic Management	Pre-trip information In-route driver information Route guidance Ride matching and reservation. Traveler information services Traffic control Incident management Emissions testing and mitigation Highway rail intersection
Public Transportation Operations	Public transportation operations In-route transit information Personalized public transit Public travel security
Electronic Payment	Electronic toll collection
Commercial Vehicle Operations	Commercial vehicle electronic clearance Automated roadside safety inspection On-board safety monitoring Commercial vehicle administrative process Hazardous materials incident response Freight mobility
Advanced Vehicle Control and Safety Systems	Longitudinal collision avoidance Lateral collision avoidance Intersection collision avoidance Vision enhancement for crash avoidance Safety readiness Pre-crash restraint deployment Automated vehicle operations
Emergency Management	Emergency notification and personal security Emergency vehicle management
Information Management	
Maintenance and Construction Management	

Figure 1 illustrates the hierarchical arrangement among the generic framework architecture, regional ITS architecture, open standards, and individual projects. The Framework Architecture serves as a comprehensive framework for the management and integration of ITS initiatives [4]. Within this framework, a regional ITS architecture takes on a more specific role, serving as a tailored regional framework to facilitate institutional consensus and technical cohesion for the successful execution of ITS projects within a designated area [4]. The primary objective behind the development of a regional ITS architecture is to visually depict and document the seamless integration of ITS components at a regional level [4]. Additionally, it involves the identification of open standards or local protocols that have been collectively accepted by stakeholders [4]. These agreed-upon standards serve as the encoding mechanisms for information flows between various ITS elements [4]. Ultimately, the final stage encompasses the implementation of individual ITS projects [4]. This illustration aims to facilitate organized and coordinated planning and deployment processes.

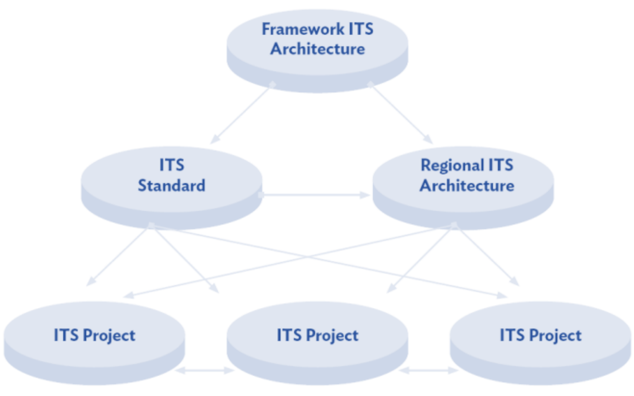

Fig.1: Hierarchical Structure of ITS Architecture [4, Fig. 2]

This study commences with a comprehensive overview of ITS and their user services within Commercial Vehicle Operations (CVO), collectively referred to as ITS/CVO. Subsequent sections delve into an in-depth exploration of ITS/CVO technologies, highlighting their benefits for motor carriers while addressing challenges tied to technological advancements. Additionally, the study explains the role of Systems Engineering in the design and implementation of ITS projects. Furthermore, the research extends its focus to evaluating the broader impacts of ITS/CVO technologies on safety and sustainability. As part of this assessment, the exploration of transportation-inventory models is undertaken as a method for effectively gauging the benefits derived from these technologies. To illustrate practical implications, the evaluation is further expounded through an analysis of case studies and projects that are specific to commercial vehicles. This analysis not only serves to evaluate the global influence of ITS technologies but also anticipates their future potential in shaping the landscape of Commercial Vehicle Operations.

II. Systems Engineering for ITS Projects

A. *Significance of Systems Engineering in ITS projects*

Systems engineering (SE) is a multifaceted approach that addresses the mitigation of risks associated with the creation, implementation, and maintenance of complex interconnected elements throughout their life spans [4]. The final product will be a blend of elements that function together harmoniously to accomplish a beneficial task [4]. SE is a methodical process that begins with defining the functional and physical requirements of a system derived from fundamental mission objectives [4]. The fundamental goals of Systems Engineering (SE) can be distilled into two primary objectives: first, ensuring that projects are acquired within the specified budget and designated timeline; and second, fulfilling all the initially envisioned requirements and objectives, commonly referred to as the "scope" of the project [4]. SE achieves these by identifying and addressing defects at an early stage when corrections are more cost-effective [4]. The intricacy of a project directly correlates with the demand for SE, as the complexity introduces a higher likelihood of challenges during the phases of operation and maintenance [4]. Unattended errors at the project's outset become progressively more expensive to rectify as the project advances [4].

The application of Systems Engineering principles is crucial in ITS projects, given the inherent challenges they pose. The complexity arises from the integration of numerous sophisticated technologies and the involvement of multiple stakeholder entities, each with their distinct ITS elements [4]. Achieving interoperability, wherein information is shared across institutional boundaries, becomes a critical aspect [4]. However, this sharing of information introduces potential risks, especially when multiple development processes are employed in implementing regional ITS elements [4]. Embracing a Systems Engineering is a strategic approach that can significantly decrease both the quantity and severity of risks in ITS projects and help in protection of private data [4].

B. *V-model for ITS Projects*

Figure 2 shows the SE V-model for generic ITS projects. This model visually outlines the successive phases involved in moving from a regional planning in the top-left to the implementation and maintenance in the top-right. It begins with regional planning, where regional

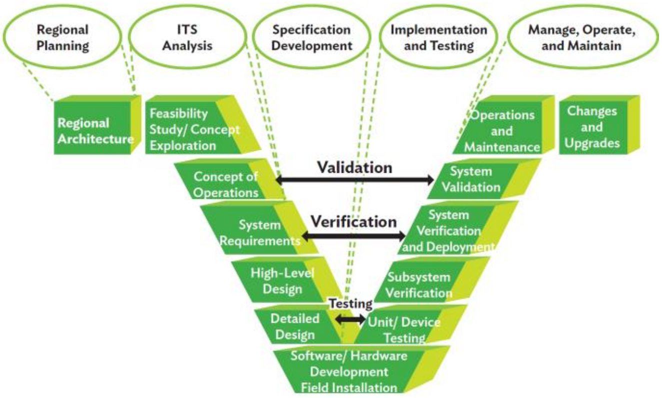

Fig.2: Systems Engineering Vee Diagram for ITS Projects [4, Fig. 1A]

needs and objectives are identified, and a regional ITS architecture is developed, specifying services and stakeholder elements [4]. The second step, ITS analysis, utilizes the regional ITS architecture for the Feasibility Study Report (ITS FSR), outlining system requirements and analyzing costs, benefits, and technology choices [4]. Following this, the requirements development phase establishes functional, performance, and environmental requirements that correspond to the objectives in the ITS FSR [4]. The implementation and testing phase involves decomposing objectives into system requirements and progressing through detailed design, hardware/software procurement, integration, testing, and validation [4]. Lastly, the manage, operate, and maintain phase ensures the system's ongoing success, including maintenance, potential upgrades, changes, and eventual replacement or retirement [4]. Throughout, the decision-making process, guided by a Systems Engineering Management Plan (SEMP), helps determine the necessity of each stage based on identified risks [4].

C. *ITS as a System of Systems (SoS)*

According to [5], Intelligent Transportation Systems can be characterized as a System of Systems (SoS), enhancing data processing capabilities for more effective transportation planning. An SoS is formed when independent, task-oriented systems are integrated into a larger construct, delivering unique capabilities that individual systems cannot achieve alone [6]. This integration allows constituent systems to operate independently, manage their own lifecycles, and collaborate to realize capabilities beyond the scope of individual systems [6]. According to [5], European ITS architecture operates as a collaborative SoS, where component systems work together for central goals. However, central management lacks coercive power over individual component systems. In contrast, American and Canadian ITS systems follow a directed SoS structure with centralized management [5]. This approach offers clear authority and co-ordination but lacks flexibility and adaptability compared to the collaborative European model [5].

III. ITS SYSTEMS FOR COMMERCIAL VEHICLES (ITS/CVO)

The sector of commercial motor carriers is a diverse landscape, ranging from individual owner-operators to massive fleets with a multitude of vehicles serving both freight and passengers. In the European Union alone, this sector boasted an annual revenue of approximately 940.5 billion euros and a production value of around 746 billion euros in 2020, as per [7]. The vitality of the economy hinges on the transportation system's capacity to deliver a wide array of products securely and effectively—ranging from groceries, furniture, computers to hazardous chemicals—to the market [2]. ITS plays a pivotal role in elevating safety and regulatory procedures within commercial vehicle operations [2]. By constantly re-evaluating and fine-tuning operations, it not only enhances efficiency but also transforms the dynamics of how authorities at the federal and state levels engage with the motor carriers [2].

A. *Overview of Intelligent Infrastructure Systems in CVO*

ITS/CVO has a wide-ranging scope that encompasses the various tasks linked to the transportation of both cargo and passengers in commercial vehicles [2]. This includes the necessary operations for regulating these activities, ensuring safety, managing credentials and taxes, overseeing field operations, handling logistics and fleet management, and ensuring the smooth operation of vehicles [2]. Commercial vehicle operations benefit from various ITS/CVO technologies under Intelligent Infrastructure Systems, including Safety Information Exchange Systems designed to streamline the collecting, distributing, and retrieval process of vehicle safety information during field inspections [2]. Electronic Screening enables compliant trucks to bypass inspection and weigh stations, reducing delays [2]. Additionally, Electronic Credentialing Systems facilitate seamless electronic processes for submitting, approving, invoicing, paying, and issuing credentials, alongside electronic tax filing, auditing, and engagement in clearinghouses for efficient accounting and dispersal of fees among states [2].

1) Safety Information Exchange Systems: This involves electronic sharing of safety data and associated credentials details related to carrier agencies, trucks, and drivers [2]. This data is utilized by enforcement entities and relevant firms to make well-informed decisions based on past safety records [2]. The system facilitates automated collection of safety performance information, augmentation with supporting credentials data, enhanced access to safety and credentials information for carriers, vehicles, and drivers, proactive updates of such information, and support for programs aimed at identifying and encouraging unsafe operators to enhance their performance [2].

2) Electronic Screening: 'Screening' within commercial vehicle operations refers to a selection process aimed at identifying high-risk users and optimizing the utilization of weighing terminal and inspection tools [2]. Electronic screening, commonly referred to as e-screening, leverages various technologies to enhance screening judgements, which leads to improved traffic flow, heightened safety, and lower operational costs [2]. This approach enables states to identify, weigh, and verify the safety and credentials of trucks at highway speeds. Drivers of compliant trucks receive notifications and are directed past the inspection station seamlessly [2].

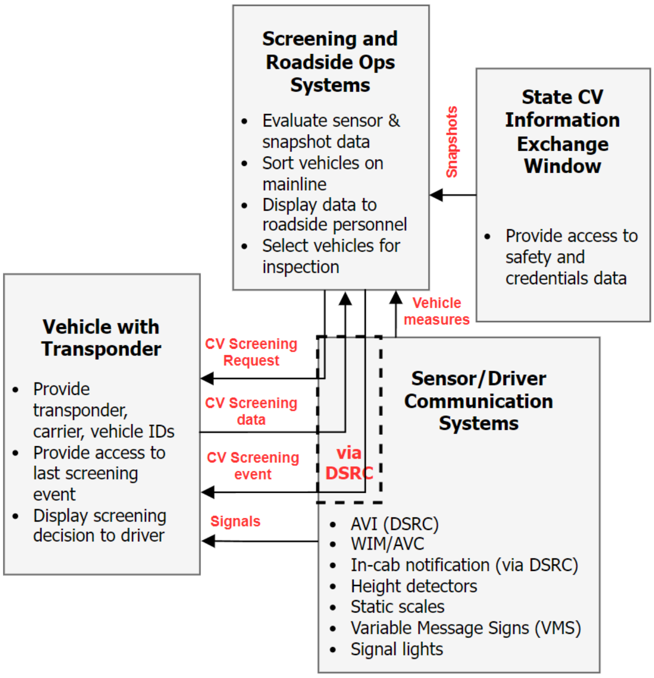

Fig.3: Electronic Screening Overview [2, Fig. 4]

Figure 3 illustrates the overview of electronic screening systems. The technologies employed in Electronic Screening Systems include:

a) Dedicated Short Range Communications (DSRC): DSRC facilitates data transmission between running vehicles equipped with transponders and field reader equipment to support the screening process [2]. It belongs to the radio frequency identification (RFID) technology subset, employing the 5.9GHz band in the USA and the 5.8GHz band in Japan and Europe for ITS applications [10].

b) Weigh in Motion (WIM): This system enables the determination of gross vehicle weight and axle weights without requiring vehicles to stop on a scale [2]. These systems demonstrate their efficacy in enhancing truck safety [9]. The presence of overloaded trucks poses significant threats to the smooth functioning of road transportation, escalating risks for road users, compromising road safety, and distorting fair competition among transportation modes and operators [9]. Additionally, there are considerable repercussions on infrastructure durability, particularly pavements and bridges, further impacting road safety [9]. When a truck surpasses its maximum permitted load, various adverse consequences may unfold such as truck instability, braking capacity reduction, loss of maneuverability, tire overheat and increased risks in transporting dangerous goods [9]. Implementing WIM systems addresses these challenges, contributing significantly to the enhancement of overall road safety and the efficiency of transportation operations [9].

c) Automatic Vehicle Classification (AVC): This system categorize the vehicle by automatically identifying number of axles WIM locations, crucial for accurately calculating vehicle weights [2]. By efficiently categorizing vehicles, AVC contributes to effective traffic management and ensures compliance with weight regulations [2].

d) Automatic Signing: This involves controlling lane indicators and VMS signs based on field operations and the detected site of vehicles, using Tracking Loops [2]. This helps in elevating overall safety and providing live details to drivers, improving overall traffic management.

The tangible benefits of Electronic Screening, in terms of time savings, are evident for both carriers and state agencies. Test statistics demonstrate quick bypass of vehicles taking time ranging between 1.5 and 4.5 minutes per bypass [2].

3) Electronic Credentialing: A credential serves as proof of meeting specific qualifications, authorized and granting certain rights or authority [2]. Operating a commercial vehicle involves obtaining various credentials, depending on whether it's for intrastate (single state) or interstate (multiple states) operations [2]. These credentials cover areas such as "vehicle registration, insurance, title, fuel tax payments, oversize/overweight permits, hazardous materials hauling permits (HAZMAT), federal heavy vehicle use tax, and compliance with state-specific regulations" [2]. Efficient administration by state agencies is crucial for legal operation, encompassing the application, review, and approval of credentials, fee payment, fuel tax returns, information management, and support for interstate agreements like "International Registration Plan (IRP) and International Fuel Tax Agreement (IFTA)", ensuring reconciliation of fees among states for interstate carriers [2].

B. Intelligent Vehicle Systems in Commercial Vehicles

Due to the integration of artificial intelligence, internet of things and information systems into motor vehicles, the automotive market has seen the emergence of advanced Intelligent Vehicle Systems (IVS) technologies [11]. The rapid adoption of these technologies is not only aimed at enhancing the comfort and safety of individual vehicles but also at improving overall road traffic safety [11]. As mentioned in the introduction, intelligent vehicle systems encompass in-vehicle monitoring and safety technologies. Examining how in-vehicle ITS/CVO technologies contribute to safety, it's crucial to discuss the level of assistance they provide to drivers and whether they supplement or replace driver control [11]. This analysis can be informed by existing in-vehicle ITS/CVO technologies, which fall into three categories: technologies that offer assistance through information presentation and control during typical driving scenarios, technologies which issue warnings during critical situations, and finally, technologies that directly implement control measures in pre-crash scenarios [11].

1) Advanced Driver Assistance Systems (ADAS): ADAS for commercial vehicles consists of a diverse range of technologies tailored to enhance the driving experience for professional drivers [11]. These systems aim to bolster safety and efficiency on the road, especially when integrated with a secure and user-friendly Human-Machine Interface (HMI) [11]. Examples of such systems include “adaptive cruise control, collision avoidance systems, driver drowsiness detection, in-vehicle navigation systems (utilizing GPS for real-time location updates), lane departure warning systems (LDWS), night vision view, lane change assistance and traffic sign recognition” [11].

2) Tyre Pressure Monitoring Systems (TPMS): This enhances vehicle safety by continuously monitoring and providing real-time updates on tire pressure [11]. Additionally, it plays a crucial role in minimizing carbon dioxide (CO_2) emissions, contributing to a more environmentally friendly driving experience [11].

3) Intelligent Speed Adaptation (ISA): This is another component of ADAS that utilizes information and communication technology to relay speed limit data directly onto the vehicle's dashboard [11]. The process involves integrating a digital road map with real-time GPS position information, allowing the ISA to present the current speed limit alongside a warning for the driver [11].

4) Night Vision: This entails installing infrared cameras, which improve vision for drivers in low-visibility situations like fog and low light conditions.

5) Blind Spot Detection: This is also one of the technology in ADAS that is crucial for commercial vehicles, where rear-view mirrors are limited by blind angles—those side areas that drivers cannot see without physically turning their heads [11]. In this, systems with cameras and electronic image processing units alert drivers when other vehicles attempt to overtake the truck [11].

When it comes to ADAS, both warnings and controls are crucial for enhancing safety [11]. Effective warnings have the potential to mitigate driver limitations, thus aiding in the prevention of road accidents [11]. High-priority alerts are conveyed through user interface system for promoting awareness and prompt driver responses in emergency scenarios [11]. ADAS equipped with high-priority warnings include systems like “Lane Departure Warning (LDW), Blind-Spot Warning (BSW), Forward Collision Warning (FCW), and backup emergency alert systems” [11]. Alongside these systems, numerous in-vehicle safety technologies are now commonplace in commercial vehicles. These contain “ABS (Anti-lock Braking System), TCS (Traction Control System), ESC (Electronic Stability Control), Brake Assist Systems (BAS), and EBD (Electronic Brake Distribution)” [11].

C. Cooperative ITS (C-ITS) technologies

The concept of cooperative systems involves establishing a network where vehicles maintain constant wireless communication with the infrastructure systems, primarily on highways but potentially extending to other road types as well [11]. This network facilitates the exchange of data and pertinent information tailored to each road type, aiming to enhance safety and facilitate cooperative traffic control [11]. C-ITS technologies encompass V2V and V2X communication, with the inclusion of truck platooning for commercial vehicles [11].

1) V2V and V2I Communication : Vehicle-to-Vehicle communication entails the collaborative exchange of data among vehicles using wireless technology, typically spanning distances from a few meters to a few hundred meters [11]. Meanwhile, Vehicle-to-Infrastructure communication involves wireless cooperative interaction between vehicles and infrastructure systems, aiming to enhance road safety and performance by facilitating seamless communication and integration between vehicles and various infrastructure components [11].

2) Truck Platooning: This technique involves a group of two or more trucks driving closely together in a convoy, autonomously linked to exchange information [12]. However, human drivers are still necessary to steer and oversee the platoon's entry and exit process [12]. The front truck (platoon leader) is operated normally, while the ones behind it (platoon members) switch to temporary autonomous mode for braking and acceleration [12]. Platooning and V2X technology are closely intertwined, as V2X is essential for enabling platooning at close distances [12].

IV. Evaluation of the Impact of ITS/CVO Technologies

This section aims to evaluate the impact of ITS/CVO technologies on several parameters such as safety, efficiency, mobility, energy consumption, and sustainability. To conduct a thorough analysis, it is crucial to trace the timeline of ITS implementation, from action plan initiation to the deployment of state-of-the-art technologies. For this, the EU's progress in the transportation industry after the adoption of ITS is considered. Furthermore, this study broadens its focus to assess case studies and specific projects in the realm of CVO, with a focus on enhancing efficiency, safety, and mitigating CO_2 emissions.

According to [13], the ITS Directive 2010/40/EU came into effect in August 2010, laying down a legal structure aimed at facilitating the implementation of ITS in Europe. It also allowed member states the autonomy to choose which applications and services to prioritize investment in [13]. The release of the ITS Action Plan in 2013 laid out a strategic roadmap for the development and deployment of ITS initiatives [13]. In 2016, the launch of C-ITS deployment marked a significant step towards enhancing communication and cooperation among vehicles and infrastructure [13]. By 2019, the implementation of C-ITS services had further solidified the integration of advanced technologies into transportation networks [13]. Recently, in November 2023, the European Commission announced Directive (EU) 2023/2661, with amendments in previous Directive 2010/40/EU [14]. This move signifies a renewed commitment to transforming Europe's transportation system, with a strong emphasis on leveraging new technologies, particularly in C-ITS, to create a safer and more sustainable ecosystem [14]. In the following section, the overall impact of ITS on safety and sustainability will be evaluated based on the results spanning from 2011 to 2023.

A. *ITS Contribution to overall road safety in EU*

ITS directly influenced road activity, serving as a valuable tool for enhancing both traffic efficiency and safety [11]. As illustrated in Figure 4, according to the 2023 report by ACEA, road fatalities have decreased by 32.8% since 2010 despite a 17.3% increase in the number of cars on EU roads [1]. As per [15], a total of 39,553 road deaths were prevented in the EU during the period spanning from 2013 to 2022. The implementation of roadside equipment and additional ITS services significantly contributed to the modern and advanced management of roadways [11]. In former times, road operators conducted road surveillance manually; today, they have access to remote monitoring and automatic incident detection technologies, enhancing their vigilance and responsiveness significantly [11].

B. *Impact of ITS technologies on Sustainibility*

The integration of in-vehicle technologies and C-ITS applications within ITS holds promise for greatly improving driving dynamics and the overall efficiency of road networks [16]. Consequently, when integrated with other non-ITS approaches, they contribute significantly to reducing fuel consumption, greenhouse gas emissions, and pollutants detrimental to air quality and public health, such as particulate matter [16]. Figure 5 demonstrates the varying potential of various ITS applications in reducing CO2 emissions applicable for passenger vehicles, vans, and light commercial vehicles [16]. Navigation and eco-driving systems emerge as the most cost-effective and readily implementable solutions, offering a CO2 reduction ranging from 5% to 10% each. However, their effectiveness hinges on the existing scope for improvement [16]. In simple words, if a driver already operates with high efficiency and follows the most optimal routes, the incremental advantages of these systems may be marginal. Regarding infrastructure, intelligent traffic signal applications have shown significant potential for savings, typically falling within the range of 3% to 7% for established urban traffic control (UTC) systems utilizing green wave technology. While in-vehicle applications are generally more successful on rural, uncongested routes, infrastructure-based technologies seem to be most viable when applied in urban areas.

In 2016, the European Road Transport Telematics Implementation Coordination (ERTICO) conducted an internal study, backed by ACEA, to explore how ITS measures could reduce CO2 emissions and enhance safety for heavy commercial vehicles. This study highlighted a variety of project initiatives and validated trial results, which were supplemented by studies using driving simulators or models. The study highlights several key findings: Eco-driving support shows promise in reducing CO2 emissions on non-urban roads, with potential savings of 7% to 10% and up to 25% in specific scenarios, although its impact in urban areas is limited [12]. Eco-routing offers benefits primarily in urban areas, with potential CO2 reductions of 4% to 12% for freight transport [12]. “HGV accidents can be greatly reduced by 17% to 24% with the use of Lane Departure Warning (LDW) and Advanced Emergency Braking System (AEBS)” [12]. Truck platooning shows significant promise in mitigating CO2 emissions. Initial findings from the US project "Driver Assistive Truck Platooning" (DATP) suggest a reduction of 4 to 7% in CO2 emissions for trucks employing this technology [12]. Similarly, the EU project “SARTRE” reported savings ranging from “1 to 8% for the leading truck and 8 to 16% for the trailing trucks” [12]. “Traffic simulations conducted in Japan echoed these results, indicating potential savings of 0 to 9% for the front truck and 12 to 22% for the trailing trucks” [12]. Moreover, platooning also holds the potential to enhance road capacity and alleviate congestion by allowing vehicles to travel in closer proximity [12]. Utilizing V2V communication for in-vehicle hazard warning can significantly improve driver visibility, especially in blind spots, resulting in increased safety [12]. Intelligent Truck Parking offers the potential to reduce CO2 emissions by 2% in long-distance freight transport by minimizing the need for extra driving to find parking, while also decreasing accidents related to driver fatigue or illegal parking [12]. Intelligent Speed Adaptation helps vehicles maintain the speed limit, particularly in urban areas and low-speed zones, potentially reducing accidents for HGVs by 1-2% with advisory ISA and 4.5-5% with a voluntary system on rural roads [12].

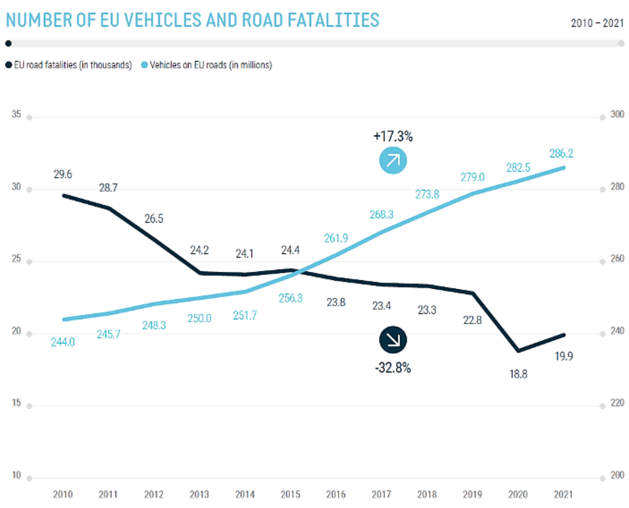

Fig.4: Graph of EU road fatalities against total number of vehicles [1, p. 76]

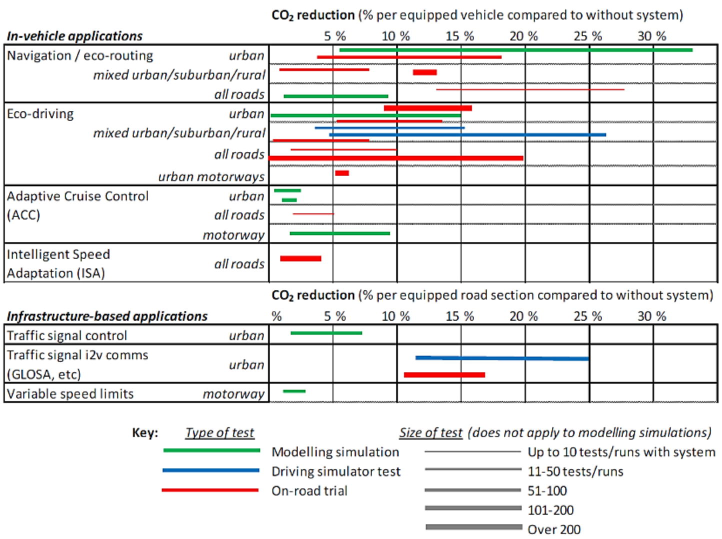

Fig.5: Chart outlining the spectrum of effects of ITS applications on CO2 reduction across various types of road networks [16, Fig. 1]

V. Results and Discussion

Road transport expansion, particularly in emerging economies, persists amid economic downturns and rapid urbanization. This urban influx fuels issues like traffic congestion, air pollution, and more accidents, impacting both urban and non-urban areas. Existing infrastructure struggles to cope, highlighting the need for modern transport management reforms. These are domains where ITS provides feasible solutions. The potential benefits of implementing ITS technologies are substantial, provided a deliberate, systematic, and progressive strategy is adopted [11]. Table II showcases the assets and challenges of ITS deployment that can be derived from this research. These assets outnumber and are more clearly defined than the potential challenges that might emerge. Nevertheless, traffic admins and ITS structure designers encounter various variables like human factors, and technological constraints, which could impede the effectiveness of ITS [11].

The future of transportation innovation will require a global, harmonized approach. Governments will need to demonstrate strong commitment, facilitating extensive public-private partnerships, while also increasing financing for ITS projects. Integration of 5G communication into C-ITS, particularly in V2X communication, will enable real-time data exchange among vehicles [11]. Leveraging new business models, advanced telematics technologies with the use of artificial intelligence (AI) and IoT will lead to improved traffic flow, reduced congestion, and consequent decreases in fuel consumption and emissions, thereby promoting environmental sustainability.

TABLE II
Benefits and Challenges of ITS deployment

Assets	Challenges
i. Increased safety with reduction in fatalities & injuries ii. Enhanced mobility iii. Reducing environmental impact iv. Reduced traffic congestion v. Faster emergency response vi. Reducing travel uncertainty vii. Increased efficiency of road operators viii. Public-private Partnership (PPP) ix. Industrial Development x. Increased comfort for road users	i. Rapid Urbanization ii. Interoperability between different countries iii. Regional differences and applicability of ITS user services iv. Varying paces within the public and private sectors v. Human factor & lack of or limited ITS training vi. Security and Protection of private data

VI. Conclusion

In conclusion, this research underscores the significant role that ITS plays within the commercial transportation ecosystem, demonstrating how ITS effectively maximizes road capacity and utilizes established technologies to their fullest potential. Moreover, it emphasizes the significance of systems engineering in the design and implementation of ITS projects, emphasizing the importance of a systematic approach. By assessing the broader impacts of ITS/CVO technologies on road safety, CO2 emissions, and fuel consumption, it becomes clear that ITS not only enhances operational efficiency but also contributes significantly to sustainability efforts. The study effectively illustrates the practical implications and global influence of ITS technologies in the realm of CVO, while also anticipating their continued evolution and potential.

References

[1] ACEA, "The Automobile Industry: Pocket-guide 2023-2024," *The European Automobile Manufacturers' Association, Brussels, Belgium*, Sept. 2023, Retrieved from: https://www.acea.auto/files/ACEA-Pocket-Guide-2023-2024.pdf

[2] S. Agrawala and H. Kallianpur, "Intelligent transport systems in commercial vehicle operations," *International Journal of Computer and Communication Technology*, pp. 27–35, Jan. 2010, doi: 10.47893/ijcct.2010.1004.

[3] H. Husseiny, B. Meligy, and M. Hassan, "The opportunities and challenges of applying intelligent transport systems (ITSS) on road transport in egypt: a case study on cairo-alexandria desert road," *International Conference on Business and Entrepreneurship, The Business and Management Review*, vol. 8, no. 5, May 2017.

[4] Asian Development Bank, "Conceptual design of the Intelligent Transport Systems Project-Case in Gui'an New District," Nov. 2019, doi: 10.22617/tcs190561-2.

[5] I. Phillips and R. Kenley, "Verification of Intelligent Transportation Systems: Challenges And Possibilities," *IEEE, 17th Annual Systems of Systems Engineering Conference (SOSE)*, Jun. 2022, doi: 10.1109/sose55472.2022.9812702.

[6] W. K. Vaneman, "The system of systems engineering and integration 'Vee' model," *2016 Annual IEEE Systems Conference (SysCon)*, Apr. 2016, doi: 10.1109/syscon.2016.7490599.

[7] Statista Research Department, "Light commercial vehicle market in Europe," *Statista*, Jan. 2024, Retrieved from: https://www.statista.com/topics/7315/light-commercial-vehicle-market-in-europe/#topicOverview

[8] E. Sampson, L. Signor, M. Flachi, E. Hemmings, and G. Somma, "The role of Intelligent Transport Systems (ITS) in Sustainable Urban Mobility Planning (SUMP) - make smarter integrated mobility plans and policies", *ERTICO – ITS Europe*, Sept. 2019, Retrieved from: https://www.eltis.org/sites/default/files/the_role_of_intelligent_transport_systems_its_in_sumps.pdf

[9] J. Oskarbski and D. Kaszubowski, "Implementation of Weigh-in-Motion System in freight traffic management in urban areas," Science Direct, Transportation Research Procedia, vol. 16, pp. 449–463, Jan. 2016, doi: 10.1016/j.trpro.2016.11.042.

[10] S.-H. An, B.-H. Lee, and D.-R. Shin, "A Survey of Intelligent Transportation Systems," *Third International Conference on Computational Intelligence, Communication Systems and Networks, IEEE*, Jul. 2011, doi: 10.1109/cicsyn.2011.76.

[11] United Nations Economic Commission for Europe (UNECE), "Intelligent Transport Systems (ITS) for sustainable mobility," Geneva, Feb. 2012, ISBN: 9788897212034. Accessed: Dec. 29, 2023. Available: https://unece.org/transport/publications/intelligent-transport-systems-its-sustainable-mobility

[12] A. Winder, "ITS4CV – ITS for Commercial Vehicles," *European Road Transport Telematics Implementation Coordination (ERTICO - ITS Europe)*, Sept. 2016, Retrieved from: https://erticonetwork.com/wp-content/uploads/2016/09/ITS4CV-Report-final-2016-09-09.pdf

[13] European Commission Directorate General for Mobility and Transport., TEPR., and Ricardo., "Support Study for the ex-post evaluation of the ITS Directive 2010/40/EU: final report," *LU: Publications Office*, 2019. doi: 10.2832/254167.

[14] European Parliament and the Council of the European Union, "DIRECTIVE (EU) 2023/2661 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL," *EUR-Lex, Official Journal of the European Union*, Nov. 2023, ISSN 1977-0677, Retrieved from: http://data.europa.eu/eli/dir/2023/2661/oj

[15] J. Carson, G. Jost, M. Meinero, "RANKING EU PROGRESS ON ROAD SAFETY," *17th Road safety performance index report, European Transport Safety Council (ETSC)*, Jun. 2023. Retrieved from: https://etsc.eu/wp-content/uploads/ETSC-17th-PIN-Annual-Report-DIGITAL-1.pdf

[16] A. Winder, and D. Brizzolara, "How ITS can contribute to reducing CO2 emissions of road transport: The quick wins," *ResearchGate, 12th ITS European Congress, European Road Transport Telematics Implementation Coordination (ERTICO)*, no. TP0999, Jun. 2017.

[17] M. Kadłubek, "Expectations for the use of Intelligent Transport Systems applications in the management of freight transport enterprises," *Science Direct, Procedia Computer Science*, vol. 192, pp. 2318–2329, Jan. 2021, doi: 10.1016/j.procs.2021.08.22