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# A Brief Survey on Cooperative Intelligent Transportation Systems and Applications

Özgür Talih[1*] and Necla Tektaş[2]

0000-0002-5899-2511, 0000-0002-8190-4532

[1]*Graduate School of Natural and Applied Sciences, Master's Program on Intelligent Transportation Systems and Technologies Bandırma Onyedi Eylül University, Balıkesir, Türkiye*

[2]*Faculty of Economics and Administrative Sciences, Department of Econometrics, Head of Department of Operations Research, Bandırma Onyedi Eylül University, Balıkesir, Türkiye*

**Abstract**

Cooperative Intelligent Transport Systems (C-ITS) have emerged to provide a range of intelligent transport services that optimize traffic management, improve the travel experience of road users, increase road safety and security, and reduce the negative environmental impacts of transport. C-ITS, which aim to ensure that intelligent transport services function effectively and efficiently, communicate and exchange data with vehicles, road users, traffic control centers, and road infrastructure as well. In this study, an overview of C-ITS related activities in the world and in Türkiye are discussed. C-ITS studies in literature and the objectives and benefits of C-ITS, its stakeholders, its relationship with ITS, its components and services are examined. After summarizing C-ITS studies in the world, policies and strategies in Europe, USA and Asian countries, and the current situation in Türkiye is provided. In addition, since there are limited studies on C-ITS in Türkiye, where ITS is still in its development stage, it is aimed to contribute to the literature by presenting recommendations for
Türkiye to support the dissemination of C-ITS.

Keywords: Cooperative Intelligent Transportation Systems, C-ITS, Connected Vehicle, Smart Infrastructure, ITS, Vehicle Communication Systems

**Review Article**

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* Corresponding author
Özgür Talih
ozgurtalih@ogr.bandirma.edu.tr
Address: Graduate School of Natural and Applied Sciences, Bandırma Onyedi Eylül University, Balıkesir, Türkiye
Tel: +903122028653

## 1. Introduction

With the rapid increase in urbanization in the world and in our country day by day, traffic congestion has become a problem for which solutions are sought for cities and which is also constantly changing and gaining momentum. For the solution of this problem, Intelligent Transportation Systems (ITS), consisting of many communications and information technology applications for the efficiency, durability and safety of transportation, which emerged as a product of social, economic and technological development, have gained a great importance.

Within the framework of many problems, such as accidents resulting in loss of life in crowded cities and air pollution caused by the increase in greenhouse gases, research on smart urbanism solutions focus on the concept of Cooperative Intelligent Transport Systems (C-ITS), which is seen as a step beyond ITS.

All over the world, digital and innovative technologies and systems relying on them are being used effectively in all activities in different modes of transportation. Cooperative Intelligent Transportation Systems (C-ITS), mostly used in road transportation, are within these improvements. These systems include technologies that enable communication between different types of vehicles, smart roads, road users, roadside units, control centers and other elements. By improving the reliability and quality of road data, C-ITS ensures traffic efficiency, road safety and security within the framework of cyber security and data protection. It also helps reduce transportation-related energy consumption and emissions. Furthermore, an unprecedented level of cooperation across multiple sectors is needed for C- ITS deployment to succeed. In this context, roles and responsibilities in the value chain should be defined and existing concepts should be clarified. Today, it is essential to incorporate autonomous, connected and cooperative vehicles within sustainable and impact mobility planning, including approaches to active travel types such as public transport, walking and cycling. Citizen engagement is also crucial to ensure that C-ITS technologies are widely accepted, including all stakeholders, while maximizing their economic and social impact. In addition, the activities related to the deployment and creation of C-ITS should be completely user-oriented.

A digital transportation system will be more efficient if it creates solutions in horizontal layers that intersect different industries and transportation modes, rather than a structure that includes vertical sectors like telecommunications, energy or transportation. In today's world where technology is rapidly differentiating, changing and evolving, it has become a necessity to move towards connected, co-operative and autonomous solutions rather than solutions that focus only on infrastructure components such as roads and vehicles.

C-ITS will provide users, decision makers, road administrations and all developers in this field with a test environment where digital processes in transportation can be observed in the best way. This will positively affect the lives of local people in many ways, and will also provide an attractive urban environment for many public and private institutions operating in different sectors. Thus, the digitalization of cities will be supported and they will become smarter.

In this study, the status of C-ITS and test corridors in the World and in Türkiye is discussed. In this context, firstly, the definition of ITS and its relationship with C-ITS is analyzed, its place in the literature is evaluated and C-ITS policies and strategies, studies and developments in our country are examined. Within the framework of the results obtained, evaluations and recommendations for Türkiye are given.

## 2. Cooperative Intelligent Transport Systems (C-ITS)

C-ITS, which enables vehicles to interact directly with each other and with the surrounding road infrastructure, is an innovative technology that aims to improve the efficiency, safety, security, comfort and environmental performance of road freight and passenger transport. It basically involves communication and information exchange between vehicle-infrastructure (V2I), infrastructure-infrastructure (I2I), vehicle-vehicle (V2V) and vehicle-everything (V2X) such as vehicles, pedestrians, and cyclists. In short, C-ITS are technologies that can receive information about various incidents occurring on the road by communicating with in-vehicle, roadside and on-road communication devices [1]. (Fig.1)

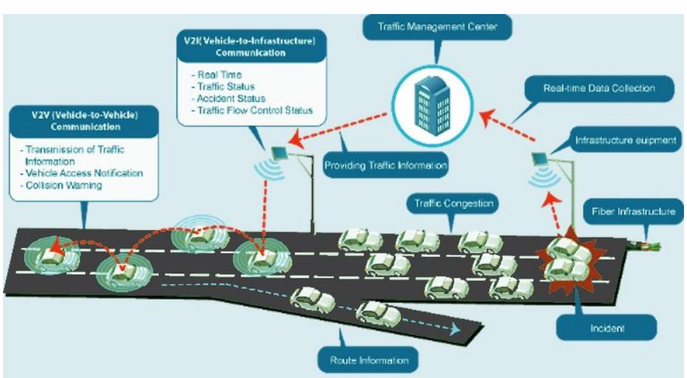


Fig. 1. Cooperative Intelligent Transport Systems [1]

C-ITS enables vehicles to communicate with each other and with infrastructure [2], which potentially improves road safety, optimises traffic management, improves end-user experiences, increases energy efficiency, and reduces traffic emissions and congestion, especially in urban areas [3; 4]. C-ITS can be described as the ITS services that offer cooperation between two or more Intelligent Transport Systems (ITS) sub-components (pedestrian, vehicle, roadside and hubs) with a higher quality and improved service level aiming to increase the efficiency, safety and environmentally sensitive performance of transport systems on the highway [5]. The most important aspect of C-ITS is that it relies on real-time data during the communication between two or more ITS components. Wireless technology is used to provide real-time communication [6]. Thus, better coordination between road users can be achieved and safer and more efficient traffic flows can be possible (Fig. 2).

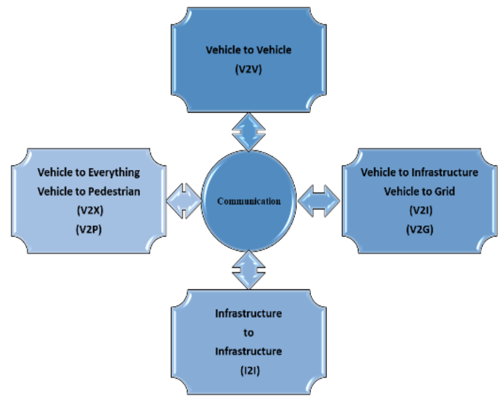


Fig. 2. C-ITS conceptual structure

The first phase of C-ITS is about warning systems, the second phase is about the sensory phase where vehicles collect data from different signals and read the traffic situation, and the last phase is about the co-operation between vehicles [6]. C-ITS is even more broadly defined in ISO and CEN standards, in particular as so-called "ITS stations", i.e. hardware and software units mounted on the vehicle or a roadside unit on the road that perform various tasks in the whole network of co-operative systems [7].

By focusing on the communication between all kinds of road users, including pedestrians, and ITS components in elements such as vehicles, infrastructure, roads, centers, etc., it will be possible to express the innovative transportation technology concept application as C-ITS, which provides safe and efficient cooperation at an advanced service level, thus defining the technology and standards that will be needed.

C-ITS covers a wide range of applications that aim to increase travel safety, minimize negative environmental impacts, improve traffic management, and maximize the benefits of transportation for all road users. In general, C-ITS aims to achieve the benefits of ITS and beyond.

C-ITS will first help improve road safety by extending the vision of vehicles beyond the drivers' line of sight or the vehicle's sensors. It will improve traffic efficiency by coordinating the actions of road users improving road capacity, which will indirectly reduce the negative external impacts of congestion, such as inefficient fuel use and increased emissions, and the negative environmental impact of driving. It will also help drivers' decision-making ability and improve driving comfort by providing information about the traffic situation [8].

ITS is an advanced method that supports innovative services to be implemented in transportation and traffic management by using the data obtained through the transportation network in an intelligent and coordinated manner [9]. C-ITS, on the other hand, emerges as a concept that deals with the communication between the components within ITS. Reviewing the literature on C-ITS, it is seen that theses heavily focus on the development of technologies used in C-ITS and the impact of C-ITS on traffic, while articles and papers generally cover topics such as the development of communication technologies, approaches to security, infrastructure technologies, test corridors, cyber security, traffic impact and management as well as environmental impact and social impact. From a global perspective, it is seen that various projects have been put forward for the deployment of test corridors and the development of connected vehicle technologies for the spread of C-ITS.

### *2.1 C-ITS Objectives and Benefits*

C-ITS has a positive impact on road safety as it enables sensitive information to be sent directly to drivers as warnings quickly and efficiently. Road safety is improved through the rapid detection of traffic problems (at C-ITS stations) and by providing related warnings to all drivers who are approaching a dangerous situation. The extent to which ITS contributes to the reduction in accidents has not yet been quantitively determined. This is because there are currently not enough installations and tools to assess this for an entire infrastructure network. Depending on the type of accident, it is currently estimated that if all vehicles were equipped with C-ITS systems, their use could lead to a reduction in accidents between 8% (in a highway environment) and 60-80% (in crashes at intersections in urban areas) [7]. C-ITS is an important approach to provide what vehicles need to know about the road at the right time and in the right place.

The seven main functions and advantages of C-ITS can be listed as follows [10]:

- Collection of driving data,
- Real-time exchange of information about traffic,
- Real-time information exchange about road hazards,
- Real-time information exchange about vehicle hazards,
- Directing traffic at intersections,
- Toll collection,
- Pedestrian protection.

C-ITS is an innovative and promising technology that is expected to provide safer, faster and more environmentally friendly transportation. It is based on communication between vehicles equipped with radio frequency communication technologies and roadside infrastructure. However, transportation-related applications must ensure maximum safety and reliability to avoid dangerous situations and possible injuries to passengers [11].

Vehicles and infrastructure equipped with C-ITS can send an alert to each other, after which drivers are timely informed about the upcoming traffic situation in order to take the necessary measures to avoid potential harm. Other potential benefits of C-ITS include reducing traffic congestion and improving driver comfort [12]. C-ITS platforms can provide all road network users and authorities with instant access to data such as road conditions, traffic conditions, route information, while also maximising traffic safety and security.

The main benefits of C-ITS services for mobility can be summarised as follows: i) reduction of accidents and their negative consequences for safety and security; ii) improvement in managerial issues such as traffic congestion, waiting times, transportation planning for operational efficiency; iii) ensuring transportation accessibility, sustainability and equity for mobility and comfort; iv) reducing energy and fuel consumption to eliminate the negative environmental impacts of transportation. In addition, the possible benefits of C-ITS for road users can be listed as follows [13], Fig 3:

- Warn about dangerous situations such as road works, stopped vehicles, traffic jams, queuing,
- Providing information about open and closed lanes and the speed at which they can travel,
- Providing information about the duration of traffic lights (how long they turn red or green),
- The ability to display the appropriate maximum speed limit for each section of road and advise drivers on the speed they can travel,
- Providing information on the condition of bridges and parking spaces,
- Warning about objects they may encounter on the road,
- Providing prioritization in traffic so that ambulances, firefighters and police vehicles can move more quickly, smoothly and safely in an emergency.

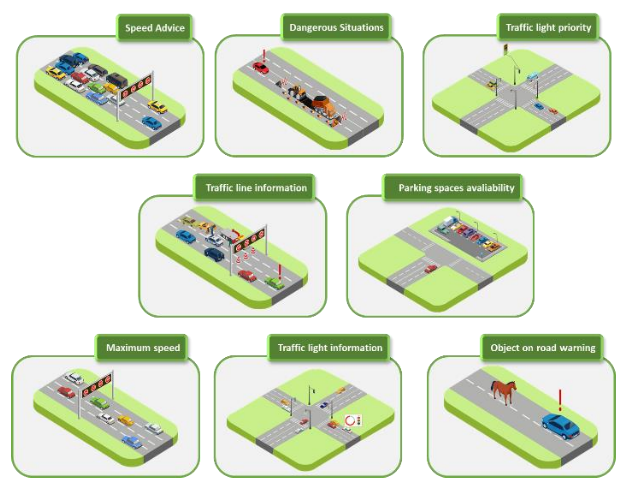


Fig. 3. The possible benefits of C-ITS

C-ITS will first help to improve road safety by extending the visibility of vehicles further beyond the drivers' field of vision or the detection angle of the vehicle's sensors. This will improve traffic efficiency by improving road capacity and coordinating the activities of road users. This will indirectly reduce the negative external impacts of congestion and the negative environmental impact of driving, such as inefficient fuel use and increased emissions. It will also help the driver to make decisions and improve driving comfort by providing information about the traffic situation [8].

### 2.2 ITS and C- ITS Relationship and Stakeholders

ITS components need dynamic data exchange to interact and fulfill their functions. It is important to understand that C-ITS is not an end in itself, but a combination of techniques, protocols, systems and subsystems to enable collaborative and cooperative service delivery. In a C-ITS world, vehicles can exchange data and even control mechanisms with other vehicles [14].

While ITS focuses on digital technologies that provide information placed on the roadside or in vehicles, C-ITS focuses on the communication between the subcomponents of ITS. Based on the results of various studies and projects, it can be said that the ITS platform helps the vehicle user to adapt to the traffic situation and make the right decisions during the journey. As a result, it is concluded that the cooperation between intelligent systems has the potential to significantly improve road safety [12].

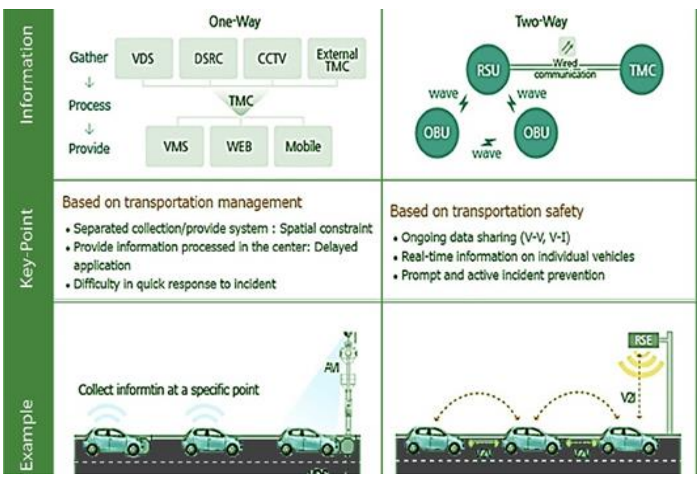


Fig. 4. ITS C-ITS differences [15]

ITS can be seen as a system for collecting information based on transportation information and making it available to all road users, while C-ITS can be seen as an approach based on real-time data to prevent unexpected situations. A system stakeholder is an individual, team or organization, or their associations, that has interests or concerns related to a system. C-ITS stakeholders cover the entire transportation environment, including users, operators, distributors and maintainers of roads, devices and vehicles [14].

Often, drivers are expected to adapt to C-ITS applications, but this may not always be possible. For this reason, as a result of the developments in innovative technologies, new features added to vehicles may require new regulations and adaptations regarding the training of drivers, measurement and certification of their competencies. It is also important that drivers are familiar with road and vehicle safety equipment components. In addition, it is known that there are efforts to develop C-ITS solutions for vulnerable road users [12].

A system stakeholder is a person, group or organization that has interests or concerns about a system. Accordingly, C-ITS stakeholders cover a wide range of the transportation environment, including users, operators, distributors and maintainers of roads, devices and vehicles. C-ITS stakeholders include transportation users and operators, public safety providers, information service providers, environmental managers including emission and air quality monitors, vehicle equipment manufacturers (OEMs), in-vehicle device manufacturers, communication service providers including cellular networking, software and application developers, and regulatory, supervisory and policy-making bodies [14].

One of the priorities for the realization of activities in accordance with the definition of C-ITS, which is the provision of more effective and efficient service in transportation with the cooperation of more than one ITS component, is the establishment of an ITS architecture. Thus, it will be possible to gather and integrate systems under a single roof, determine communication protocols, and ensure data integrity [16]. From this point of view, it can be said that the spread and development of C-ITS is directly connected and interconnected with the field of intelligent transportation.

Like ITS, C-ITS is a multi-stakeholder approach consisting of road user individuals, central government, local governments, universities, NGOs and private sector organizations. C-ITS is seen to serve different groups of road users and passengers, public transport users, local communities, transport professionals and policy makers, road network operators and vulnerable road users such as the elderly, children, those with physical disabilities and those with limited mobility.

### 2.3 C- ITS Components and Services

C-ITS has significant potential to improve the transportation network. What underpins the initial deployment and emergence of C-ITS is the research conducted within the scope of ITS. ITS concepts such as probe data generation and collection, the Pub/Sub solution and the 5.8 GHz Dedicated Short-Range Communications (DSRC) architecture are largely the basis for C-ITS. ITS does not aim to replace or mandate existing transportation equipment technology or transportation hubs [14].

Regarding C-ITS, there are four types of subsystems that make up the communication architecture. These are [8]:

- In-vehicle ITS Subsystem or On-Board Unit (OBU), which is installed or retrofitted to the vehicle by the manufacturer. These technologies enable V2V and V2I communications.
- Personal ITS subsystems, which are formed by portable devices that are not connected to the information path of a vehicle, such as individual navigation applications, tablets, cell phones, etc. These technologies allow V2I communication and are expected to allow V2V communication in the future when technical barriers such as transmission delay and message overflow need to be overcome.
- Infrastructure ITS subsystems are roadside units (RSUs) and sensors that can be deployed along the road. They form the basis for V2I communication and need to be deployed and subsequently maintained by their respective departments.
- Equipment operated by organizations responsible for multiple ITS applications form the central ITS subsystem. The centralized system can be used to deliver, monitor, maintain and track services and many processes.

In this direction, it can be said that on-board units (OBU), roadside units (RSU), smart toll collection systems, automatic incident detection systems, pedestrian detection systems, road weather information systems, traffic signal control systems, traffic management centers are among the most important components of C-ITS, which come into the scene mostly with connected vehicle technologies.

The ITS architecture provides a multi-perspective, or specification, of the rules and structural features necessary to focus on specific areas that are closely related to the system. In other words, it defines the stakeholders of a system's architecture and their concerns, demands and interests. The architecture describes in detail five key elements, chosen to meet the demands and address the concerns of stakeholders: organizational, functional, connectivity, communication and information [14].

Looking at examples, the literature, projects, legislation, etc. for the implementation of C-ITS components and architecture in the field, it is seen that the first step is to define Day 1 services. These services include safety and security related warnings that should be prioritized and implemented in the first stage. (Fig 5)

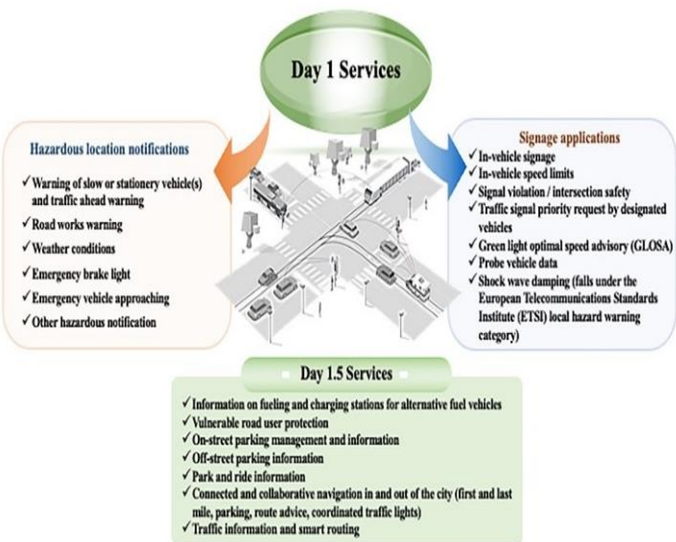


Fig. 5. C-ITS Day 1 and 1.5 Services [8;17]

Among the C-ITS services, those related to weather conditions or roadwork alerts are considered particularly useful for road transportation, while those related to priority requests such as GLOSA or dynamic parking and traffic lights are most suitable for urban services. In urban areas, there is a large component related to traffic lights, emergency vehicles and public transportation, which would be beneficial for a smoother flow in crowded city traffic [8].

Public transport optimization by understanding the competencies required for C-ITS and efforts to reach the highest level of maturity at the institutional level allow the improvement of safe and clean mobility by reducing traffic congestion and carbon emissions while reducing accident rates. C-ITS can make fully autonomous and collaborative decisions under real-world (stress) conditions using prediction, forecasting, simulation, rules, optimization, and artificial intelligence methods. It can also be adapted and resized in real time according to load monitoring or passenger demands, while becoming operational, efficient, proactive and flexible [18].

Elements such as vehicles, roadside components, passengers, drivers, road operators, organizations responsible for managing the road and the road itself may differ in each C-ITS design to be put forward as a solution. These designs may vary according to the structural characteristics of each city and the planned framework. This design plan, in which vehicles and all other entities related to the highway will share data in order to cooperate, is principally based on data to be obtained from many different environments. The approach is based on collecting driving and road data, exchanging real-time information about traffic and dangerous situations involving roads and vehicles, directing traffic at intersections, collecting tolls, and supporting driver, pedestrian and passenger safety.

With the emergence of the smart city concept and the in-crease in initiatives and developments in this direction, it is aimed to minimize and eliminate accidents at intersections on intersecting roads, delay times in journeys, traffic congestion and traffic chaos thanks to intelligent transportation and advanced traffic systems, one of the most important components of these [19]. Data exchange interfaces such as V2V and V2I can further increase security risks by greatly expanding the potential cyber-attack surface and vectors [20], which can lead to information about a city's transportation infrastructure being used by malicious actors to commit various crimes. The digitalization of assets within the usual structure of the smart city phenomenon, along with many benefits, also contains a very serious potential for cyber security vulnerability [21], and for C-ITS applications, which is an issue that requires serious measures to be taken.

### 3. C-ITS Policies and Strategies

It is argued that one of the most important data sources in smart cities is built on the information and communication technologies involved in ITS and subsequently in C-ITS applications. These sources of information can be collected and processed, and can support services that can be integrated into transportation infrastructure and then create applications that can influence traffic, thereby opening up new opportunities for city authorities. Research shows that the responsibility for smart mobility initiatives often rests on the shoulders of city authorities. This is because authorities need good solutions to achieve the goals they have set for their region. This is why many cities want to guide the development of C-ITS and other smart mobility technologies [8].

Looking at European C-ITS policy initiatives, the studies pertaining to 2010-2017 timeframe are [2]:

- European Commission (EC) Directive 2010/40/EU
- EC, White Paper on "*Roadmap for a Single European Transport Area - Towards a competitive and resource efficient transport system*" dated 2011
- Roadmap for infrastructure and the automotive industry on the initial establishment of Cooperative ITS in Europe, prepared by Amsterdam Group dated 2013

- EC, List of Day 1 Services dated 2016
- Amsterdam Group White Paper
- Final Report of the C-ITS Platform Phase 1 document, January 2016
- Roadmap prepared by The European Commission in 2016 "*A Master Plan for Building Interoperable Collaborative ITS in the EU*", ITS Master Plan
- "Declaration on Cooperation in the Field of Connected and Autonomous Driving", adopted by the EC in 2016, Amsterdam Declaration
- EC, C-ITS Certification Policy about the Deployment and Operation of the European C-ITS dated 2017

U.S. C-ITS, policy initiatives in the period 1996-2017, [2]:

- National ITS Architecture (U.S. Department of Transportation, 2019)
- Turbo Architecture (U.S. Department of Transportation - U, 2019)
- Standards that will enable the creation of Connected Vehicle (CV) technologies that the U.S. Department of Transportation's ITS Joint Program Office (USDOT ITS JPO) is evaluating
- "*EU-US Joint Declaration of Intent on Research Cooperation in Cooperative Systems*", dated 2009
- "*2015 FHWA (Federal Highway Administration) Vehicle-to-Infrastructure Deployment Guidance and Products"* from the U.S. Department of Transportation, *2014*
- U.S. Department of Transportation's 2017, system architecture framework document, "Connected Vehicle Reference Application Architecture (CVRIA)"
- U.S. Department of Transportation's 2017, *"Architectural Reference for Cooperative and Intelligent Transportation (ARC-IT)"*
- U.S. Department of Transportation's 2017, "*Regional Architecture Development for Intelligent Transportation (RAD-IT)* "and "*Systems Engineering Tool for Intelligent Transportation (SET-IT)"*

The EC has outlined a strategy summarizing the roadmap to the establishment of C-ITS in the aspect of commercialization in the EU by 2019 in order to protect the integrity of the market and maintain the competitiveness of the EU. The key steps set out in this strategy can be summarized as follows: (i) adopting a legal framework to provide infrastructure for investors; (ii) providing EU funds to finance these projects; and (iii) establishing and maintaining cooperation between all stakeholders internationally and within the EU. The strategy also addresses key issues like technical specifications, data protection, cybersecurity and systems interoperability. At the same time, pilot continuing projects are improving the sharing of experience and knowledge for those who are indirectly active in this field. Some of the actions identified by the EU Commission for the deployment of C-ITS [17] are as follows:

- Ensuring the implementation of C-ITS, by road operators, vehicle manufacturers, local authorities, member states and the ITS industry, at least fully supporting the list of scenarios for C-ITS Day 1 services
- The Commission to support the subject sector and Member States through the European Fund for Strategic Investments, the European Structural and Investment Funds and the Connecting Europe Facility to roll out C-ITS Day 1 services
- Commission to fund R&D for innovative technologies for C-ITS Day 1.5 services and beyond through H2020 and possibly through the European Structural and Investment Funds
- The Commission to update the 1.5 Day services and future service lists within the C-ITS framework, ensuring continuity of the C-ITS Platform processes

The main objectives for Day 1 Services are presented in [7], the C-ITS Strategy of Austria, which is a member state of the European Union. These objectives include ensuring the most optimal level of data exchange between transportation infrastructure and vehicles, and good management of coordination between public and private stakeholders in the C-ITS deployment phase and processes. These are necessary for the deployment of C-ITS for an enhanced cooperation between all parties involved in Austria. The use of C-ITS affects the entire transportation system, from the road and motorway network and interfaces to the secondary road networks in the street area, thereby affecting the entire urban and intercity road network [7].

By definition, C-ITS is seen as a fiction built on highway infrastructure. With the dissemination of these systems in the future, it will be possible for innovative approaches to emerge by thinking together with different modes of transportation such as rail systems, airways and maritime routes in order to improve traffic flow and safety. For example, in railways, drivers will be able to be informed about an approaching train in advance with real-time data from the center thanks to a device inside their vehicles, thus reducing the loss of life at level crossings.

### *3.1 C-ITS Studies*

C-ITS projects continue to be developed in all countries and are of particular interest in the U.S., E.U. and Japan. In the E.U., the European Commission has played an important role in the development of C-ITS, by launching supportive projects for cooperative systems in 2005, which have continued to expand and focus on E.U. countries. As a result, countries such as the U.S., Australia, China, Korea and Japan have started this digitalization, while the European Commission established a European strategy on C-ITS in 2016. The main objective of this strategy is to accelerate the development of C-ITS and ensure coordination at European level, creating synergies between projects and developing an interoperable system. Importantly, the directive established a legal framework that makes these objectives possible for C-ITS projects across Europe. The ultimate focus of this strategy is to make transport systems smart and expand the context of C-ITS to enable collaborative, connected and automated mobility (CCAM). C-ITS can be seen as a vital jumping-off point for autonomous vehicles, as research has shown that without connectivity, autonomous mobility can worsen rather than improve traffic conditions. Furthermore, the C-ITS platform and C-Road initiatives have been established to develop a common vision within Europe and implement large-scale projects in various countries. These initiatives encourage the gathering of experience and knowledge sharing between pilot sites and pioneer cross-border deployment.

The main objective of C-ITS projects involving a test and deployment corridor is to test and validate C-ITS units and components. It is expected to help ensure the same functionality everywhere along this corridor and for all vehicle brands to guarantee full interoperability.

Table 1. C-ITS Project [9]

| Project Name | Period |
|---|---|
| FleetNet | 2000-2003 |
| OKI | 2004 |
| Watch over | 2006-2008 |
| Com2React | 2006-2007 |
| CVIS | 2006-2010 |
| SAFESPOT | 2006-2010 |
| COMeSAFETY | 2006-2009 |
| I-WAY | 2006-2009 |
| COOPERS | 2006-2010 |
| DRIVE C2X | 2011-2013 |
| COMeSAFETY2 | 2011-2013 |
| FOTsis | 2010-2014 |
| Ko-Fas | 2009-2013 |

Apart from the ones shown in Table 1, Europe also has projects directly or indirectly related to C-ITS; such as SAFERIDER, euroFOT, SISCOGA (FOT-NET DATA), PRESERVE, ITSSv6, MOBiNET, P4ITS, VRUITS, COMPANION, HeRO, HeERO2, TeleFOT, DRIVE C2X, eCoMove, interactIVe, OVERSEE, FREILOT, COSMO, PROSPECT, CODECS, XCYCLE, COBRA, CoCarX, SPITS, DITCM, ECo-AT [2]. (Fig. 6)

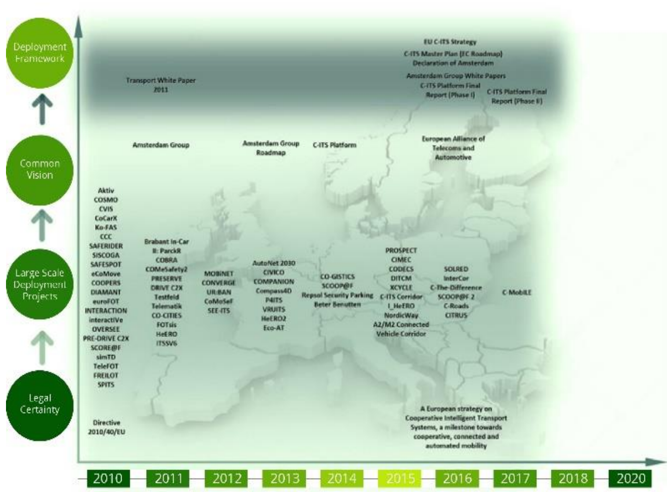


Fig. 6. Overview of ITS Europe activities [2]

USA, C-ITS Activities [2]:

- A pilot project, "*Arizona Emergency Vehicle Infrastructure Integration (E-VII)*", was developed in collaboration with Michigan and Maricopa County DOT and Arizona State University, Arizona Transportation Research Center In 2008.
- The Michigan DOT, the Information Industry Institute and the University of Michigan Transportation Research Institute (UMTRI) the "Multipath Signal Phase and Timing (SpaT) Broadcast project" in 2009.
- In cooperation with USDOT and UMTRI, the "Connected Vehicle Safety Pilot Model Deployment (SPMD)" project started in 2011. Michigan and the U.S. DOT and Federal Highway Administration (FHWA) sponsored the "Integrated Mobile Observations 2.0 (IMO)" project in 2011. Auburn University and FHWA sponsored the "Heavy Truck Cooperative Adaptive Cruise Control (CACC)" project.
- The project "Enhancing Safe Traffic Operations Using Connected Vehicle Data" was coordinated by the University of Washington in 2015. The "Connected Vehicle Pilot Installation Program" was launched by USDOT in an effort to mainstream connected vehicle technology. Another project called "Smart City Challenge" was launched by USDOT in December 2015 in mid-sized American cities to build a new intelligent transportation system. Here, the "*Columbus Smart City Demonstration*" project, which includes an integrated data platform for the deployment and development of connected vehicle infrastructure, was successful.
- The "Truck Park Information Management Systems-TPIMS" project was supported by the Federal Tiger Grant in 2016.
- The "5.9 GHz Dedicated Short Range Communication Vehicle-Based Road and Weather Application" project, which aims to obtain road and weather information, was started in 2017.

Table 2. Connected vehicle activities for Asia [9]

| Country | Project |
|---|---|
| Republic of Korea | ITS 21 plan, Ubiquitous city, C-ITS project |
| China | Autonomous vehicle activities, autonomous new energy vehicle partnership, connected taxi use, General Motors and Shanghai Automotive Industry Company autonomous vehicle activities, real-time data, star wings, traffic data control structure model |
| Japan | Vehicle data and communications service, ITS Japan, Electronic Toll Collection, ITS point service, driving safety control structure, advanced safety vehicle and smart road, start ITS from Kanagawa and Yokohama project, energy management of ITS project, Nissan autonomous vehicle public road evaluation |
| Singapore | Real-time information, autonomous electric vehicles partnership, Singapore MIT alliance for research and technology, One North public roads autonomous vehicle deployment |
| Taiwan | Automotive research and evaluation program, industrial technology research program |
| Australia | 5.9 GHz bandwidth provision for ITS, smart speed control trial, Cohda wireless program, C-ITS initiative, smart access assessment, autonomous vehicles partnership |
| New Zealand | National ITS architecture |

As seen in many good practice examples around the world, traffic management activities have become easier and more effective after the beginning of ITS implementation. In addition, with ITS applications using innovative approaches and technologies, transportation has become safer, more convenient, comfortable and efficient for all road users, including drivers. With urbanization, the demand for road transportation has increased, resulting in traffic congestion. This has made it necessary to focus on ITS and mobility related efforts in Türkiye.

Since September 2012, the Ministry of Transport and Infrastructure (MoTI) has been a member of ERTICO (European Road Transport Telematics Implementation Coordination), the common civil platform of ITS stakeholders of European countries and has been closely following the work done by ERTICO. At the end of 2019, MoTI became an "Associated Member" of the C-Roads Platform, which coordinates pilot studies for C-ITS with the financial support of the European Commission [22].

The National ITS Strategy Document and 2020-2023 Action Plan, which were prepared by the Ministry of Transport and Infrastructure and came into force in August 2020, contains short-, medium- and long-term targets that are a roadmap within the framework of digitalization of transportation and promotion of mobility in Türkiye. The National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan prepared by the Ministry of Transport and Infrastructure includes the following long-term targets for C-ITS:

- Carrying out preparatory work to make the existing infrastructure suitable for connected vehicles and autonomous driving, and developing and deploying fully autonomous vehicles across transportation modes,
- Carrying out studies for the domestic and national production of autonomous and connected vehicle technologies, especially in-vehicle information and communication systems,
- Establishing Autonomous Driving Test and Certification Centers where functional and operational tests of autonomous vehicles are conducted and certification services are provided,
- Anonymizing the collected transport data and using it for research and development of innovative applications.

Project studies are being carried out by the General Directorate of Highways, in line with the action aiming to establish a C-ITS test and application corridor that will contribute to the transformation of solutions into final products, which is included as a short-term goal in the aforementioned document [1].

Within the framework of long-term goals, the Ministry of Transport and Infrastructure is conducting the "Determination of Driving Architecture for Autonomous Vehicles and Connected Vehicle Traffic Test Scenarios" project, which is indirectly related to C-ITS. The Ministry has also initiated a project under the action of "Determining the Technical Requirements of In-Vehicle Information Communication Systems", which is underway. The outputs of these projects can be considered as the first steps in the deployment and development of C-ITS in Türkiye.

To date, the studies conducted in Türkiye within the framework of connected vehicles are generally considered to be related to C-ITS. In this respect, the Service and Application Working Group within the 5GTR Forum, which was established to develop products, technologies and services for next generation communication systems, and the Türkiye Automobile Initiative Group (TOGG) are carrying out studies on connected vehicles. In addition, the Türkiye Connected and Autonomous Vehicle Cluster (TCAV) was established by 62 different organizations, including TOGG, under the coordination of the Automotive Supply Industry Specialized Organized Industrial Zone (TOSB) Innovation Center and Istanbul Technical University Automotive Technologies Research and Development Center (ITU OTAM) in order to strengthen the cooperation between companies. The 5G-MOBIX project, in which organizations such as TÜBİTAK BİLGEM (Informatics and Information Security Advanced Technologies Research Center), Turkcell, Ericsson TR and Ford Otosan from Türkiye and Cosmote, Ericsson GR and WINGS from Greece are stakeholders, focuses on autonomous vehicle studies and as a result, these vehicles are designed to move along the Türkiye-Greece border crossing corridor [23].

In addition, individual studies are being carried out by various institutions in Türkiye within the scope of connected and autonomous vehicles. For example, the Vehicular Networking and Intelligent Transportation Systems Research Lab (VeNIT Lab) at the Dragos Campus of Marmara University continues pilot studies on V2I, V2V, V2P and in-vehicle applications in the field of C-ITS [23].

Today in Türkiye, C-ITS is seen to be much more than just associated with connected vehicles and this is reflected in the work of many sectors such as academia, public, private and local governments in this field, albeit slowly. The completion of the pilot project for the deployment of the C-ITS test and application corridor, which is included as an action of the Ministry of Transport and Infrastructure and is planned to be carried out in a real environment open to live traffic, will set an example for the studies to be carried out in this field in Türkiye and may increase the awareness and recognition of this issue. With the progress and completion of the C-ITS Test and Implementation Corridor project, it is seen as a possible result that new projects with different needs will emerge [1].

Also, in order for the projects that are directly or indirectly related to C-ITS to find financial support, it will be necessary to carry out some studies in the upcoming periods. Within the scope of this study, recommendations for Türkiye can be summarized as follows:

- Develop skills and competencies, especially human resources, related to C-ITS
- Ensure that C-ITS meets information security and privacy requirements
- Conducting studies on the legal framework,
- Creating an implementation guideline for Türkiye (This can be done by referencing best practices in other countries or by taking into account the experience and know-how gained from small and medium-sized pilot initiatives in Türkiye)
- Trying to find governance and business models for C-ITS operation
- Integrate C-ITS services into daily operations

- Oversee quality aspects related to data and services
- Preparing a roadmap on how C-ITS relates to future developments

## 4. Conclusion

When the projects of European, American and Asian countries are analyzed, it is seen that European member countries use common standards and legislations in C-ITS projects, while in the USA and Asia, this situation is carried out individually at the level of needs. In Europe and the USA, projects related to C-ITS and connected vehicle technologies are generally funded. In this context, it has been observed that the approach to deploying a C-ITS corridor in Türkiye is rather new. However, many projects directly or indirectly related to this issue are being carried out by public institutions and organizations, private sector organizations and universities. It is clear that strategic plans and budgets spreading over years should be created within the scope of C-ITS deployment and implementation. In this context, considering the intensified studies in Europe, the USA and Asian countries, more emphasis should be given to studies on C-ITS, connected vehicles and even autonomous mobility.

There are a number of challenges that stand in the way of large-scale deployment of C-ITS services. First, for C-ITS services to be sufficiently useful and operational, the road infrastructure and vehicles need to be equipped with the right communication technologies. However, this can be both time-consuming and costly. In addition, if C-ITS services are considered in the context of urban areas, they may require adaptation to specific historical, geographical, demographic and cultural contexts.

As a solution to all these problems, Türkiye needs a legal framework similar to the European directive, but also needs to start working on clarifying the standards and creating a C-ITS architectural framework. The obstacle in terms of high costs and infrastructure can be overcome by starting small pilot projects and slowly expanding them.

With the start of the project for the Deployment of the C-ITS Test and Implementation Corridor, which is determined by the National ITS Strategy Document and 2020-2023 Action Plan, it will be possible to reveal more requirements. In this direction, there is a need to determine policies and strategies within the framework of the expansion of the corridor not only within the country but also abroad.

As an innovative design of technology, C-ITS aims to improve the efficiency, safety, security and comfort of freight and passenger transportation by enabling vehicles to interact with each other and the surrounding road infrastructure. Today's vehicles are recognized as connected devices in many ways.

In the very near future, these vehicles will appear in projects that directly cooperate and interact with other vehicles, other road users and road infrastructure. The subject cooperation and interaction are related to the concept of C-ITS, i.e., the use of previously unavailable information by traffic managers, road users and other interested parties to coordinate various transportation-related activities. Many countries in Europe, America and Asia are working, researching and implementing projects on this topic. In particular, the EC has prepared a strategy document on C-ITS and established the C-Roads Platform. America and Asia are advancing their activities by creating policies at the state, city and country levels.

In Türkiye, studies on ITS have started many years ago, but the transformation of activities into C-ITS projects has only recently been brought to the agenda.

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## Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

## CRediT Author Statement

**Özgür Talih:** Project administration, Conceptualization, Investigation, Visualization, Writing - original draft, Writing - review & editing
**Necla Tektaş:** Supervision, Conceptualization, Writing - review & editing

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