TÜRKİYE'S CURRENT SITUATION ANALYSIS OF C-ITS

THE PROJECT OF DETERMINATION OF AUTONOMOUS DRIVING ARCHITECTURE AND CONNECTED VEHICLE TRAFFIC TEST SCENARIOS

Türkiye's Current Situation Analysis of C-ITS

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List of Turkish Abbreviations

Abbrevation	English	Turkish
İSBAK	Istanbul IT and Smart City Technologies	İstanbul Bilişim ve Akıllı Kent Teknolojileri
JEMUS	Gendarmerie Integrated Communication Information System	Jandarma Entegre Muhabere Bilgi Sistemi
TUBITAK	Scientific and Technological Research Council of Türkiye	Türkiye Bilimsel ve Teknik Araştırma Kurumu
UDHAM	Transportation, Maritime and Communications Research Center	Ulaştırma, Denizcilik ve Haberleşme Araştırmaları Merkezi

List of English Abbreviations

Abbreviation	English	Turkish
3G	3rd Generation	3.Nesil
3GPP	3rd Generation Partnership Project	3. Nesil Ortaklık Projesi
4G	4th Generation	4.Nesil
5G	5th Generation	5.Nesil
5GAA	5G Automotive Association	5G Otomotiv Birliği
AC	Alternating Current	Alternatif Akım
ACC	Adaptive Cruise Control	Adaptif Hız Sabitleyici
ACEA	European Automobile Manufacturers' Association	Avrupa Otomobil Üreticileri Derneği
ADAS	Advanced Driver Assistance Systems	Gelişmiş Sürücü Yardım Sistemleri
AECC	Automotive Edge Computing Consortium	Otomotiv Uç Nokta Bilgi İşlem Konsorsiyumu
AFV	Alternative Fuel Vehicle	Alternatif Yakıtlı Araç
ARC-IT	The Architecture Reference for Cooperative and Intelligent Transportation	Kooperatif ve Akıllı Ulaşım İçin Referans Mimari
C2C-CC	Car2Car Communication Consortium	Araçtan Araca Haberleşme Konsorsiyumu
CACC	Cooperative Adaptive Cruise Control	Kooperatif Adaptif Hız Sabitleyici
CAN	Controller Area Network	Denetleyici Alan Ağı
CAT-M	Category M	Kategori M

CEPT	The European Conference of Postal and Telecommunications Administrations	Avrupa Posta ve Telekomünikasyon İdareleri Konferansı
CF-IVC	Cluster Formation for Inter-Vehicle Communications	Araçlar Arası İletişim için Küme Oluşturma
C-ITS	Cooperative Intelligent Transportation Systems	Kooperatif Akıllı Ulaşım Sistemleri
COOPERS	Cooperative Networks for Intelligent Road Safety	Akıllı Yol Güvenliği için Kooperatif Ağlar
CPD	Change Point Detection	Değişim Noktası Analizi
C-V2X	Cellular Vehicle-to-Everything	Hücresel Ağ Üzerinden Araçtan Her Şeye
CVIS	Cooperative Vehicle Infrastructure Systems	Kooperatif Araç Altyapı Sistemleri
DC	Direct Current	Doğru Akım
DGComms	Directorate General of Communications	Haberleşme Genel Müdürlüğü
DGH	Directorate General of Highways	Karayolları Genel Müdürlüğü
DSRC	Dedicated Short Range Communication	Tahsis Edilmiş Kısa Mesafeli Haberleşme
ECC	Electronic Communication Committee	Elektronik İletişim Komitesi
ECU	Electronic Control Unit	Elektronik Kontrol Ünitesi
EDCAF	Enhanced Distributed Channel Access Function	Geliştirilmiş Dağıtılmış Kanal Erişim İşlevi
EMRA	Energy Market Regulatory Authority	Enerji Piyasası Düzenleme Kurumu

ERTICO	European Road Transport Telematics Implementation Coordination	Avrupa Karayolu Taşımacılığı Telematik Uygulama Koordinasyon Örgütü
ERTRAC	European Road Transport Research Advisory Council	Avrupa Karayolu Taşımacılığı Araştırma Danışma Konseyi
ETSI	European Telecommunications Standards Institute	Avrupa Telekomünikasyon Standartları Enstitüsü
EU	European Union	Avrupa Birliği
EV	Electric Vehicle	Elektrikli Araç
EVSE	Electric Vehicle Supply Equipment	Elektrikli Araç Şarj Besleme Donanımı
EWMA	Exponentially Weighted Moving Average	Üstel Ağırlıklı Hareketli Ortalama
GPS	Global Positioning System	Küresel Konumlandırma Sistemi
GSR	General Safety Regulation	Genel Emniyet Regülasyonu
GSMA	Global System for Mobile Communications Association	Mobil İletişim için Küresel Sistem Birliği
HMI	Human Machine Interface	İnsan Makine Arayüzü
HSM	Hardware Safety Module	Donanım Güvenlik Modülü
I2V	Infrastructure-to-Vehicle	Altyapıdan Araca
ICTA	Information and Communication Technologies Authority	Bilgi Teknolojileri ve İletişim Kurumu
IEEE	The Institute of Electrical and Electronics Engineers	Elektrik ve Elektronik Mühendisleri Enstitüsü
IMM	Istanbul Metropolitan Municipality	İstanbul Büyükşehir Belediyesi

IoT	Internet of Things	Nesnelerin İnterneti
ISA	Intelligent Speed Assistance	Akıllı Hız Asistanı
ISO	International Organization for Standardization	Uluslararası Standardizasyon Örgütü
ITS	Intelligent Transportation Systems	Akıllı Ulaşım Sistemleri
ITS-G5	Frequency Band for Intelligent Transportation Systems	Akıllı Ulaşım Sistemleri için Frekans Bandı
ITS-S	Intelligent Transportation System Stations	Akıllı Ulaşım Sistemleri İstasyonları
ITU	International Telecommunication Union	Uluslararası Telekomünikasyon Birliği
ITU-T	International Telecommunication Union Telecommunication Standardization Sector	Uluslararası Telekomünikasyon Birliği Telekomünikasyon Standardizasyon Birimi
IVICS	In-Vehicle Information and Communication System	Araç İçi Bilgi ve Haberleşme Sistemi
LDM	Local Dynamic Map	Yerel Dinamik Harita
LIDAR	Light Detection and Ranging	Işık Algılama ve Uzaklık Ölçümü
LOS	Line of Sight	Görüş Hattı
LPWAN	Low Power Wide Area Network	Düşük Güçlü Geniş Alan Ağı
LTE	Long Term Evolution	Uzun Süreli Gelişim
MAC	Medium Access Control	Ortam Erişim Kontrolü
MEC	Multi Access Edge Computing	Çoklu Erişim Uç Bilişimi
MoIT	Ministry of Industry and Technology	Sanayi ve Teknoloji Bakanlığı
MoTI	Ministry of Transport and Infrastructure	Ulaştırma ve Altyapı Bakanlığı

NB-IoT	Narrowband Internet of Things	Dar Bant Nesnelerin İnterneti
NGMN	Next Generation Mobile Networks	Yeni Nesil Mobil Şebekeler
NLOSb	Non-Line-of-Sight Links Obstructed by Buildings	Binalar Tarafından Engellenen Görüş Hattı Bağlantıları
NLOSv	Non-Line-of-Sight Links Obstructed by Vehicles	Araçlar Tarafından Engellenen Görüş Hattı Bağlantıları
NTCIP	National Transportation Communications for Intelligent Transportation System Protocol	Akıllı Ulaşım Sistemi için Ulusal Ulaşım İletişimi Protokolü
OBD	On-board Diagnostics	Araç Üstü Teşhis
OBU	On-board Unit	Araç Üstü Birim
OECD	Organisation for Economic Co-operation and Development	Ekonomik Kalkınma ve İş Birliği Örgütü
OMNeT++	Objective Modular Network Testbed in C++	C++'da Amaç Modüler Ağ Test Alanı
PHY	Physical Layer	Fiziksel Katman
PKI	Public Key Infrastructure	Açık Anahtar Altyapısı
PLNC	Physical Layer Network Coding	Fiziksel Katmanlı Ağ Kodlama
R&D	Research and Development	Araştırma Geliştirme
RFID	Radio Frequency Identification	Radyo Frekansıyla Tanımlama
RSU	Roadside Unit	Yol Kenarı Ünitesi
SAE	Society of Automotive Engineers	Otomotiv Mühendisleri Topluluğu

SAFESPOT	Cooperative Systems for Road Safety "Smart Vehicles on Smart Roads"	Yol Güvenliği için Kooperatif Sistemler "Akıllı Yollarda Akıllı Araçlar"
SNR	Signal to Noise Ratio	Sinyal Gürültü Oranı
SpaT	Signal Phase and Timing	Sinyal Faz ve Zaman Bilgisi
SUMO	Simulation of Urban Mobility	Kentsel Hareketlilik Simülasyonu
SWOT	Strengths, Weaknesses, Opportunities, and Threats (SWOT)	Güçlü, Zayıf, Fırsat, Tehdit
TCU	Telematics Control Unit	Telematik Kontrol Birimi
TURKSTAT	Turkish Statistical Institute	Türkiye İstatistik Kurumu
UMTRI	University of Michigan Transportation Research Institute	Michigan Üniversitesi Ulaştırma Araştırma Enstitüsü
UNECE	United Nations Economic Commission for Europe	Birleşmiş Milletler Avrupa Ekonomik Komisyonu
V2I	Vehicle-to-Infrastructure	Araçtan Altyapıya
V2N	Vehicle-to-Network	Araçtan Ağa
V2P	Vehicle-to-Pedestrian	Araçtan Yayaya
V2V	Vehicle-to-Vehicle	Araçtan Araca
V2X	Vehicle-to-Everything	Araç Her Şeye
WLAN	Wireless Local Area Network	Kablosuz Yerel Alan Ağı

Definitions

Adaptive Cruise Control (ACC)	**:**	The system dynamically and automatically adjusts vehicle speed to maintain a safe following distance from the vehicle in front.
Artificial Intelligence	**:**	The branch of computer science, which is concerned with a computer's or another machine's ability to perform actions related to human intelligence, such as learning, logical inference, reasoning, making decisions based on experience, and understanding spoken language based on insufficient or contradictory information.
Cellular Networks		3G, 4G, 5G, and 6G mobile communications. Wide range communication in IMT spectrum bands.
Cellular Vehicle-to-Everything (C-V2X)	**:**	Communication of the vehicle with everything such as infrastructure, center, pedestrians, etc. via cellular systems.
CEN-TC 278	**:**	CEN (European Committee for Standardization) is a technical committee with various sub-working groups working to set standards in the field of Intelligent Transportation Systems.
Cloud Computing	**:**	A generic name for Internet-based computing services for computers and other devices that provide computing resources that can be used at any time and shared among users.
Connected Vehicle	**:**	A vehicle that uses a range of different communication technologies to communicate with the driver, other vehicles on the road, roadside infrastructure, and other systems and services through the cloud.
Controller Area Network (CAN)	**:**	Message-based protocol used in the OBD-II vehicle diagnostics standard, specifically designed for automotive applications.
Cooperative Adaptive Cruise	**:**	It is a continuation of ACC. The CACC performs automated vehicle control in the longitudinal direction. In addition to ACC, which uses radar, camera, and/or LIDAR measurements to obtain the distance of the vehicle

Control (CACC)		ahead, the acceleration of the vehicle ahead is also used in the feedback loop. By allowing connected and autonomous vehicles to drive cooperatively, CACC increases traffic flow, reduces fuel consumption, and enables a vehicle train to travel safely.
Cooperative Awareness	**:**	Informing road users and roadside infrastructure about each other's location, dynamic data, and characteristics.
Cyber attack	**:**	Intentional actions taken by a person or information systems anywhere in cyberspace to compromise the confidentiality, integrity, or availability of information and industrial control systems in cyberspace or the information processed by these systems.
Cyber security	**:**	The whole set of activities covering the protection of the information systems that make up cyberspace from attacks, ensuring the confidentiality, integrity, and accessibility of the information processed in this environment, detecting attacks and cyber incidents, activating response mechanisms against these incidents and then returning the systems to their pre-cyber incident state.
Dedicated Short-Range Communications (DSRC)	**:**	A short- or medium-range wireless communication standard designed for vehicles on the road, enabling two-way communication between vehicles and each other and between roadside equipment.
Edge Computing	**:**	A distributed computing paradigm that moves computing and data storage closer to where they are needed to improve response times and save bandwidth.
GPS	**:**	It is a satellite-based radio navigation system owned by the US government and managed by the US Space Force. It is one of the global satellite navigation systems that provide geographic position and time

information to GPS receivers on and near Earth, provided they can see at least four GPS satellites.

IEEE 802.11 **:** Wireless Local Area Network (WLAN), Wi-Fi, is part of the IEEE 802 LAN protocols and specifies media access control (MAC) and physical layer (PHY) protocols, communication at various frequencies, including but not limited to dedicated frequency bands at 2.4 GHz, 5 GHz, and 60 GHz frequencies.

IEEE 802.11p **:** Temporary short-range WLAN communications specifically designed for automotive applications. Created as a result of modifications to the IEEE 802.11 standard to add wireless access to any vehicular communication system.

Indoor Test Area **:** A traffic-free test site where technologies such as vehicles, communications, security, etc. are tested.

Intelligent Transportation **:** Transportation which includes information and communication technologies that provide mobility and transportation efficiency, increase safety, maximize the use of current transportation facilities and energy resources, and save the environment.

Intelligent Transportation Systems (ITS) **:** It is the name given to information communication-based systems that include monitoring, measurement, analysis, and control mechanisms with multi-directional data exchange between the user, vehicle, infrastructure, and center developed to reduce travel times, increase traffic safety, make efficient use of existing road capacities, increase mobility, make efficient use of energy, and reduce environmental damage.

Light Detection and Ranging (LIDAR) **:** Sensing technology that uses laser pulses to determine the distance of an object or surface.

Long-Term Evolution (LTE)	**:**	LTE, also known as 4G, is a technology that not only provides a fast and high-quality infrastructure in daily life by providing higher bandwidth and lower latency than 3G but also takes security applications one step further.
Medium Access Control (MAC)	**:**	A sublayer that determines which network element can transfer data to the network medium (e.g. cable) and at what time interval.
Mobility	**:**	The activity of using transportation systems.
Radio-frequency Identification (RFID)	**:**	A method to recognize objects individually and automatically using radio frequency. It uses electromagnetic fields to automatically identify, and track tags placed on objects. An RFID system consists of a radio transponder, radio receiver, and transmitter.
On-board Unit (OBU)	**:**	Unit/equipment fixed to or supplied with the vehicle, including portable devices.
Open Test Area	**:**	A test site which is open to traffic where technologies such as vehicles, communications, security, etc. are tested.
Physical Layer (PHY)	**:**	In the seven-layer OSI model of computer networking, the physical layer, or layer 1, is the first and lowest layer. It is the layer in the network architecture most closely associated with the physical connection between devices. This layer can be implemented by a PHY chip. OSI is the model created by ISO that allows different computer systems to communicate with each other using standard protocols.
Radio Detection and Ranging (Radar)	**:**	An electromagnetic sensor that measures relative distance and relative speed relative to a target.
Roadside Unit (RSU)	**:**	Hardware which is placed along the road that can communicate with vehicles, hubs, and each other.

Signal Phase and Timing (SPaT) **:** A type of message that describes the current state and phasing of the signal system and relates it to specific lanes (and therefore movements and approaches) at the intersection; signal phase and timing message of common traffic lights according to ISO/TS 19091:2017.

Simulation of Urban Mobility (SUMO) **:** SUMO is a free and open-source traffic simulation package. It has been in use since 2001. It allows the modeling of intermodal traffic systems, including road vehicles, public transport, and pedestrians. Included in SUMO are numerous supporting tools that automate key tasks for the creation, execution, and evaluation of traffic simulations, such as network transfer, route calculations, visualization, and emission calculation.

Smart City **:** A new concept and a new model where new generation information communication technologies such as the IoT, cloud computing, big data, and integrated geographical information systems are applied to facilitate city planning, management, construction, and smart services. It is an urban area that uses different types of electronic IoT sensors to collect data and then uses the information obtained from these sensors to efficiently manage assets, resources, and services.

Smart Tachograph **:** Digital tachograph devices are enhanced by adding communication with intelligent transportation systems interfaces, Global Navigation Satellite Systems (GNSS), and Dedicated Short-Range Communication (DSRC) Technologies.

Telematics Systems **:** Integrated use of communication and information technologies to transmit, store, and retrieve information over a network from telecommunication devices to remote objects. It is a system that uses real-time tracking and data transfer technologies. With the installation of this system in vehicles, information such as the location of the vehicle, whether the person driving the vehicle is obeying the rules or not, or the driving style is sent via GPS to the computer where a program is installed to monitor the system and recorded on this computer.

Traffic Management	**:**	Management of traffic flow (freight, passengers, and vehicles) by demand management, traffic information, traffic control, and other metrics.
Traffic Simulation	**:**	Mathematical modeling of real traffic behavior at small (individual vehicles) or large levels (traffic flows).
V2I (Vehicle-to-Infrastructure)	**:**	V2I is the wireless exchange of critical safety and operational data between vehicles and road infrastructure, primarily to prevent or reduce motor vehicle accidents, but also to provide safety, mobility, and environmental benefits. Data exchange between vehicles and infrastructure is provided through OBUs and RSUs.
V2N (Vehicle-to-Network)	**:**	Vehicles' sharing information with objects using cellular communication infrastructure.
V2P (Vehicle-to-Pedestrian)	**:**	The type of communication which covers a wide range of vehicular pedestrian groups, including people on foot, children in strollers, people using wheelchairs or other mobility devices, passengers getting on and off buses and trains, and people cycling.
V2V (Vehicle-to-Vehicle)	**:**	Vehicle-to-Vehicle Communication (V2V) technologies enable vehicles to exchange information about their speed, position, and direction. V2V allows vehicles to broadcast and receive multi-directional messages, creating a 360-degree "awareness" of other vehicles nearby.
V2X (Vehicle-to-Everything)	**:**	Modern wireless communication technologies allow vehicles to transmit and receive information at any time, from anywhere, to any network. The general name given to vehicle communication technologies used in this context is Vehicle-to-Everything Communication (V2X) systems. There are different communication systems under V2X, which is used as an umbrella definition. These are Vehicle-to-Vehicle Communication (V2V),

Vehicle-to-Infrastructure Communication (V2I), Vehicle-to-Pedestrian Communication (V2P), Vehicle-to-Network Communication (V2N), etc.

Wireless Local Area Network (WLAN) **:** Term for ad hoc short-range communication based on IEEE 802.11p or extended IEEE 802.11bd. A standardized ITS-G5 wireless local area network for V2X.

SECTION I

1. INTRODUCTION

One of the most significant consequences of increasing global needs is the growing need for high-capacity transportation. This requirement also brings along some negative effects, which mainly are loss of time caused by heavy traffic, excessive fuel consumption, traffic incidents, and high amounts of exhaust gas emissions.

In Türkiye and around the world, traffic on urban and intercity roads is getting busier because of the increase in the number of vehicles and mobility needs. According to Turkish Statistical Institute (TURKSTAT) data, the total number of registered vehicles was 9.03% higher in December 2021 compared to December 2019 (Turkish Statistical Institute, 2020, 2022). An increase in accidents is observed which is related to the increase in traffic densities and congestion. According to TURKSTAT data, the total number of accidents increased by 1.55% in 2021 compared to 2019 (Road Traffic Accident Statistics, 2021, 2022).

The issue of global climate change has been a concern, which is on the agenda of all countries and related institutions. In this direction, R&D studies have started to be carried out in different sectors and fields within the framework of the search for solutions to mitigate or stop global climate change. The transportation sector is one of the most important sectors that cause the emission of carbon dioxide gas, which is among the causes of global climate change (Göncü, 2017). While nearly 30% of the carbon emissions caused by the EU and OECD countries are connected to the transportation sector, this rate is around 18% in Türkiye. Approximately, 25% of energy consumption in Türkiye comes from the transportation sector. For this reason, it is aimed to increase traffic efficiency in the transportation sector; thereby, achieving gains such as efficient fuel consumption, efficient energy use, and low carbon emissions. As set out in the European Union Green Deal, it is aimed to reduce the greenhouse gas emissions related to the transportation sector by 90% by 2050 (European Council,2022). In this context, it has become important to implement C-ITS applications, which will lead to significant gains in lessening greenhouse gas emissions, and reducing energy and fuel consumption while increasing sustainability (Cooperative Urban Mobility Portal | CO-UMP, 2021).

As set out in the Sustainable and Smart Mobility Strategy of the European Commission, the opportunities offered by intelligent digital solutions need to be seized to make transport safer, more efficient, and sustainable (C-ROADS, 2021).

In recent years, the application of advanced technologies to both transportation infrastructure and vehicles has been one of the most important strategies to improve the efficiency and safety of the transportation system.

Intelligent Transportation Systems (ITS), which is a part of the strategy to improve the performance of the transportation system, is the application of advanced telecommunications, computing, and sensor technologies to improve the safety, efficiency, and sustainability of the transportation system in general (Williams, 2011).

ITS, which enables more efficient use of current infrastructure, increased traffic safety, proper management of transportation demand, and more effective planning; builds a multimodal transportation system that integrates all modes into a seamless mobility service, enabling people and freight to travel seamlessly from door to door, encourages social innovation and facilitates mobility for all, and ensures more efficient use of resources.

Cooperative Intelligent Transportation Systems (C-ITS), one of the technologies used in ITS applications, covers a group of technologies that allow effective data exchange between components and actors in the transportation system or between vehicles and infrastructure through wireless communication technologies (C-ROADS, 2021). C-ITS is a transportation management, traffic information-based data collection, and management delivery system where vehicles and intelligent transportation facilities are separated. In this system, collected data on traffic conditions is processed to directly convey to the road users. Therefore, collecting and delivery systems are different in ITS applications. C-ITS, on the other hand, provides real-time information to vehicles to prevent unexpected situations, which is why C-ITS has less latency and faster reaction capability to traffic incidents compared to ITS (Ministry of Land Infrastructure and Transport & Korea Expressway Cooperation, 2023). C-ITS, which provides advantages for road users enables vehicles to interact with each other, the surrounding infrastructure, and other transportation users, providing drivers with the right information at the right time depending on where they are and the situations they encounter; thereby, increasing traffic efficiency and comfort.

The report prepared within the scope of “The Project of Determination of Autonomous Driving Architecture and Connected Vehicle Traffic Test Scenarios,” which focuses on the current status of C-ITS in Türkiye, introduces the basic technology of C-ITS. In the context of accelerating the implementation and deployment of C-ITS in Türkiye, the current opportunities and challenges of C-ITS technologies are discussed.

This study, prepared in the direction of the objectives of the national Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan, includes transportation solutions related to C-ITS with a focus on technological developments on a global scale.

SECTION II

2. METHODOLOGY

In this report, various studies have been conducted to reveal the current situation of C-ITS in Türkiye. These studies include a detailed academic literature review, surveys completed with stakeholders in the industry, project information obtained apart from the survey studies, a review of strategies and action plans published by institutions and organizations, and research on the standards employed in the projects carried out in Türkiye. This section provides information on how the report was prepared, and how the research was conducted.

Türkiye's Current Situation Analysis Report of C-ITS consists of 10 **sections**. **The first section** provides an introduction to global climate change, traffic accident data in Türkiye, the development of ITS, and its relationship with C-ITS. **In the second section**; definitions of the relevant terms used in the report are provided. "Intelligent Transportation Systems Glossary" published by the Ministry of Transport and Infrastructure (MoTI) General Directorate of Communications (DGComms), articles, and online resources were used while providing definitions (Ministry of Transport and Infrastructure of Türkiye, 2022). **The third part** involves a methodology section concerning how the report was prepared, with which stakeholders the survey was completed, and in which environments these surveys were conducted. **In the fourth section**; the definition and general framework of C-ITS and information on C-ITS scenarios categorized by the European Commission as Day 1 and Day 1.5 are presented. **In the fifth section**, communication technologies and protocols used within the framework of C-ITS technologies are explained and the technologies used in Türkiye are mentioned. **In the sixth section,** a literature review on academic studies prepared to analyze the current situation in Türkiye on C-ITS and to create the current status report is presented. **In the seventh section**, project information obtained through online and face-to-face surveys with project stakeholders is presented. In addition, some institutions were asked to fill out the survey. With these surveys, C-ITS studies conducted in Türkiye were identified while the hardware, software, and competencies of the stakeholders and the requirements offered and needed in this field were identified. Surveys were conducted with 30 stakeholders in total. Table 1 encloses the stakeholders questioned within the extent of the surveys. In addition to these, research was conducted on the internet, and C-ITS projects carried out by institutions and organizations that were not included in the survey studies were included in the 7th section. In addition to the project information obtained through surveys, the studies on C-ITS in Türkiye which were realized as a result of the research, are also included in this section.

Table 1. Stakeholders Interviewed in the Survey

STAKEHOLDERS INTERVIEWED WITHIN THE SCOPE OF THE SURVEY					
Ministry of Transport and Infrastructure	Directorate General of Communications	Department of Strategy Development		General Directorate of Transportation Services Regulation	
Ministry of Industry and Technology					
Ministry of Environment, Urbanisation and Climate Change					
Ministry of Interior					
Ministry of Energy and Natural Resources					
Public institutions and organizations that provide ITS service or plan, develop, operate, and maintain ITS services	Information and Communication Technologies Authority	General Directorate of Security Traffic Department	General Directorate of Highways	Personal Data Protection Authority	Gendarmerie General Command Traffic Department
Local governments	İstanbul Metropolitan Municipality				
Universities	Istanbul Technical University	Marmara University-VeNIT Lab.		Istanbul Okan University	
Civil society organizations	ITS Türkiye Association		Turkish Metal Industrialists Union		
Private sector organizations	LeoDrive	OTOKAR	TURKCELL	TEMSA	FORD
	ADASTEC	HAVELSAN	ASELSAN	İSUZU	Türk Telekom
	ULAK Haberleşme				

ITS service users are	Pedestrians	Cyclists	Drivers	Vulnerable road users	Passengers

In the eighth section; the classification and definitions of the standards used by the stakeholders, which are obtained as a result of the studies carried out in the field of C-ITS studies in Türkiye are included. **In the ninth section**, to steer to the C-ITS studies in Türkiye, the C-ITS-related actions of public institutions and organizations and international organizations in legislation, strategy, and policy documents are included. **In the tenth section**, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted to identify the strengths and weaknesses of Türkiye for C-ITS and the opportunities, and threats arising from the external environment. **In the final section of the report**, recommendations are given on the work to be done to increase the efficiency, speed, and quality of the work carried out by the institutions and organizations carrying out C-ITS activities.

Stakeholder interviews and surveys carried out to demonstrate the current situation of C-ITS studies in Türkiye' were conducted in different environments. Face-to-face meetings were held with certain stakeholders, while others were contacted online or via e-mail. Istanbul Technical University, Istanbul Okan University, Marmara University, Ministry of Interior, MoIT / General Directorate of National Technology, Gendarmerie General Command - Traffic Services Department, General Directorate of Security – Traffic Department, Istanbul Metropolitan Municipality (IMM), Directorate General of Highways (DGH), Turkish Employers' Association of Metal Industries, Turkish Intelligent Transportation Systems Association (AUS Türkiye), Energy Market Regulatory Authority (EMRA), Ford Otosan, HAVELSAN, OTOKAR, LeoDrive and ASELSAN are interviewed online. Ministry of Environment, Urbanisation and Climate Change, MoTI – Department of Strategy Development, MoTI – Directorate General for Regulation of Transport Services are interviewed face to face. In addition to them, Anadolu Isuzu, Personal Data Protection Authority, Information and Communication Technologies Authority (ICTA), TURKCELL, TEMSA, ADASTEC, Türk Telekom, ULAK Communications, and ITS service users (pedestrians, cyclists, drivers, vulnerable road users) are contacted via e-mail.

SECTION III

3. COOPERATIVE INTELLIGENT TRANSPORTATION SYSTEMS

C-ITS are systems that focus on the communication between two or more subcomponents of intelligent transportation systems (related to pedestrians, vehicles, infrastructure, roadside, center, etc.) by providing safe, effective, high-quality, and more advanced service level cooperation between these systems and in this demand, they offer implementations predominantly within ensuring road safety. C-ITS covers a group of technologies and applications that allow effective data exchange through wireless communication technologies such as vehicle-to-vehicle communication (V2V), vehicle-to-infrastructure communication (V2I), vehicle-to-network communication (V2N) and vehicle-to-pedestrian communication (V2P) within vehicle-to-everything communication (V2X) to develop safer and more efficient traffic flow among road users.

C-ITS services are based on data exchange between vehicles of any type (cars, trucks, buses, emergency vehicles, and private vehicles, etc.), roadside and urban infrastructure units (traffic lights, toll roads, variable message signs, etc.), cellular network access points, control, and service centers in the cloud (traffic control centers, service providers, map providers, etc.), and other road users (pedestrians, cyclists, etc.) (International Organization for Standardization, 2020a).

There are three main operational tasks that C-ITS applications aim to accomplish:

- Providing information to road users to improve road safety and comfort during a journey,
- Demonstrate regulatory boundaries using signs that inform road users about specific obligations, restrictions, or prohibitions,
- To warn road users about incidents ahead and their nature.

The history of studies on C-ITS applications dates back to the early 2000s. In 2005, the European Commission launched three integrated projects under the FP6-IST funding scheme (Lu et al., 2018). One of these projects, CVIS (Cooperative Vehicle-Infrastructure Systems) is focused on infrastructure and traffic efficiency (CORDIS | European Commission, 2016). The SAFESPOT (Cooperative Systems for Road Safety “Intelligent Vehicles on Smart Roads” project focuses on the in-vehicle side and traffic safety (CORDIS | European Commission, 2007). The last of these projects, COOPERS (Cooperative Networks for Smart Road Safety) is focused on the road operator domain (CORDIS | European Commission, 2008). The studies carried out in the field of C-ITS with the integrated projects identified by the European Commission are the beginning of C-ITS applications.

In the US, the work in C-ITS began in 2008 with the "Arizona Emergency Vehicle Infrastructure Integration" project. In 2008, the Arizona Transportation Research Center, Arizona State University, Maricopa County, the Arizona State Department of Transportation, and the Michigan State Department of Transportation funded the "Arizona Emergency Vehicle Infrastructure Integration" pilot project. The scope of this project is to develop and test advanced technologies for emergency vehicles that better respond to traffic incidents (Saleem & Nodes, 2008). In 2009, the State of Michigan Department of Transportation, the University of Michigan Transportation Research Institute (UMTRI), and the Information Industry Institute launched the "Multipath Signal Phasing and Timing (SpaT) Broadcast" project (Kotsi et al., 2020). The project aims to provide speed advice to drivers to safely cross the green phase of the next signalized intersection. Furthermore, the SpaT project has developed a counter that displays the remaining green phase time to the drivers through the vehicle interface (Robinson & Dion, 2013).

Studies in the field of C-ITS in Türkiye have accelerated in recent years. Studies on Day 1 and Day 1.5 services and their related applications are continuing. Public institutions and organizations, the private sector, universities, local administrations, etc. are making significant contributions to the development of C-ITS in Türkiye with the projects they carry out as well as strategy documents and action plans.

Within the scope of the 2020 roadmap published by the Car 2 Car Communication Consortium (C2C-CC), C-ITS applications are divided into 3 classes Day 1, Day 2, and Day 3+ (Car 2 Car Communication Consortium, 2020). Day 1 applications include warning and information scenarios within the scope of "Awareness Driving". Day 2 applications include advanced warning, semi-autonomous driving, coordination with traffic lights, and applications that will increase the safety of vulnerable road users within the scope of "Sensing Driving". Day 3+ applications include cooperative autonomous driving and autonomous driving in coordination with infrastructure under "Cooperative Driving" (Car 2 Car Communication Consortium, 2020). In the report titled

"Platform for the Implementation of Cooperative Intelligent Transport Systems in the EU" published by the European Commission (EC) in 2016, C-ITS services are classified as Day 1 and Day 1.5 (Asselin-Miller et al., 2016). Day 1 services can be considered a top priority, while Day 1.5 services are appropriate to be implemented one step later (C-ROADS, 2023b). The classification of Day 1 and Day 1.5 C-ITS services are listed in Table 2.

Table 2. Classification of Day 1 and Day 1.5 C-ITS Services by the EC

	Application Name	Description
Day 1 C-ITS Services	**Emergency brake light**	It aims to prevent rear-end collisions (which can result in fatalities) if a vehicle in front brakes suddenly, especially in heavy driving conditions or with reduced visibility. The driver is warned before he or she realizes the vehicle in front is braking aggressively, especially if the vehicle cannot be seen directly (vehicles in between) (Cooperative Urban Mobility Portal, 2021a).
	Emergency vehicle approaching	An emergency corridor formation is activated by informing other road users about an approaching emergency vehicle with a message emitted by vehicles with priority passes (SWARCO, 2023).
	Slow or stationary vehicle(s)	Slow or stationary vehicle warning is a safety-related Cooperative Intelligent Transportation System (C-ITS) application that mainly aims to reduce the number of accidents associated with slow or stationary vehicles (C-ROADS Germany, 2023d). The moment when a slow or stationary vehicle is detected, drivers are informed about the issue, and their awareness is raised.

	Traffic congestion ahead warning	This application aims to reliably detect traffic congestion and provide timely information to drivers upstream about the back end of the traffic congestion. In this way, drivers will be able to adjust their driving behavior accordingly (C-ROADS Germany, 2023e).
	Road works warning	Road work warning is safety related C-ITS service that mainly aims to reduce the number of accidents caused by road works. The aim is to send a punctual warning so that the driver can adjust his/her driving behavior (C-ROADS Germany, 2023b).
	Weather conditions	This C-ITS service aims to inform the driver about hazardous weather conditions such as fog, rain, and ice. The system also warns of hazardous weather conditions, which are difficult to perceive visually by the driver, such as wind gusts (European Transport Safety Council, 2017).
	In-vehicle signage	This C-ITS service provides signs, signals regulatory information, and warning information directly to drivers via in-vehicle devices (United States Department of Transportation, 2023).
	In-vehicle speed limits	This kind of service informs the vehicle of the effective speed limit that applies to the road on which it is traveling. For example, Intelligent Speed Assist (ISA) technology where the speed limit communicated to the driver, changes dynamically, is the C-ITS application that aims to improve safety and traffic efficiency (European Transport Safety Council, 2017).
	Probe vehicle data	This C-ITS application is concerned with the collection of data generated by vehicles. The collected traffic data can be used as

		input for operational traffic management, long-term strategic objectives, (e.g., road maintenance planning), and passenger information services (Cooperative Urban Mobility Portal, 2021b).
	Shockwave damping	Shockwave damping is a C-ITS service that aims to regulate traffic flow, mainly by giving optimal speed recommendations in heavy traffic conditions and displaying them on a vehicle via Human Machine Interface (HMI). This system aims to achieve optimal utilization of road capacity (C-ROADS Germany, 2023c).
	Signal violation	Also known as the Red-Light Violation Alert, this service allows drivers to be warned when they are in danger of a red-light violation or when another vehicle is likely to commit a red-light violation (Asselin-Miller et al., 2016).
	Traffic signal priority requests by designated vehicles	The traffic signal priority system for specific vehicles allows priority vehicle drivers (e.g., emergency vehicles) to be given priority at signalized intersections. This service works by extending or terminating the current traffic light phase to ensure that the required traffic light phases are displayed (Asselin-Miller et al., 2016).
	Green Light Optimal Speed Advisory (GLOSA)	This system aims to guide drivers with speed advice (via infrastructure-to-vehicle communication) using accurate information on traffic signal timing and traffic signal locations, resulting in less time spent at traffic lights and a more optimal journey with less stopping time (Stevanovic et al., 2013).
Day 1.5 C-ITS Services		

Day 1.5 C-ITS Services	**Information on AFV fueling & charging stations**	This application allows drivers to be informed about the booking schedules of fuel stations and charging points and make reservations. This provides a more convenient driving experience and allows vehicle owners to plan roads based on the location and availability of suitable refueling points (Asselin-Miller et al., 2016).
	Vulnerable road user protection	Vulnerable road users are defined as non-motorized road users such as pedestrians and cyclists, motorcyclists, and persons with disabilities or reduced mobility and orientation. A warning system for vulnerable road users provides the possibility to alert which vehicle drivers, targeting the detection of risky situations.
	On-street parking management and information	It is aimed to provide drivers looking for a parking space with appropriate parking space information, enabling them to park safely and quickly. This reduces the time spent searching for a suitable parking space (Asselin-Miller et al., 2016).
	Off-street parking information	It is aimed to provide drivers looking for a parking space with appropriate parking space information, enabling them to park safely and quickly. This reduces the time spent searching for a suitable parking space (Asselin-Miller et al., 2016).
	Park & Ride information	This system, along with other parking information systems, allows drivers to determine the most appropriate parking option while maximizing the benefit from the operator's perspective. This system improves overall network efficiency and can provide productivity and environmental benefits (Asselin-Miller et al., 2016). In addition, it also provides public

		transportation vehicle information to drivers. In this way, an integrated system is created that allows drivers to travel to the city center by public transport after parking their vehicles.
	Connected & Cooperative Navigation in and out of the city	This C-ITS service applies to both traffic management centers and road users. It aims to enable road users to navigate in a connected way inside and outside the city to ensure a coherent distribution of traffic strategies in urban and interurban areas (C-ROADS Germany, 2023a). In this direction, it is aimed to provide appropriate route suggestions to passengers.
	Traffic information and smart routing	Traffic management is achieved by optimizing routes based on traffic flow information, traffic lights, and speed limits by re-routing vehicles based on real-time traffic information status alerts.(Asselin-Miller et al., 2016). In light of this information and traffic management, intelligent routing can be provided to users.

SECTION IV

4. COMMUNICATION TECHNOLOGIES AND PROTOCOLS

C-ITS utilizes communication technologies that enable road vehicles to communicate with other vehicles, traffic signals, infrastructure, and other road users. There are several types of communication used in this context (CAR 2 CAR Communication Consortium, 2023a).

Modern wireless communication technologies allow vehicles to transmit and receive information at any time, from anywhere, to any network. (Hasan et al., 2020). The general name given to vehicle communication technologies used in this context is vehicle-to-everything communication (V2X) systems. There are different communication systems under V2X which is used as an umbrella definition. These are Vehicle-to-Vehicle Communication (V2V), Vehicle-to-Infrastructure Communication (V21), Vehicle-to-Pedestrian Communication (V2P), Vehicle-to-Network Communication (V2N), Vehicle-to-Grid Communication (V2G), etc. Figure 1 shows the representation of these communication types.

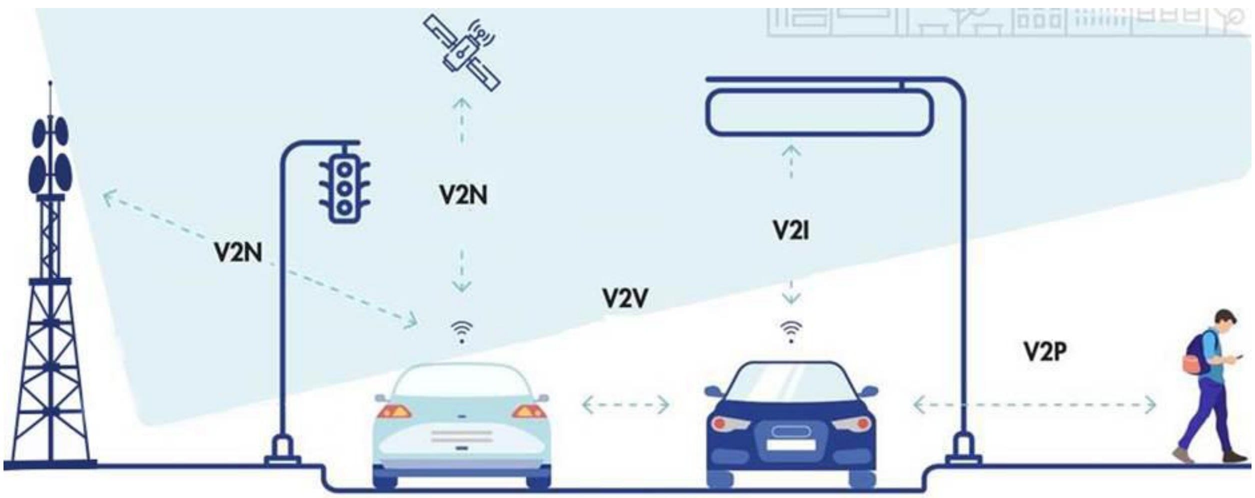


Figure 1. Sample Demonstration of V2X Communication Technologies (Thales Group, 2023)

V2V is a wireless communication system within V2X that enables vehicles to communicate with other vehicles. V2V technologies enable vehicles to exchange data about their speed, position, and direction. V2V allows vehicles to broadcast and receive multi-directional messages, creating a

360-degree “awareness” of other vehicles nearby (NHTSA | National Highway Traffic Safety Administration, 2023).

Figure 2. Illustration of Connected Vehicles and V2V Communication Technologies (Vehicle to Vehicle (V2V) Connectivity, 2020)

Different from V2V, V2I communication technologies provide the link between vehicles and infrastructure units. V2I is the wireless exchange of critical safety and operational data between vehicles and road infrastructure, primarily to prevent or reduce motor vehicle accidents, but also to provide safety, mobility, and environmental benefits (Péter et al., 2014). The data exchange between the Vehicles and the Infrastructure is provided by OBUs (On-board Units) and RSUs (Roadside Units). The V2I representation is available in Figure 3.

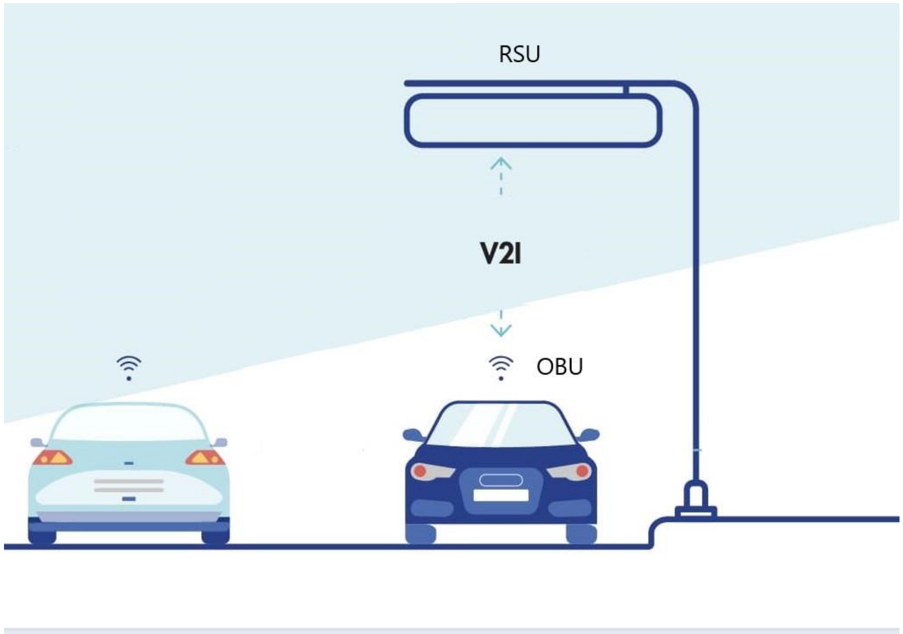


Figure 3. Sample Demonstration of V2I Communication Technologies (Thales Group, 2023)

OBU as used in V2I is the unit/equipment fixed to or supplied with the vehicle, including portable devices (Türkiye Cumhuriyeti Ulaştırma ve Altyapı Bakanlığı, 2022). RSU is the hardware placed along the road that can communicate with vehicles, centers, and each other.

V2N is the car's way of sharing information with objects using cellular communication infrastructure (Türkiye Cumhuriyeti Ulaştırma ve Altyapı Bakanlığı, 2022). V2P is a type of communication that covers a wide range of vehicular-pedestrian groups, including pedestrians, children in strollers, people using wheelchairs or other mobility devices, passengers getting on and off public transportation, and cyclists (Türkiye Cumhuriyeti Ulaştırma ve Altyapı Bakanlığı, 2022). On the other hand, V2G is a system that enables electric vehicles to communicate with the public power grid and provides the opportunity to push back the electricity held in the vehicle battery to the grid to meet the existing energy demand (Aptiv,2022) [See Figure 1].

There are various wireless communication technologies used within V2X communication technologies. One of these is Dedicated Short Range Communications (DSRC) technology. DSRC is a short or medium-range wireless communication technology designed for vehicles on the highway, enabling two-way communication between vehicles and also between vehicles and roadside equipment (Türkiye Cumhuriyeti Ulaştırma ve Altyapı Bakanlığı, 2022). It is a wireless communication technology based on IEEE 802.11p that provides highly secure and high-speed direct communication. It also does not require any cellular infrastructure for short-distance communication (Odak R&D Center, 2023).

IEEE 802.11, wireless local area network (WLAN), Wi-Fi, is part of the IEEE 802 LAN protocols and specifies medium access control (MAC) and physical layer (PHY) protocols, communication at various frequencies, including but not limited to dedicated frequency bands at 2.4 GHz, 5 GHz and 60 GHz frequencies (Türkiye Cumhuriyeti Ulaştırma ve Altyapı Bakanlığı, 2022). DSRC communication technology uses IEEE 802.11p, an ad hoc short-range WLAN communication specifically designed for automotive applications (Türkiye Cumhuriyeti Ulaştırma ve Altyapı Bakanlığı, 2022). It was created as a result of modifications to the IEEE 802.11 standard to add wireless access to any vehicular communication system (Péter et al., 2014). MAC and PHY protocols are used in IEEE 802.11.

In addition to DSRC communication technology, C-V2X (Cellular Vehicle-to-Everything) is a communication technology that has been used in the field of C-ITS in recent years. C-V2X refers to the communication of the vehicle with traffic elements such as infrastructure, centers, pedestrians, etc. over cellular systems (Türkiye Cumhuriyeti Ulaştırma ve Altyapı Bakanlığı, 2022). This technology combines secure, wide-area, and short-range connectivity over the cellular network (TechTarget, 2023). C-V2X communication technology, developed to replace DSRC communication technology and build a more optimized, secure, and effective C-ITS ecosystem with the connection advantages it provides, continues its technological development with the development of cellular communication technologies.

The C-V2X was developed especially because of security applications utilized within transportation systems by the telecommunications industry and then standardized at the application layer by automotive and transportation stakeholders. C-V2X is supported by a family of standards called LTE-based C-V2X. These standards are specified in 3GPP Version 14 released in 2017, and Version 15 released in 2018. There is also 5G and NR-based C-V2X in 3GPP Version 16 released in 2020 (ISEMAG, 2021).

5G communication technology started to be implemented in 2018 with demonstrations in various countries and areas. Korea Telecom and Telstra have implemented 5G application demonstrations at the 2018 Winter Olympics and 2018 Commonwealth Games, respectively. In the United States, all four major operators (AT&T, Verizon, Sprint, T-Mobile) made 5G launches during these years. Vodafone made its first batch of trials using midband spectrum in April 2018, and China Telecom's first 5G organization also started using midband spectrum in 2018. With the widespread use of 5G communication technology, various gains can be achieved. 5G promises superior speeds compared to 4G in most conditions. Another gain area, latency, is the time it takes for a message to be transmitted from the sender to the receiver. With the introduction of 5G, latencies will be reduced. 5G mobile networks will help reduce response times in autonomous vehicles and other applications that require a fast response, such as C-ITS. Many new usage areas that were impossible in the old network standards will be implemented with the 5G network, which includes high bandwidth, low latency, and high-density connections (CITS, 2023).

With the 5G-based C-V2X, achieved by developing communication technologies, various C-ITS applications can be applied. Among these applications are communication between vehicles and cyclists, traffic lights broadcasting information to drivers, warning of danger to drivers, and informing drivers about cooperative driving and available parking spaces (Alepo, 2021).

There are similarities between DSRC and C-V2X communication technologies. Both communication technologies are used to exchange the same types of information. These are simply traffic information such as location, acceleration, and speed for each device. Both utilize digital signatures to guarantee security and ensure the validity of the established communication. Both C-V2X and DSRC communicate directly using the 5.9 GHz band (GTT Wireless, 2021).

In addition to similarities, there are also areas where they have advantages over each other. The advantages of DSRC communication technology over C-V2X are summarized below:

- DSRC is designed fully for the automotive industry and is a proven technology that has been used in projects and applications for years,
- The great advantage of using WLAN due to low latency,
- The messages transmitted with DSRC communication technology have a very low data volume.

The areas in which C-V2X is superior to DSCR are as follows:

- The C-V2X will be able to utilize existing cellular infrastructure, which is increasingly being used both on the roadside and in vehicles, and is, therefore easier to install and maintain,
- Utilizing already well-established cellular network technology, and using technology that people are already familiar with, a comprehensive network can be created that enables high-speed communications in high-density locations,
- C-V2X is on a clear upgrade path as 5G networks become increasingly available and will be able to take advantage of high speeds with the future roll-out of 5G,

Tests have shown that C-V2X communication technology can operate at 20-30% greater distances than DSRC and perform better when encountering obstacles (GTT Wireless, 2021).

The literature review conducted within the scope of this report and the studies of the institutions in the sector show that both DSRC and C-V2X communication protocols are used in Türkiye. For example, both DSRC and C-V2X technologies are envisaged to be used in the 30-kilometer C-ITS test corridor planned to be deployed in Hasdal/Istanbul. However, with the developments in cellular communication technologies in recent years, the applicability of 5G technology has increased. For this reason, development studies on 5G-based C-V2X have started in our country. ICTA's 5G Open Test Site project and the work carried out within this site are examples of these development efforts. In this context, while DSRC and C-V2X communication protocols, which are the most intensively used in the field of ITS worldwide, are also used intensively in our country, R&D studies in this field are emphasized due to the advantages of C-V2X in the light of technological developments.

SECTION V

5. ACADEMIC STUDIES ON C-ITS CONDUCTED IN TÜRKİYE

In this section, the academic studies carried out in the field of C-ITS in Türkiye are examined under two main headings: (i) theses and dissertations, and (ii) articles and papers.

5.1. Theses and Dissertations

In the literature review on the theses and dissertations written in the field of C-ITS in Türkiye, it has been realized that the theses and dissertations were divided into two categories in terms of their subjects: (i) the development of technologies used in the field of C-ITS, and (ii) the impacts of C-ITS on traffic.

5.1.1. Studies on Technology Development

For C-ITS applications to work smoothly, seamlessly, and efficiently, improvements need to be made in certain areas. When the theses and dissertations conducted in Türkiye on the development of C-ITS technologies are examined, it is seen that these areas focus on the development of communication technologies and - cyber security.

5.1.1.1. Studies on the Development of Communication Technologies

The majority of the theses and dissertations on C-ITS technologies in Türkiye focuses on communication technologies and the security of the information used within the scope of these technologies. Theses and dissertations on the development of communication technologies seek solutions to problems, such as corruption in data integrity, inefficiency in data transfer speed, and interruptions, that can be encountered in the future when C-ITS applications become more widespread (Aksoy, 2012; Arslan, 2017; Başaran, 2016; Bozkaya, 2015; Çetinkaya, 2015; Hamza, 2021; Kuzulugil, 2021; Obaida, 2020; Özdemir, 2017; Sarıtaş, 2014).

In regions without cellular network coverage and where infrastructure works have not yet started, communication systems can be provided by ad hoc wireless networks. Vehicular ad-hoc networks are an emerging technology for enabling communication between vehicles and nearby infrastructure-based (roadside) equipment through wireless networking technologies and constitute a subset of mobile ad-hoc networks, which can be seen as a form of wireless ad-hoc networks. In 2008, simulation studies were conducted within the scope of a thesis titled “Cluster Structure Design for Inter-Vehicle Communication” which showed that to prevent pileups, all vehicles within a radius of 500 meters of the accident site should be notified within 0.5 seconds. In this context, the CF-IVC protocol was proposed, and performance testing studies were conducted on this protocol. The working principle of this protocol is to divide the vehicular networks into small parts, manage access to the communication environment, and create a routing backbone in a virtual environment. The network efficiency and management effectiveness of the proposed system are tested in a simulation environment. The simulation studies were created on OMNeT++. OMNeT++ is a C++-based open-source discrete event simulation environment for simulating computer networks and various distributed systems. It supports the modeling of pretty big networks built from reusable model components. In light of the data obtained as a result of the simulation studies, it was determined that the CF-IVC protocol is successful in terms of connection requirements and meets these requirements in a less costly way compared to other protocols (Kayış, 2008).

In 2017, thesis titled “Analysis of lane changes for vehicle strings on highways: String stability, driving safety and comfort”, the effect of lane change function on steering stability was studied. Steering stability is achieved if the position of the vehicles has a certain pattern. Accordingly, the use of Cooperative Adaptive Cruise Control (CACC) technology for short-range vehicle tracking is considered to be useful. CACC is a technology that enables the sharing of position and speed information between vehicles (Sağlam, 2017). Thus, it is aimed to make vehicle tracking safer and more accurate.

In a study titled “Optimal Control Problems for Safe and Efficient Lane Changes of Self-Driving Vehicles”; conducted in 2017 on creating a function for self-driving vehicles to change lanes safely and efficiently, it was deemed appropriate to use CACC technology to solve problems on curved roads. CACC, which can process acceleration data and also position and velocity data, can thus accomplish the appropriate acceleration process with the integration of other sensors (Haseeb, 2017).

In 2017, another thesis titled “Machine Learning Based Anomaly Detection Technique For In-Vehicle Networks” which is an intrusion detection method using machine learning-based techniques was proposed for CAN applications. With this method, position, speed, and direction information that can undergo cyber attacks and changes during V2V and V2I communication within the scope are protected. This method, which has a very important potential to prevent accidents, will increase the awareness of vehicles to each other and their surroundings. This study, which will lead to V2X communication technology, will also increase the importance of roadside units and in-vehicle units (Akar, 2017).

While many studies in the literature investigate the communication speed, quality, and robustness between RSU and C-ITS components, some studies aim to provide efficient deployment of RSUs by considering optimized resource distribution and ensuring uninterrupted and fast communication. In this context, in the thesis study titled “An RSU Placement Framework For V2I Scenarios” conducted in 2019, it is stated that, Edge Computing methods are more effective and efficient than Cloud Computing methods and that Edge Computing methods will be more efficient in the implementation of intelligent transportation systems. In this study, an RSU deployment structure that takes into account the coverage area, resource demand, and traffic characteristics of the road network is proposed. A simulation tool has been developed and made suitable for testing the scenarios created in the study to test this application. The developed simulation application is a V2I version of the EdgeCloudSim simulation software and it is called as V2Isim. The components of the scenario simulations are shown in Figure 4 (Kara, 2019). In this study, three different RSU deployment models were built. These models are differentiated according to the distribution model used. These distribution models are uniform, weighted, and optimized distribution. The scenarios simulated on V2ISim were run with eight different traffic volume demands. According to the results obtained, the RSU deployment implementation using the optimized distribution model gave better results than the others for all traffic demands. It is stated that an efficient RSU deployment system will be obtained if implemented. What distinguishes this study from the other studies in the literature is that while previous studies usually consider communication and network coverage issues, this study considers computing and resource allocation.

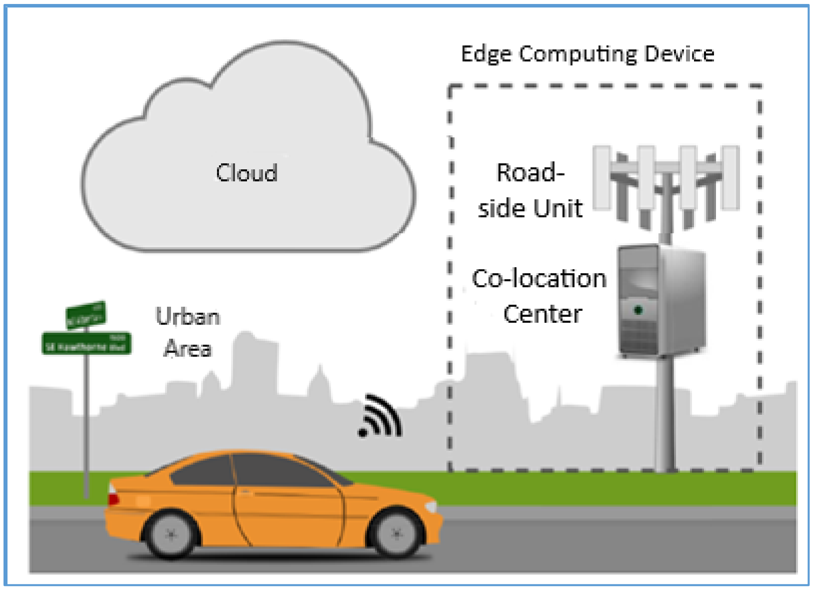


Figure 4. System Components Used in the Scenarios (Kara, 2019)

A thesis study titled "Channel Measurement for Cellular V2X Communication at 5.9 GHz Band" was conducted in 2021 for the development of V2X communication technology in Türkiye and to support intelligent transportation systems communicating in the 5.9 GHz frequency band. This study suggests that during V2V communication, the environment changes dynamically as well as the transmitter and receiver units as they also dynamically change. In this context, the importance of determining the characteristics of the communication channels was emphasized and tests were carried out in different regions of Ankara/Türkiye under different traffic conditions. These tests were conducted using ICTA's 5G Valley Open Test Field infrastructure and the signals used by Keysight Technology Inc. Within the scope of the tests, the signals sent to the channel and the results obtained were analyzed and the characteristics of the channel were determined. With these results, it is stated that it is possible to create a C-V2X channel model that will be created for Ankara and will operate in the 5.9 GHz frequency band (Arıkan, 2021).

5.1.1.2. Studies on Cyber Security

In addition to the studies carried out in areas such as increasing the speed of information transfer by making technological advances in communication methods, preventing disconnections during this transfer, protecting data integrity, etc., ensuring the security of information transfer has become a very important issue and new methods have been developed in this field within the scope of theses and dissertations in the academic literature of Türkiye.

Public Key Infrastructure (PKI) is a set of roles, policies, hardware, software, and procedures needed to create, manage, distribute, use, store, and revoke digital certificates and to administer public key cryptography. In 2010, a thesis on cyber security in vehicles using communication technologies titled "Security and Privacy in Vehicular Networks" stated that different elements can divert connected vehicles from their routes by spreading false information or recording the location and personal data of the target vehicle (Bayrak, 2010). The protocol proposed in this study aims to protect vehicles against direct cyber-attacks by anonymizing their identities through shared keys and PKI techniques and to provide security in information communication. Thanks to PKI techniques, the anonymity of these systems is ensured and the information owned or sent during communication cannot be detected by others and in this context, the possibility of cyber-attack is reduced. This will prevent the transmission of misinformation to the vehicles by third parties. The proposed protocol has been tested against previous security requirements, and the results indicate that it meets all the requirements.

In 2018, in a thesis titled "Security Attacks in V2V Communication", two different cyber attack detection algorithms were selected and these algorithms were tested with the data set created within the scope of the study. The main objective of the study is to find out which of the two algorithms is more applicable and also more efficient and effective against cyber attacks (Okul et al., 2018).

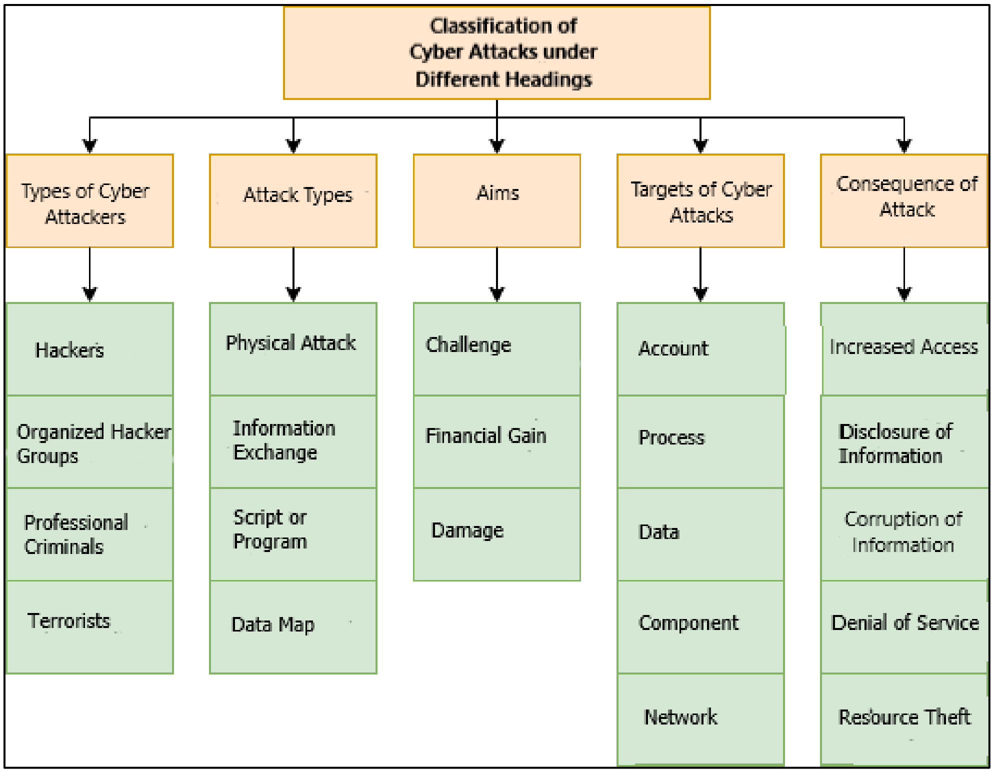


Figure 5. Classification of Possible Cyber Attacks (Okul et al., 2018).

As can be seen in Figure 5, vehicles using communication technologies can be exposed to cyber-attacks aimed at different purposes and targets. For this reason, it is of great importance to detect the cyber-attack quickly and before it can show its effect. In this study, two different cyber-attack detection algorithms, namely Exponential Weighted Moving Average (EWMA) and Change Point Detection (CPD), were tested. EWMA detects large shifts in the system by performing examinations at regular intervals. CPD takes the average of all checkpoints over the historical data and detects unusual incidents by comparing the instantaneous data in the general algorithm flow. The data set used in the tests covers 70-80% of non-attack cases and 20-30% of cyber attacks. With the information obtained from the study, it has been stated that the usability of the EWMA cyber attack detection algorithm is higher than the CPD algorithm.

In the study conducted in 2020 which is titled “Fuzzy Based Cyber Security Risk Model for Smart Car”, it was stated that many components of smart vehicles are open to cyber attacks. As seen in Figure 6, with the advancement of connected and smart vehicle technologies and the transformation of vehicle components into units that can communicate with electronic and other components, numerous connected and smart vehicle components have become open to cyber attacks. All components shown in the figure are vulnerable to attacks either physically or through the communication structure (Muratoğlu, 2020).

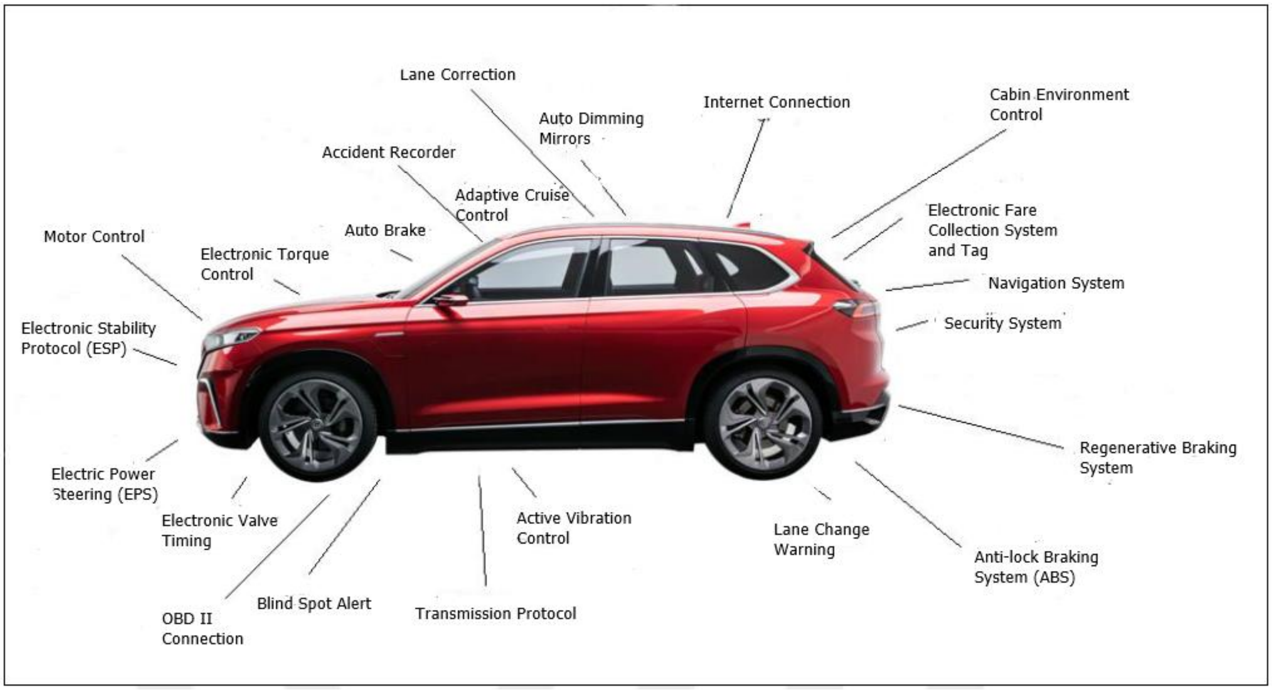


Figure 6. Components Vulnerable to Cyber Attacks (Muratoğlu, 2020).

In the same study, it was stated that cyber attacks on these vehicles can be realized in different ways. Information system intrusion attacks, CAN bus attacks, sybil attacks, and OBD attacks are examples of attacks that can occur. A sybil attack is a type of cyber attack against a computer network service in which an attacker creates a large number of pseudonymous identities, subverts the service's reputation system, and uses them to gain a disproportionately large influence. It is a type of attack inherited from information systems, especially in smart vehicle networks, and in this type of attack, a malicious node that has illegally joined the network can disrupt the stability of the network in its favor by spreading false messages (Muratoğlu, 2020). CAN is a communication protocol used by all vehicles for communication between safety and performance critical units (Tomlinson, 2019). By infiltrating this network, it becomes possible to send unwanted and potentially dangerous messages to vehicle units that are important for security and performance. (Lin & Sangiovanni-Vincentelli, 2012). These attacks are called CAN bus attacks. OBD attack is a type of attack carried out by devices plugged into the OBD ports in the vehicle after making the in-vehicle networks vulnerable to cyber attacks (Klinedinst, 2016). These and similar attacks can be carried out by physical connection to the vehicle or accessing the Bluetooth and CAN network. However, as stated in the study, the number of methods developed to detect and evaluate such attacks and the historical data of these attacks are very few. For this reason, a model based on the CORAS technique, which is based on expert opinions and a formal risk relationship, was established. CORAS is a method developed for security risk analysis and provides a customized graphical language for threat and risk modeling. Within the scope of this model, sub-incidents that may lead to cyber-attacks were identified. The risks of these sub-incidents were calculated based on expert opinions. Accordingly, with the sub-incidents identified before the cyber-attack occurs, attacks can be predicted and necessary actions can be taken. Within the scope of this study, an important model has been established that can prevent loss of lives or traffic disruptions.

5.1.2. Studies on the Impacts on Traffic

Traffic volumes are also increasing in areas due to the increasing population and number of vehicles. In today's conditions, especially in urban areas, traffic congestion remains for long periods and traffic density reaches very high levels. Therefore, improving traffic management and congestion management has become a very important issue. In addition to the theses and dissertations on the development of communication technologies used for C-ITS, theses, and dissertations have also been carried out on the effects on traffic if different C-ITS applications are used in traffic management.

5.1.2.1.Traffic Management

With the development of communication technologies and their integration into ITS; promising, new, and effective traffic management methods are emerging that can be applied to C-ITS.

In 2011, a thesis titled "Design of GCDC 2011 Semi-autonomous Cooperative Adaptive Driving Racing Vehicle" was prepared in which the infrastructure of the vehicle developed to participate in the GCDC (Great Cooperative Driving Competition), the vehicle system, and the results of the semi-autonomous cooperative adaptive speed control (CACC) were developed in the simulation environment and the real world were presented. For the CACC system to work, first of all, an infrastructure needs to be created for the vehicles to share data such as speed, location, etc. In this direction, a modem was placed in the developed vehicle, and communication with other vehicles was enabled. In addition to this modem, various hardware such as sensors, LIDAR, GPS, etc. was installed for the vehicle to perceive its surroundings. After providing information about the necessary hardware and software technologies, the implementation of the CACC system was presented. It is stated that in non-cooperative Adaptive Cruise Control (ACC) applications, there is some noise in the information received from LIDAR and sensors. For this reason, it is stated that ACC systems using speed and position information transmitted via communication technologies are more efficient and effective. The results obtained within the scope of the simulation tests were compared with the real tests performed on the Tuzla track, and the 0.6-second following distance, which was desired to be tested in the competition, was successfully achieved in both simulations and real tests. With the use of the CACC system in traffic, vehicles will be able to move in platoons and more efficient traffic will be achieved by keeping the following distances at low levels. In this context, the system developed in this thesis has important gains for future applications. Another issue mentioned in the study is that the failures in the connection and communication systems cause errors in the CACC system and therefore the desired following distance cannot be achieved. As a result, it has been revealed that traffic management can be realized more effectively with CACC systems thanks to the development of communication technologies in future studies (Karaahmetoğlu, 2011).

The Cooperative Adaptive Cruise System is defined as an assistance system for drivers with the data obtained through V2V and V2I communication technologies, and this technology can be made more widespread with hardware and software improvements (Göl, 2013). In 2013, a study titled "Intelligence on Asphalt" emphasized the potential for a decrease in accident rates with newly developing technologies. Among the traffic management methods researched or proposed within the scope of C-ITS, there are studies aiming to increase traffic efficiency as well as studies aiming to ensure traffic safety and prevent accidents. In this context, in the study titled "Proposal on A System Rear-End Collision Accident Prevention with V2V" conducted in 2015, a system proposal was made to prevent rear-end collision accidents using V2V communication systems. With the system proposed in this study, all data collected from vehicles or infrastructure was stored in a central computer. The data in the created memory was shared with the vehicles again and thus, communication was established between the vehicles following each other, and the vehicles were informed about the following distances. It is aimed to provide fast communication between vehicles with DSRC. In the proposed method, if the following distance falls below the specified threshold, the drivers will be warned audibly or visually by the interfaces built into the vehicle. If the drivers do not take any action against these warnings, automatic intervention stages will be activated gradually. This intervention is aimed to be carried out with the ACC system. For the proposed rear-end crash prevention system to work, it is stated that there is certain equipment that must be installed in the vehicles. These pieces of equipment can be compiled as radar sensors, temperature sensors, precipitation sensors, fatigue detection systems, smart cameras, steering vibration motors, audio warning systems, central computer systems, and control and warning systems. As stated in the study, with the implementation of this system, traffic can be controlled without the need for any external control system (traffic police, radar, etc.). With the data collected in the central computer, drivers who do not comply with traffic rules can be detected. Most importantly, the majority of rear-end collisions can be prevented with the proposed system (Karabay, 2015).

In the 2018 thesis study titled “Investigation of the European Strategy for Cooperative Intelligent Transportation Systems and Recommendations for Türkiye’s National Intelligent Transportation Systems Strategy” C-ITS components were defined. The cornerstones abbreviated as V2V (vehicle-to-vehicle), V2I (vehicle-to-infrastructure), and V2X (vehicle-to-everything), which are necessary for the system to work more integrated and optimized, were explained in detail. The study, drawing on that of the European Commission, emphasizes the lack of legislation and standards in Türkiye and suggests that work on this issue should be accelerated (Koyuncu, 2018).

For the C-ITS traffic management methods to be implemented to increase traffic efficiency or ensure safety to work efficiently and effectively, the communication between vehicles or between the vehicle and the infrastructure during traffic management must be secured against cyber-attacks to prevent any threats in traffic and to prevent interruption of these applications. In this context, a thesis study titled “Security of Vehicles Platoon from Inside and Outside Attacks” was conducted in 2020 to ensure the security of vehicle platoons against internal and external attacks. As stated in the study, vehicle platoons are one of the traffic management methods that have gained popularity in providing communication between vehicles. With the implementation of this system, vehicle groups move as a single unit and the front vehicle is the leader of this group. The security of the communication between the lead vehicle and the other vehicles is of great importance. Any cyber-attack on this system poses a great risk to traffic safety. In this context, two different cybersecurity applications are considered in this study. One of these applications handles external attacks while the other one handles intra-platoon attacks. At the same time, with the proposed method, the vehicle that poses a threat in intra-platoon attacks will be detected and the vehicle that poses a risk will be removed from the platoons by the lead vehicle and the platoon will be reorganized (Al_sheikhly, 2020).

In the study, applications such as message encryption and message authentication codes were tested to prevent external attacks and it was seen that these applications can provide security. At the same time, the tests showed that the sybil attack is the attack type with the highest risk factor. Within the scope of internal attacks, it was seen that the proposed method can work efficiently and effectively. The proposed system identifies the occurrence of a cyber attack and which vehicle is attacked. Then, the lead vehicle throws the attacked vehicle out of the platoon and rearranges the platoon. Thus, the security of the vehicles in the platoon is ensured.

5.2. Articles and Papers

In Türkiye, there are many articles and papers in the literature addressing C-ITS from different perspectives or addressing the same issues from different aspects. In the literature review, studies on technology development concentrated in two different areas, namely communication technologies and security technologies, were identified. In addition to these areas, there are also studies on the impacts of C-ITS on traffic.

5.2.1. Studies on Technology Development

There are many articles and papers in the literature on the development of C-ITS technology. In these studies, the definitions of C-ITS components and potential technological advances based on or derived from this definition have been examined. The studies are mostly theoretical and based on modeling and simulation.

5.2.1.1.Studies on the Development of Communication Technologies

Published in 2008, the study entitled "Performance Analysis and Optimization of Relay Assisted Vehicle-to-Vehicle (V2V) Cooperative Communication" aimed to analyze the efficiency of V2V communication. Since the Rayleigh fading model is a realistic model for V2V links, developers were able to improve performance by making this model work better. Rayleigh fading is a statistical model for the effect of a propagation medium on a radio signal, such as those used by wireless devices. The team believes that more reliable vehicle-to-vehicle communication can be achieved by using relays at the side of the road, and this study focuses on a method based on "amplify and forward relaying". They also investigated the effect on performance by using diversity instead of a single relay. In the model of the study, the team, which considers establishing communication through two vehicles and electrical circuit control elements, has made the necessary calculations and error analysis for this. The data used within the scope of error performance was obtained as a result of computer simulation studies. In the comments made in light of the data that emerged in the later stages of the research, it was stated that diversity can be increased by equal power sharing. In addition, if the optimal power allocation is set, the performance can be even higher. Accordingly, the optimal power allocation provides a performance gain of close to 3 decibels compared to equal power allocation (İlhan et al., 2008).

Published in 2009, the study entitled "Cooperative Diversity for Intervehicular Communication: Performance Analysis and Optimization" focuses on cooperative diversity in V2V links. In the existing literature, cooperative diversity is limited to the Rayleigh attenuation model. This model describes the relationship of wireless connectivity between a mobile station at street level and a stationary base antenna above roof level. In this paper, cooperative diversity in V2V links is analyzed using Nakagami fading. This aims to provide a more realistic description of V2V links. In addition, V2V communication is planned to be more robust. The Monte Carlo simulation model is used as a method in the study. The Monte Carlo simulation model is a simulation method in which a large number of probabilities are obtained by randomly generating all other independent variables of a situation. Relay-assisted V2V communications are tested by changing the relay locations. In the simulations, a method that delivers performance gain was found, and its name is Nakagami fading (İlhan et al., 2009).

Published in 2015, the study entitled “Relay Antenna Selection for V2V PLNC System”, the problem of focal relay selection was investigated. Electromagnetic circuit switches act as a base that transfers the signal in V2V communication. In V2V communication, the quality and positioning of the relay used are important for the data transfer to be healthy. For this reason, the PLNC (physical layer network coding) model was tested to integrate it into the “amplify and forward relaying” system used. This project, which started with the aim of increasing the efficiency of relays, is based on the idea that vehicles also act as relays. SNR (Signal Noise Ratio) was used as a performance measure (Figure 7) (S. Ö. Ata & Altunbaş, 2015). As a result of the computer simulations, the efficiencies between PLNC and conventional relays were compared. Accordingly, lower and upper limits for end-to-end SNR were determined. Then, it was observed that the probability of outage increases as the number of antennas on the relay increases.

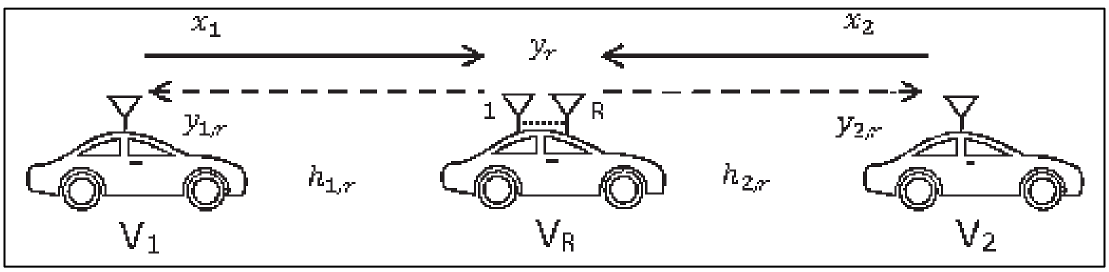


Figure 7. V2V Communication with PLNC (S. Ö. Ata & Altunbaş, 2015)

Published in 2016, the study entitled “V2V System Module for Inter-Vehicle Communication” investigated the connection of an advanced driver assistance system called ADAS with V2V communication technology. The benefits of V2V communication technology include the ability to share vehicle position and speed information with other vehicles, sharing information such as stopped vehicles or road collision warnings with other drivers, and making it safer for drivers. In the future, it is aimed to provide a safer journey by detecting warnings from out-of-sight environments. In this study, the efficiency of the V2V communication technology developed by the project team was investigated. Within the scope of the test carried out at Eskişehir Osmangazi University campus, the developed V2V system was integrated into two vehicles parked back-to-back (See Figure 8). With V2V communication technology, the first vehicle sends its position, speed, and processor speed data to the second vehicle, and the second vehicle is expected to receive these data in full. In this experiment, different test scenarios were created and the relationship between the distance between the vehicles and the speed of the vehicles, and the packet loss in the data stream was revealed. According to the results of the study, no packet loss occurred up to 550 meters when both vehicles were stationary. Packet loss refers to lost data packets that do not reach their destination after being transmitted over a network (IR, 2023) k. In another scenario, the first vehicle was stationary while the other vehicle was moving at average speeds of 20 km/h, 40 km/h, and 60 km/h respectively. It is concluded that the synchronization between V2V modules can be enhanced by Doppler frequency (physical waves are perceived differently by the moving observer) and high speeds. Because 3 out of 151 packets traveling at an average speed of 40 km/h at a distance of 500 meters were lost, while only 1 out of 108 packets traveling at an average speed of 60 km/h at a distance of 500 meters were lost. It is emphasized that in future research, the efficiency of V2V communication technology in moving vehicles should be further investigated and the Doppler tolerance should be studied in detail (Özdemir et al., 2016).

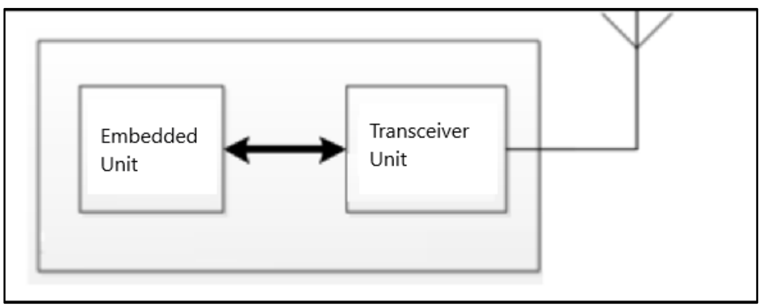


Figure 8. General Block Diagram of the V2V System Module (Özdemir et al., 2016)

In the study conducted in 2017 and titled "Traffic Delay Estimation with V2X Communication for an Isolated Intersection", a traffic delay estimation model using V2X communication technology was suggested. In the simulation studies carried out to test this model, connected vehicles with low penetration rates were used and the average speed data of these vehicles were kept. With the obtained speed data, the arrival and departure times of the vehicles to and from the isolated intersection were calculated. Traffic delay was estimated using the calculations. As a result of the simulation studies, it was found that the proposed model works with high accuracy (Salman et al., 2017a).

Published in 2017, the study titled "Fuzzy Logic Based Traffic Surveillance System Using Cooperative V2X Protocols with Low Penetration Rate" measured the time spent by connected vehicles connected to an RSU at signalized intersections in a simulation environment. It is aimed to establish a relationship between the measured times and the traffic situation and to accurately determine the traffic situation. When the data obtained as a result of simulation studies were analyzed, it was found that the proposed method works with high accuracy (Salman et al., 2017b).

The impact of buildings, number of vehicles, and road structure on V2V communication was examined in the study titled "The Effect of Buildings, Number of Vehicles and Road Types on Vehicle to Vehicle (V2V) Communication Channels" conducted in 2018. Investigating how V2V communication results in different traffic scenarios is significant for the development of the technology. For this reason, unlike other studies, in this research, in addition to the number of vehicles, buildings, and types of roads are also included in the study. Accordingly, four different scenarios were created. A straight road without buildings, a straight road with buildings, an intersection road without buildings, and an intersection road with buildings were the scenarios where V2V communication was conducted. SUMO, OpenStreetMap, and GEMV2 (Geometry-based Efficient propagation Model for V2V communication) software with Matlab integration were used to create the simulation model. The implementation divided V2V communication into three main categories, namely LOS, NLOSv, and NLOSb, and calculated their variations. The results of the study showed that the presence of buildings plays a major role in the decrease in the power of V2V communication. In addition, it was also found that there was a decrease in intersections, and when the effect of intersections and buildings were compared with each other, it was revealed that the effect of buildings is more effective in decreasing the power of communication (Kuzulugil et al., 2018).

A study was conducted in 2018 on the optimization of V2V communication using the space-time trellis codes (STTC) technique. Space-time trellis codes are a set of codes that describe wireless access over multiple antennas. This technique, which is also used in mobile-to-mobile and machine-to-machine communication, can also be adapted to V2V communication. Simulations showed that this technique improves V2V performance (S. Ata & Altunbas, 2018).

Published in 2019, a study titled "A Compilation on Internet of Things in the Automotive Sector", the impact of the IoT technology on the transportation sector was investigated. Accordingly, although this technology has recently become widespread in Türkiye, certain companies collect and process data. It is stated that the IoT, which is considered an important technology for C-ITS, will pave the way for the spread of autonomous vehicles (Tokody et al., 2019).

V2X technology, which enables vehicles to communicate with each other and with other cellular services, is currently widely defined by LTE standards, but there has not yet been sufficient progress in terms of delays and secure communication following the number of vehicles and network capacity requirements. If implemented within the framework of 5G standards, these communication technologies will be able to be used in wider and more comprehensive application areas. A study published in 2019 examined the benefits of V2X communication technology and shared the results of performance measurement in a realistic environment. In this study, a large-scale simulation model was prepared, which includes a variable number of vehicles, application and network services, road network infrastructure, as well as new solutions to improve system performance. In the study, a realistic traffic environment was built by using the SUMO application. Accordingly, vehicles travel at an average speed of 50 km/h with 10 km/h deviations on a two-lane road network with a certain mobility pattern. V2X communication technology is integrated into this simulation, and the quality and performance of the service are analyzed. According to the results, V2X communication technology cannot meet the demand as the number of vehicles increases. As a result of the studies on this subject, it was determined that the critical vehicle threshold value is 300. This is because, in environments with a very high vehicle density (i.e. when there are 350 vehicles and more) the number of unmet demands is 4 times higher compared to when there are 300 vehicles, which can have destructive results. In other words, it was seen that the number of unmet demands increases exponentially when there are 300 or more demands. Moreover, the delay increases with the number of vehicles. As the number of successfully met demands increases, so does the latency. In other words, although 300 vehicles is the optimum number of successful vehicles, it is the scenario with the highest latency. It is stated that the integration of the MAC scheduler into V2X technology will be one of the key mechanisms for the improvement of this technology (Nur Avcil & Soyturk, 2019).

In the study conducted in 2020 and titled "5G NR C-V2V for High-Speed Train Safety Applications", the impact of 5G technology's contributions to V2V technology on safety in high-speed trains was investigated. According to this study, the existence of a technology such as 5G, which is expected to become widespread in the future, should not be ignored, on the contrary, appropriate designs should be prepared now and steps should be taken toward the future. 5G NR C-V2V (5G New Radio Cellular V2V) is an emerging communication technology that is expected to provide very low end-to-end latency during communication. Within the scope of the study, 5G NR C-V2V technology was used in high-speed trains for safety implementation. The results of the study show that up to 20% improvement in coverage and lower end-to-end latency during communication were achieved (Bulut, 2020).

A study published in 2021 titled “Sensing, Control and System Integration for Autonomous Vehicles: A Series of Challenges” emphasized the importance of sensing, control, and system integration in the design of autonomous vehicles. The study, which states that past examples can guide future studies, reveals that by following the road lines of the vehicles, the steering and braking system of the vehicle can be intervened by someone other than the driver. With the Global Positioning System (GPS), the position of the vehicle is processed as real-time data. At the same time, the Inertial Measurement Units (IMU), enable the vehicle’s internal mechanisms, such as wheel speed and steering, to be integrated with the sensor. This can be an important revolution for V2I communication technology (Özgüner & Redmill, 2021).

A study conducted in 2021 titled “Stability Analysis of Connected Vehicles with V2V Communication and Time Delays: CTCR Method via Bézout’s Resultant”focused on optimizing the time spent for V2V communication between connected vehicles. Although wireless connections are quite useful and provide a lot of opportunities in life, there are delays in the order of milliseconds. Various methods are used to minimize this situation. In this study, Bezout’s CTCR (Cluster Treatment of Characteristic Root) method was used (Akkaya et al., 2021).

Published in 2021, the study titled “Towards Adoption of Blockchain Technology for Enhancing Communication in Smart Transportation”, blockchain technology is considered to be promising for the development of wireless communication technologies. It was stated that there is no obstacle to considering blockchain technology, which is the basis of Bitcoin technology in use as a currency, as a secure ground for data transfer within the scope of the IoT concept. By integrating this communication system into intelligent transportation, it is evaluated that a communication method that ensures data security can be achieved (Özdenizci Köse, 2021).

A similar study in 2021 which is titled “Blockchain Applications and Application Areas in Intelligent Transportation Systems” conveyed the advantages of blockchain technology, which is predicted to have an essential place in our future lives. The gains of using this technology in the V2V communication system, especially in the logistics sector, were highlighted. These gains are related to providing data security and transparency in a faster and more intelligent way (Tektas & Doğan, 2021).

Published in 2021, the study titled “Hierarchical Deep Reinforcement Learning based Dynamic RAN Slicing for 5G V2X” investigated the impact of 5G V2X technology on dynamic radio access networks (RAN) using deep learning. A RAN can be considered a core structure that provides connectivity between two or more pieces of hardware. According to the results of the study, it was shown that performance tests with deep learning can provide near-realistic predictions even though they have error margins (Kaytaz et al., 2021).

Published in 2021, the study titled “Traffic Violation Detection Systems: A Survey” emphasized the importance of new technologies such as artificial intelligence, RFID, and vehicular ad hoc networks in traffic violation detection systems. Vehicles with more equipment and the ability to exchange data with their surroundings provide a noticeable reduction in the number of violations. In addition, detection rates were also observed to increase on roads with advanced infrastructure with roadside units (El Atigh & Bayram Özer, 2021).

The importance of enhancing infrastructure was highlighted in the study published in 2022 titled “The Effects of Autonomous Vehicles on Intelligent Transportation Policies”. The study investigated the effects of autonomous vehicles on intelligent transportation policies. It was suggested that vehicles will be more integrated into the environment with V2I communication. The two main systems used for this purpose are perimeter radars used in object detection and collision avoidance, and the LIDAR, which acts as an optical scanner by processing the frequency band, thus providing a three-dimensional picture of its surroundings (Akkaya & Özbay, 2022).

In another study published in 2022 titled “An overview of bidirectional electric vehicles charging system as a Vehicle to Anything (V2X) under Cyber–Physical Power System (CPPS)”, was conducted on charging systems for electric vehicles because of the developing technology and the understanding of the opportunities of the virtual universe. Cyber-physical systems (CPS) are the concept of managing a physically existing mechanism through computer-based algorithms. It was stated that a local power transfer could be provided in emergency vehicles or public transport vehicles that may not be in a convenient location or may need to be in constant motion using a wireless connection with V2X communication (Elma et al., 2022).

5.2.1.2. Studies on Cyber Security

In addition to the articles and papers on the development of communication technologies; articles, and papers were also prepared on cybersecurity technologies, which is an important issue within the scope of C-ITS applications.

In 2018, a study titled “Security Attacks in V2V Communication” was conducted on the possible dangers that may arise from V2V communication. Accordingly, it was evaluated that the dangers that may occur in the infrastructure area may originate from vehicle manufacturers and service providers. On the other hand, the system can be corrupted by unauthorized access to the protocol of the system to be used and can even be used for malicious purposes. It was shared that another area is cyber-attacks originating from in-vehicle applications (Okul et al., 2018).

The study conducted in 2022 which is titled “Cyber Security And Multi-Layered Security Measures In Smart Transportation Vehicles” points out that with the development and spread of ITS, connected vehicles and infrastructures are areas that can be easily attacked. There are multiple types of cyber-attacks on smart vehicles and each has its defense mechanism. Although separate defenses can be made against these attacks, creating a multi-layered defense system can provide a collective and more secure system. An attacker can exploit a flaw in wireless connections to attack a car’s ECU (Electronic Control Unit) and cause a crash or loss of control. By exploiting vulnerabilities in the Telematics Control Unit (TCU), private conversations within a car could be eavesdropped. A car can be tracked by exploiting the GPS navigation system, which is often used to guide and control drivers, violating their privacy. Accordingly, a multi-layered cyber attack defense system is proposed in this study. The defense system, which has a multi-layered structure, tries to ensure that the driving control of the vehicle can never be obtained by the attacker by offering security in various layers as well as full security with continuous identification and various layered defenses. Three layers make up the Multi-Layer Defense System: Sensing Layer, Network Layer, and Application Layer. In the three-layer architecture, the sensing layer is at the bottom.

The sensing layer in this system consists of physical and data link layers. Given that it establishes the connectivity, it is called the network layer. This layer controls all V2V, V2I, V2P, and other sensor communications between cars and other vehicles, infrastructure, and pedestrians. The part that provides data processing and storage is the application layer. The multi-layered protection system tracks the car's main unit to detect cyber-attacks and determine whether it has full control over the car. Thanks to this defense system, the rate of avoiding cyber attacks was found to be higher than traditional methods (Avcı et al., 2022).

5.2.2. Studies on Traffic Impact

In the study conducted in 2015 which is titled "Intelligent Transportation Systems and Their Applications in Road Transportation Industry in Turkey", the importance of wireless data flow was emphasized. It was stated that accidents can be prevented by sending information about vehicles, pedestrians, and even animals to drivers through roadside units with V2V and DSRC, especially GPS-based technologies (Ersoy & Börühan, 2015).

Published in 2020, the study titled "22@Barcelona Project Analysis; Applicability in Bandırma Scale", the smart city and smart transportation model of the city of Barcelona (Spain) was examined. In this study, where new-generation transportation solutions were examined, the importance of V2V, V2I, and V2X technologies was emphasized, and it was mentioned that the use of connected vehicles could be increased with the development and widespread use of these communication technologies and sensing and positioning technologies (Kocakaya & Engin, 2020).

Published in 2020, the study entitled "Development of Connected Vehicle Technology in Turkey" examined the development of connected vehicle technologies in Türkiye. The results of this study showed that studies on this field have gained momentum in Türkiye in recent years and automotive brands such as the newly established Togg have given importance to this field (Erceylan & Akcayol, 2022).

SECTION VI

6. C-ITS STUDIES CONDUCTED IN TÜRKİYE

The C-ITS projects compiled in this section were obtained both through analysis on the websites of companies and projects and surveys conducted with stakeholders to reveal the current status of C-ITS in Türkiye.

6.1. Survey Studies with Institutions and Organizations

This section includes the projects and studies acquired through the surveys conducted with institutions and organizations.

6.1.1. Public Institutions and Organizations

MoTI

DGComms**:** The studies in the field of C-ITS are as follows:

- The "National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan" includes the action "*1.8. Establishment of Test and Application Corridor for C-ITS*" with the DGH designated as the responsible institution. Within the scope of the action, studies are being carried out to establish a C-ITS test corridor in the 30 km area between Hasdal and Istanbul Airport.
- "Within the scope of the action "1.2. Development and Publishing of the ITS Architecture" included in the "National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan", the "Satellite Assisted National Intelligent Transport Systems Automation Project" protocol was signed between DGComms, TÜRKSAT, and UDHAM on October 28, 2021. The project aims to create a framework for guiding rapidly increasing C-ITS investments in Türkiye, to bring the studies together on a common ground, to develop systems that are compatible with each other, to respond to developing needs, and to ensure the integration of transportation modes with each other. The project includes:
    - ➢ Development of Satellite Ground Systems and Establishment of Satellite Network Architecture,

- Identification and Classification of ITS Standards,
- Investigating Disruptive Innovation Technologies and Their Impacts in the Field of ITS,
- Current Situation Analysis and Inventory Study,
- Review of World Literature and Preparation of Country Reports,
- Identification of User Services,
- Creation of National ITS Architecture Service Packages,
- Establishment of National ITS Architecture,
- Development of ITS Architecture Software and Creation of User Manual,
- Development of Human Resources Capacity, Organizing Workshops, and Organizations in this Field,
- Preparation of the National ITS Platform.

- It is aimed to provide V2V, V2I, and vehicle-center communication, and transmission of data, information, images, etc. via satellite technologies. Thus, it is planned to create a framework for the establishment of compatible road infrastructure and communication systems to ensure that new-generation smart vehicles can travel smoothly on the road network, where C-ITS scenarios can be implemented by using innovative communication technologies used in intelligent transport systems. Within the scope of the action "3.3. In-Vehicle Information and Communication System (IVICS)" in the "National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan", the protocol for the "Project for Determining the Technical Specifications of the In-Vehicle Information and Communication System (IVICS)" was signed between DGComms and Marmara University on 8 September 2022.

IVICS states the systems in the roadside infrastructure, the units used in their communication with each other and with the center, and the software used in this context for informing the driver (target users in the vehicle), warning against unsafe situations, and preventing unsafe situations for traffic/driving safety, traffic efficiency, fuel saving, reduction in harmful gas emissions, energy efficiency, reduction in travel times and comfortable driving in the vehicle. IVICS provides constant and stable communication and exchanges data with other vehicles and infrastructure through the V2X communication radio unit (and software) in the vehicle. There are many components (OBU, RSU, antenna, C-ITS, management platform, etc.) including hardware and software on the vehicle, infrastructure, and center in IVICS to meet these qualifications and requirements. The project aims to specify the characteristics of these components and to design a complete system such as standards, software, architecture, and security structure used in the production and communication of these components. Therefore, the next process is aimed at producing the components of IVICS with the domestic and national resources of Türkiye to prevent the resources from going abroad and to ensure that they remain in Türkiye.

DGComms participates and contributes to the activities of the autonomous vehicle working group studies established by MoIT. DGComms is an observer member of the C-Roads platform, which is a joint initiative of European Member States and road operators to test and implement C-ITS services, and also a member of the ERTICO-ITS Europe, which works on increasing the deployment of ITS services in Europe.

Directorate General of Regulation of Transportation Services: Studies on the authorization and coordination of the use of smart tachograph equipment are being carried out. With the smart tachograph, the driver's driving and resting times are recorded and the information can be retrieved automatically. The smart tachograph is capable of wireless communication according to DSRC standards. The technical side of this hardware is handled by the MoIT. The standards used in the hardware are UNECE 2014/165 and UNECE 2016/799. Smart tachographs are intended to be used as a pre-notification system by enabling preventive inspections. In this way, increasing the efficiency of inspections is also considered an achievement of the study.

Department of Strategy Development: Preparation of the "Sustainable and Smart Mobility Strategy and Action Plan" is being carried out with Yildiz Technical University. Within the scope of the "Development of Technology, Innovation and Digitalization" objective in the Action Plan, it is aimed to carry out R&D studies on the development of connected, autonomous vehicle infrastructure and to establish a legal framework and a roadmap.

MoIT: Policies and action plans have been developed for the domestic and national development of the technologies specified in the "Mobility Vehicles and Technologies Roadmap" published by MoIT. Although there is not a field application yet, it is planned to provide incentives for the development of these technologies and to encourage new investments. It is aimed to create an area where V2X technologies can be tested in the autonomous vehicle technologies test center that is planned to be built within the scope of the road map. The regulations published by the European Union and the regulations published by the United Nations are also harmonized one-to-one.

Under the leadership of the MoIT, an autonomous vehicle working group was established with the participation of representatives from public institutions, the private sector, universities, and NGOs, and the "Report on Recommendations for the Increase the Uptake of Autonomous Vehicles in Türkiye" was prepared within the scope of establishing the test procedure and legislation for autonomous vehicles in Türkiye. The report includes priority action steps such as acceleration of the works on necessary road markings and C-ITS within the scope of establishing the road infrastructure for spreading autonomous driving.

Istanbul Metropolitan Municipality (IMM): V2I communication test work is being carried out with ISBAK for the prioritization of fire brigade vehicles. The On-board unit (OBU) installed on the fire brigade vehicle will communicate with the intersection control device to prioritize the fire brigade vehicles. Moreover, the tram tracking system is used by Metro Istanbul. The vehicles have RFID antennas which are used to determine the location of the vehicles. Data transfer is performed using RFID hardware. With the applications, gains such as improvement in operations, reducing noise, and facilitating the maintenance process have been achieved. IMM's proprietary software is used within the scope of the developed projects.

Energy Market Regulatory Authority (EMRA): EMRA does not carry out studies in the field of C-ITS. However, studies are being carried out to improve the charging infrastructure of electric vehicles and other electric vehicles using the C-ITS infrastructure.

The project "Incentives for Expanding Electric Vehicle (EV) Charging Infrastructure and Supporting the Scale-up of Electromobility Technologies in Türkiye" which is carried out in cooperation with the World Bank, is ongoing. The Project "Investigation of the Impact of Charging Stations and Electric Vehicles on the Grid and Development of Domestic Software Required for Optimizing These Loads" has entered into the implementation phase. The equipment in this area can be listed as cabling infrastructure, charging unit, charging supply equipment (EVSE), and related information system infrastructure, etc. within the scope of the "Charging Service Regulation" (Enerji Piyasası Düzenleme Kurumu, 2022). In this equipment; charging systems and socket types defined within the scope of standards numbered TS62196-2 and TS62196-3 in EMRA

Charging Service Regulation (Enerji Piyasası Düzenleme Kurumu, 2022), wiring standards, and standards that provide information about the content related to combined charging power systems that will determine AC-DC Powers are used. The “Charging Automation System” mobile application developed by EMRA is used as the software for this hardware. The application provides dynamic and static data sharing services to transfer data from the installed charging stations via web services, track the stations, determine their availability/fault-maintenance status on the map, and provide communication for making reservations. Thanks to this hardware and software, web services were created and data protocols were signed with charging network operators following the web service creation guide. After the IT infrastructures are established, data are obtained by performing the relevant tests in line with the web service guidelines and data protocols. Thanks to the established system, gains such as the healthy functioning and follow-up of the charging network operators’ processes related to charging services are provided. In the future, various simulations and tests will be conducted to analyze the network impact with other factors, especially power and utilization rates. Operators that form the charging network in field applications use network and communication technologies in cabling infrastructures, charging units, electric vehicle supply equipment (EVSE), and related information infrastructures. “Charging Service Regulation” has been prepared and issued by the EMRA.

Directorate General of Highways (DGH): Within the scope of the strategic objective of developing ITS infrastructure in the National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan, DGH is implementing the 30 km long C-ITS Test and Application Corridor project to be established between Hasdal and Istanbul Airport.

Figure 9. Hasdal-Istanbul Airport ~30km C-ITS Test Route

Fiber Optic (F/O) cables will be laid along the corridor and communication and data exchange will be provided between V2V, V2I, infrastructure-ITS Management Center. Communication along the corridor will be realized through F/O cables, short-range wireless and cellular communication technologies (4.5G, 5G, C-V2X), On-board units (OBU), roadside units (RSU), C-ITS Management Center and local central software to be developed. The designated ITS center of this corridor will be the FSM Main Control Center of the 1st Regional Directorate of Highways. It is planned to install variable message signs, variable traffic signs, and meteorological sensors and transfer the obtained data directly to drivers via RSUs and OBUs. A mobile variable message sign will be used to activate road works warning. Cameras will also be used for incident detection management to detect stopped vehicles and vehicles reversing, and this information will be transmitted to vehicles on the road through RSUs, OBUs, and centralized software. It is envisaged that all standards in the C-Roads 2.0 document (EN3026372, EN302637-3, ISO 19091, and EN302571) will be used in this hardware. It is envisaged to develop software that manages all ITS systems to be modular so that it can control ITS components such as signaling systems, vehicle sensors, etc., and to include sub-management software that controls variable message signs, and variable traffic signs. With the integration of these software and hardware, traffic densities will be mitigated, harmful gas emissions to the environment will be minimized, congestion will be reduced by directing traffic, and smooth traffic will be achieved at signalized intersections.V2I and V2V technologies will be prioritized among the communication technologies in field applications. After the standards of these technologies are established, works will be accelerated in the field of V2X. In these applications, OBU and RSU security services, security architecture, and ETSI security standards will be implemented to provide timely and reliable information on safety conditions to drivers. DGH builds on its C-ITS studies referencing C2C-CC documents and C-Roads documents. Technical specifications are determined to be used in ITS and C-ITS projects.

Gendarmerie General Command Traffic Department: With JEMUS, which is a public security communication project developed to ensure the uninterrupted, simultaneous, accurate, and secure delivery of information to the smallest Gendarmerie unit; it is possible to perform many operations such as vehicle tracking, license plate recognition, person query with the Turkish ID number and vehicle query with the license plate number at the same time. In this application, road users are informed through training, seminars, etc. on various platforms to ensure timely and reliable information to drivers. In these applications, the Road Traffic Safety Strategy Document 2021-2030 and the Road Traffic Safety Action Plan 2021-2023 are taken into consideration.

Information and Communication Technologies Authority (ICTA): The ICTA, which regulates and supervises the telecommunications sector in Türkiye, takes into consideration the regulations of organizations such as the International Telecommunications Union (ITU), the Conference of European Postal and Telecommunications Administrations (CEPT), as well as documents such as European Union (EU) decisions and relevant Electronic Communications Committee (ECC) reports.

Within the scope of the "Regulation on Radio Equipment and Systems Exempt from Frequency Allocation" (FTM Regulation), the frequency bands and technical criteria used in V2V, V2I, vehicle-user communication within the scope of C-ITS are specified in "Table 5-Technical criteria for transportation and traffic telematics systems" in the "Technical Criteria for Radio Equipment and Systems Exempt from Frequency Allocation" document published by ICTA (Bilgi Teknolojileri ve İletişim Kurumu, 2019).

6.1.2. Universities

Marmara University: "Vehicular Networks and Intelligent Transportation Systems Research Laboratory- VeNIT Lab" was established on February 11, 2013, at the Faculty of Engineering, Department of Computer Engineering. VeNIT Lab carries out R&D and applied studies in the fields of V2X communication, V2X applications, C-ITS architecture, and C-ITS applications.

In 2017, Marmara University TUBITAK took part in the "Development and Implementation of a Test Area for Vehicular Systems, Advanced Driver Assistance Systems, Connected Vehicles, and Transportation Infrastructure and Services" project submitted to the Ministry of Development by the Scientific and Technological Research Council of Türkiye (TUBITAK) Marmara Research Center and contributed to the technical support and infrastructure preparation.

In 2018, V2X communication Day 1 applications were developed, and field tests and demonstrations were conducted. Advanced Day 2 applications were developed, and field tests and demonstrations were carried out in 2020.

Within the scope of "Istanbul's C-ITS and Autonomous Vehicle Test Corridor Project" planned by IMM and ISBAK, a cooperation protocol was signed between Marmara University and ISBAK in May 2019.

Since 2020, C-ITS infrastructure has been established in Marmara University Mehmet Genç (Dragos) Campus, and R&D and product development studies are being carried out. Table 3 shows the V2X applications being tested at the campus.

Founded in 2020, BigTRI, the spinoff company of Marmara University and VeNIT Lab, has developed national products in the fields of C-ITS, V2X communication, connected vehicles, services, and applications. In addition, smart intersection infrastructure has been established on the Marmara University Mehmet Genç (Dragos) Campus, which includes traffic lights and V2X communication devices integrated into the intersection infrastructure. V2X scenarios are implemented under real field environments with communication between intersection devices and vehicles. 5G and short-distance communication standards for V2X communication are used. In addition to this, works to create a C-ITS infrastructure on another campus, Recep Tayyip Erdoğan Campus, is ongoing.

Table 3. V2X Applications Tested at Dragos Campus's C-ITS Test Corridor

<table>
<tr><th colspan="3">Tested V2X Applications</th></tr>
<tr>
<td>• Longitudinal Collision Risk Warning
• Surface Condition Warning
• Lane / Road Closure- V2I
• Traffic Light Violation Warning
• Surface Condition Warning (Bumps and Potholes)
• Electronic Emergency Brake Light (EEBL)
• Animal or Person on the Road
• Electric Vehicle Charging Point Notification</td>
<td>• Road Work Warning-V2I
• Obstacle Warning on the Road
• Dangerous Slope Warning
• Road Operator Vehicle Approaching Warning
• Emergency Vehicle Priority
• Traffic Light Prioritization
• Green Light Optimum Speed Advisory
• Traffic Light Violation Warning</td>
<td>• Hazardous Location Notification
• Traffic Congestion Ahead Warning
• Emergency Vehicle Approaching Warning
• Stalled Vehicle/Stopped Vehicle/Defective Vehicle/Status Information After Accident
• Accident Site Warning
• Weather Status Warning (Fog/Precipitation/Loss of Traction Warning)</td>
</tr>
</table>

In 2020, the Connected Cars/V2X Communications Digital Twin platform was developed. This platform enables the development, testing, and large-scale demonstration of V2X applications in virtual and real field environments. In addition, V2X communication is also used for cyber security tests.

Within the context of two H2020 and two Horizon Europe projects carried out since 2020, R&D studies are carried out in the fields of V2X communication and C-ITS as well as field demonstrations.

An H2020 project that started in 2020 "Intelligent Secure Trustable Things (InSecTT)" offers extensive solutions on intelligence, provides end-to-end encryption, reliable connection, and interoperability, aiming to generate trust in AI-driven intelligence systems and solutions (VeNIT, 2023b). Another H2020 project is "BEYOND5 - *Building the fully European supply chain on RFSOI* (Radio Frequency Silicon on Insulator), enabling New Radio Frequency Domains for

Sensing, Communication, 5G and beyond”. BEYOND5 aims to gather mobile broadband (5G), IoT, and automation connectivity for self-driving cars in a single technology platform made in Europe based on the most advanced SOI (silicon on insulator) technologies. (VeNIT, 2023a). Both projects are in progress and the planned completion date is May 2023.

One of the projects carried out within the scope of Horizon Europe is the “LoLiPoP-IoT: Long-Life Power Platforms for the Internet of Things”. This project aims to develop innovative long-life power platforms to empower wireless sensor network modules utilized in IoT applications. These platforms are used in applications for Industry 4.0, smart mobility, and energy-efficient buildings. LoLiPop-IoT aims to create an ecosystem including developers, integrators, and users to develop these platforms with a focus on lower energy consumption/more extended battery life, ease of installation, and maintenance. This project is planned to start in May 2023 and to be concluded in 2026 (BigTRI Bilişim A.Ş., 2023).

“BRIGHTER: A Breakthrough in Micro-bolometer Imaging”, another Horizon Europe project, will address micro-bolometer sensors, which are compact, lightweight, low-power, safe, and affordable infrared imaging systems. BRIGHTER aims to develop solutions that minimize the performance gap between micro-bolometers and their cooled counterparts. Marmara University will contribute with Artificial Intelligence, Communication, Image Processing, and Edge Computing technologies to the use case presented for “Smart Intersection/Safety of Vulnerable Road Users” applications. This project started in December 2022 and will be completed in December 2025 (Marmara Üniversitesi Akademik Veri Yönetim Sistemi, 2023).

In 2021; V2X Communication In-Vehicle User Interface and Applications, V2X Communication Network Devices and Infrastructure Management Platform, and Connected Cars Service Platform were developed.

“To realize the action “*3.3. In-Vehicle Information and Communication System (IVICS)*” in the National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan published by MoTI, the Protocol for the “Project for Determining the Technical Specifications of the In-Vehicle Information and Communication System (IICS)” was signed between DGComms of MoTI and Marmara University on September 8, 2022. With this project;

- IVICS components will be identified and defined,
- Within the scope of C-ITS, research will be conducted on the in-vehicle communication components in connected vehicles and the communication units that vehicles will use to communicate with the infrastructure,
- Identification of best practices and relevant standards will be ensured,
- The requirements for in-vehicle information and communication systems using cellular and wireless communication technologies and the technical infrastructure for data collection through these systems will be determined.

In addition to the above, the National RSU and National OBU development projects are ongoing with ASELSAN. In these projects, OBUs, RSUs, in-vehicle interfaces (tablet, mobile phone, etc.), in-vehicle communication units, and network devices are used as the hardware. This hardware is used for V2X communication, V2X applications, and end-to-end connected vehicle services. The software used in the operation of this hardware comprises the software provided with the hardware by OBU and RSU manufacturers, software developed byVeNIT Lab, software developed by BigTRI, and third-party ITS software (Traffic LightsController, etc.). V2X communication and data transmission standards and protocols are used in this hardware. These are IEEE 802.11p, ITS-G5 ETSI network, and facility layer protocols. At the end of these projects, R&D outputs, commercialized products, test platforms, and cyber security platforms were obtained. ETSI standards and technical reports, SAE publications and reports, UNECE regulations and strategies, and technical reports issued by CCAM Partnership, C-Roads Platform, and C2C-CC are taken into consideration in the ITS studies.

Istanbul Okan University: Istanbul Okan University provided consultancy to TOFAŞ Turkish Automobile Factory, Ford Otosan, Telemetry, and Koç Sistem for the “Communication Technologies between Vehicles for Safe Traffic(C2C)” project. The objectives of the project are to establish a secure communication system between vehicles and their surroundings, to ensure safe driving with the data to be collected through smart sensors and the information to be transmitted to drivers within the scope of the applications to be developed, and to develop value-added applications such as collision avoidance systems, vehicle position, and traffic situation information transmission systems, intersection collision warning systems, communication systems with traffic lights, and blind spot warning systems. In this study, smart sensors are used as the hardware. With these sensors, it is aimed to obtain information about the road situation. The study aims to enable drivers to travel more safely in traffic. Within the scope of the "Okan University's IntelligentTransportation Technologies Workshop Report" published in 2011, the strategies of "Deploying Infrastructure-Vehicle Communication System" "Developing V2V and V2I Systems for Autonomous Driving" and "Improving safety with V2V and V2I systems" were determined.

6.1.3. Civil Society Organizations

The interviewed civil society organizations do not have studies in the field of C-ITS.

6.1.4. Private Sector Organizations

TEMSA INC.: A project is being carried out including V2I, connected vehicle technologies, and the detection of objects around these vehicles. In this project; 1-layer LIDAR, 32-layer LIDAR, cameras, and Vehicle CAN bus telemetry are used as the hardware. While LIDAR and stereo cameras are used to scan and detect objects around the vehicle, the telemetry device is used to transmit this information to the main server and collect information in case of an accident. SAE J1939 standard and TCP/IP communication protocol was used to communicate the telemetry device with the main server. The TCP/IP protocol allows communication between several computers (called hosts) connected to a network. The telemetry devices used are manufactured by TEMSA. With the established communication system, the hardware sends the information to the infrastructure via SIM card. It is also sent from the infrastructure to the main server. In case of infrastructure problems, the information is saved in a buffer and transferred to the main system via Wi-Fi in the municipality area. In this project, TEMSA's software is used. Within the scope of the study, it is aimed to collect information about the vehicles and statistical data about the incidents that take place around the vehicle. In this way, it is aimed to make it possible to provide warnings regarding blind spots, rear-end accidents, or lane departures. The standards established by the CEN/TC278 ITS Committee are followed in the C-ITS studies.

OTOKAR INC.: Applications within the scope of the General Safety Regulation (GSR) are implemented on vehicles for R&D and mass production purposes. The equipment used for this purpose is long-range AEBS (Advanced Emergency Braking System) radar, short-range blind spot radar, AEBS-LDWS (Advanced Emergency Braking System-Lane Departure Warning System) camera, and cyber security ECU (Electronic Control Unit)/Gateway. This equipment is used for the functions in General Safety Regulation 2 (GSR2) covering M and N category vehicles. Smart vehicles, smart roads, and information security standards are used in the specified equipment (ISO 11898, ISO14229-1, ISO 15765-2, ISO 8855, ISO 4926, ISO/SAE 21434, ISO 26262, UNECE R155, UNECE R156). The software used by OTOKAR in its projects includes AEBS, LDWS, BSIS (Blind Spot Information System), MOIS (Moving Off Information System, which is an information system on the presence of vulnerable road user blind spot), ISA (Intelligent Speed Assist), ESS (Emergency Stop Signal), DDAW (Driver Drowsiness Attention Warning), and TPMS (Tire Pressure Monitoring System). The system developed within the scope of this project is aimed at detecting incidents that may cause an accident or injury to the driver in advance and warning the driver. In addition, telemetry-like systems are being studied within the scope of V2X communication technologies. With such projects, it is aimed to prevent unexpected failures and accidents that may be caused by these failures and carry out regularly scheduled maintenance activities thanks to the preventive maintenance systems to be developed. To provide timely and reliable information on safety conditions to drivers, OTOKAR Inc. aims to provide training to drivers together with after-sales services within the scope of safety practices in the GSR 2 regulation package. In addition, ECE-4807, ECE-14101, ECE-14201, ECE-15100, ECE-15800, ECE-15900, ECE-16000, EEC-2021/535, ECE-2021/1341 and EEC-2021/1958 standards are taken into consideration in the projects carried out by the company.

HAVELSAN INC.: The studies carried out in the field of C-ITS are for military applications; there are not any studies on C-ITS in the civilian area. While HAVELSAN can conduct studies for developing C-ITS software, it works with its partners in hardware production.

Within the scope of the Action Program, C-ITS joint work is being carried out together with ULAK Haberleşme, which is the main coordinator. As the scope of the Action program, HAVELSAN currently focuses on V2I; however, more focus will be also given to V2V and V2X.

C-ITS Joint Project Under the Action Program: The application made under the Action Program aims to develop C-V2X components that will constitute the infrastructure of Türkiye's autonomous vehicle systems. In this context, the works to be carried out together with ULAK Communications, TUALCOM, Hitit Defense, and HAVELSAN are listed below:

On-board Unit (OBU): The board design for the OBU with specialized processors for C-V2X will be carried out by Hitit Defense.

Development of OBU Software Layers: The protocol layers defined for C-ITS within the scope of OBU will be developed by ULAK Communications.

Road Side Unit (RSU): Hardware design for the RSU with specialized processors for C-V2X will be performed by TUALCOM.

Development of RSU Software Layers: The software layers developed by ULAK Communications under the OBU work package will be adapted to RSU.

Intelligent Transportation Platform: With the help of this platform, the monitoring, control, and management of the devices located in the field will be carried out from a single center. In this way, it is planned to centrally manage transportation functions. Within this platform, the Private Cloud Platform, IoT Platform, and Big Data Platform, which were previously developed and customized by HAVELSAN using open source software, will be used. These platforms will provide a fast, cost-effective, and target-oriented infrastructure that is in line with the architectures recommended for C-ITS systems in the world. The project aims to develop a subset of C-ITS Day 1 scenarios.

Video Analytics and IoT Gateway Edge Unit Devices and Edge Unit Software: With edge devices, images from the cameras in the field will be analyzed in real-time, and video analytics will be made (For example, objects that fall on the road and can damage vehicles will be detected instantly with the help of these units and this information will be transferred to the relevant units instantly). In addition, sensors and devices in the field that do not have a TCP/IP connection will be able to communicate with the central platform through these devices.

In addition, HAVELSAN will also develop software that will run on the edge processor unit to ensure the security and efficiency of transportation by evaluating the information received from OBUs and RSUs. The software used within the scope of the studies is running on IT equipment located at the HAVELSAN headquarters.

Information about the software used in the project is given below:

ITS Central Software: The system central software has the flexibility to be easily adapted to the ARC-IT and FRAME reference architecture. In addition, all data and workflow from roadside-vehicle-pedestrian components can be easily adapted according to the needs thanks to the existing rule engine.

Video Management and Analysis Systems: Integrated Imaging and Recording System (Orbit) and Artificial Intelligence Based Video Analysis System (Eyeminer) are software-hardware integrated structures that enable the management and video analysis of large-scale video systems independent of the camera and NVR (network video recorder) systems.

ITS IoT Platform Management System: A flexible, easily adaptable structure that enables endpoints to be monitored, managed, reported, and integrated with ITS centralized software through other open communication channels, including the NTCIP (National Transportation Communication for ITS Protocol) standard used in the US ITS architecture.

Artificial Intelligence Competence: In addition to the systems described above, the Artificial Intelligence Team within the company also creates customized artificial intelligence solutions if needed. Within the scope of the improvements made in the integration interface of the system located at the center, communication can be provided with any protocol.

ARC-IT, FRAME, and ETSI reference documents are taken into consideration in the projects carried out.

FORD OTOSAN INC.: Studies on connected and autonomous vehicles are being carried out by Ford Otosan. The main focus is to realize commercial transport on designated routes using level 4 autonomous vehicles. Although there is not any work currently being carried out on vehicles within the scope of C-ITS, this issue will be considered to be included in future studies. In addition, V2V communication tests were conducted with the OBU installed in autonomous vehicles and it was observed that messages were successfully transmitted to the vehicle via the OBU.

Ford Otosan took part in the EU-funded 5G MOBIX project. With the 5G MOBIX project, various automated mobility usage scenarios such as coordinated driving, highway lane merging, platooning, automated vehicle parking, road user detection, remote control of vehicles, environmental control, and HD (high definition) map updating were examined. Among the equipment used in the connected vehicle, the most prominent is the telematics units in trucks that are currently in mass production.

Ford Otosan has global security procedures for data storage and data sharing. There is a global key management system and security structure. Messaging is encrypted and different security keys are stored in keyholders. At the same time, there are no other layers between the cloud and the vehicle, so there is no unauthorized access.

ASELSAN INC.: R&D work in the field of C-ITS and scenario studies on V2I communication are being carried out. The aim of the R&D project is not to develop the hardware but to take this hardware in a ready-to-use form and run services over this hardware. V2I and I2V communication is planned to be implemented through central ITS software. The project is planned to be completed in March 2023. The services work on two scenarios: one priority vehicle passing at intersections and the other is on displaying the messages on the Variable Message Signs (VMS) via in-vehicle display by pressing a button. The vehicle's position information is sent to the RSU and the information displayed on the VMS is transmitted to the driver. ETSI, DSRC, and ITS-G5 standards are used in these studies. The software running on the hardware and the central software is being developed by ASELSAN. There is not currently any work on V2V communication.

TURKCELL INC.: Research studies are being conducted with Qualcomm within the scope of V2X in the field of C-ITS. In addition, the company has contributed to the preparation of V2X-related documents in the Next Generation Mobile Networks (NGMN) group, where it has been in the management team since 2013. The company participated in the trial demonstrations organized by NGMN in a closed test area in Germany and the meetings of the 5G Automotive Association (5GAA) group. The documents and updates published by the 5GAA group are also closely followed. As C-ITS hardware, the 5.9 GHz band was used on the OBU in the trial demonstration organized by NGMN in Germany. The 5.9 GHz band is free of charge and can be used in locations where there is no mobile network. NB-IoT (Narrowband Internet of Things) and CAT-M standards are used in this hardware and V2I, V2V, and V2X communication technologies are used in applications. The report prepared on this hardware is shared with everyone by the NGMN group and TURKCELL is also following this report. In addition, TURKCELL was the leader in the Ipsala-Kipi border area, one of the two cross-border corridors where works were carried out under the 5G-MOBIX project, and undertook the establishment of 5G test infrastructure and cloud integration of certain applications on the Turkish side of this corridor. The final demo of this project was successfully carried out with trucks equipped with applications communicating via 5G technologies crossing the Turkish-Greek border and traveling along this route (Foreks, 2022).

ANADOLU ISUZU INC.: Studies are being carried out for V2I, V2P, V2V, V2N, and V2X communication technologies used in the field of C-ITS, which are in the R&D phase. Studies on RSU and OBU hardware used in this field are ongoing. The standards used in this field are listed as ETSI TS 102 894-1, ETSI TS 102 894-2, ETSI TS 102 941, ETSI TS 136 101, ETSI TS 136 133, ETSI EN 302 665, ETSI EN 302 637-3, ETSI TS 102942, UNECE R155, UNECE R156, and UNECE R10.

ADASTEC INC.: Modems and OBUs are used as hardware in the studies carried out in the field of C-ITS. The purpose of using this hardware is to provide communication with the traffic light infrastructure. Communication technologies are utilized in these studies and IEEE802.11-2012 and ETSI ES 202 663 standards are used in applications. IEEE 802.11p is used as the communication standard and these studies aim to improve comfort, safety, and energy saving. Another standard considered in this field is SAE J2735.

TÜRK TELEKOM INC.: Feasibility studies are being carried out with international companies for a V2X field trial project. In these studies, conducted in the field of C-ITS, RSU and OBU are used on mobile network equipment as hardware. The communication technologies used within the scope of this hardware are ITS-G5, IEEE 802.11p, DSRC, LTE-V, and C-V2X/5G. The software comprises interface and application software provided by the companies. Reference documents published by GSMA (Global System for Mobile Communications Association), 5GAA, and Qualcomm are taken into consideration in the studies. The project has not moved from the feasibility phase to the implementation phase.

Within the organization, smart transportation/V2X is one of the application areas in 5G and beyond network infrastructure works. Therefore, developing applications in the field of V2X is closely followed.

ULAK COMMUNICATIONS INC.: ULAK COMMUNICATIONS carries out four externally funded projects and one internally funded project, and many analysis, requirement, and technical specifications determination and development studies have been carried out. Information about these projects is listed below:

- Within the scope of the OBU Development Project carried out with Anadolu Isuzu, in-vehicle communication units are being developed.
- Within the scope of the KARINCA project carried out with the Defense Industry Agency, units for V2V and vehicle-drone communication are being developed.
- Within the scope of the SUIT project supported by the TUBITAK 1004 Programme, units for V2V and V2I communication are being developed. Verification studies will be carried out by integrating the units to be developed into the autonomous vehicle.
- V2X Gateway is being developed within the scope of the SAHRA Project carried out with the Defense Industry Agency. The developed gateway will enable the military communication network and the V2X network to communicate with each other.
- Within the scope of the internally-funded project by ULAK Communications, work is being carried out to develop an RSU.
- Within the scope of the Action Program's Digital Transformation Call, an application was made for ITS. In this context, V2X Terminals and MEC (Multi-Access Edge Computing) Platform developments are aimed to be implemented. MEC moves the scheduling and processing of traffic and services from a central cloud to the edge of the network and closer to the customer. The network edge analyzes, processes, and stores the data instead of sending all data to a cloud for processing (Juniper Networks US, 2023).

Within the scope of the above-mentioned activities, V2X Terminals, MEC Platform, and V2X Gateway development studies are continuing within ULAK Communications. In addition to these developed products, smart traffic signs and terminals from third-party manufacturers are used. The specified hardware is being developed to support C-V2X and DSRC technologies and will be able to perform V2V, V2I, and V2N communications. ETSI EN 302 637 2, ETSI EN 302 6373, ETSI EN 302 895, ETSI TS 102 894-2, ETSI TS 102 636 4, ETSI TS 102 636-4-1, ETSI TS 102 636-4-2, ETSI TS 102 636 5, ETSI TS 102 636 6, ETSI TS 302 665, ISO 16750-4, ISO 16750-3, ETSI 301 489-1, ETSI EN 302 571, ETSI EN 303 413, ETSI EN 301 908-13, ETSI EN 301 908-25, EN

62368-1, UNECE R10, UNECE R155, UNECE R156, IEEE 802.11p standards are used in these hardware components.

The company uses C++ and Java programming languages and develops software compliant with ETSI standards. With the development of these systems, the development of technology in Türkiye will increase and critical communication infrastructure will be established with domestic and national designs. With the use of these systems; smart city applications, especially smart intersections, will be implemented.

Within the scope of C-ITS applications, an architecture has been determined to use edge computing platforms for delay-sensitive applications to transfer information in a timely and reliable manner. For security purposes, relevant cyber security measures and HSM (Hardware Security Module) are used.

The development strategy, the future of the market, and priority areas were determined for the application made by ULAK Communications within the scope of the MoIT's Action Program's Digital Transformation Call.

Within the scope of C-ITS studies, the documents published by 5GAA, ERTICO (European Road Transport Telematics Implementation Co-ordination Organisation), ERTRAC (The European Road Transport Research Advisory Council), AECC (Automotive Edge Computing Consortium), ACEA (European Automobile Manufacturers Association), ETSI as well as international works are followed. In addition, the "National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan" published by MoTI and MoIT's Autonomous Vehicle Working Group activities are followed.

6.1.5. Road Users

Within the scope of the surveys conducted with cyclists, pedestrians, drivers, and vulnerable road users, it was observed that they did not have any information about C-ITS; therefore, their opinions were evaluated only within the scope of the SWOT analysis.

6.2. Other Studies

This section includes the studies obtained as a result of the research conducted on the websites of companies and projects. The C-ITS studies identified as a result of the research are carried out by various institutions and organizations for different purposes. When the studies are examined in general, it is observed that the majority of the studies focus on technologies that will enable data exchange with a central system, other connected vehicles or infrastructure by connecting vehicles, and on the establishment of test sites where these technologies and C-ITS applications can be tested.

Within the scope of the “Connected Car” project carried out jointly by KoçDigital and Otokoç Automotive, it is aimed to manage 45 thousand connected vehicles belonging to Otokoç Automotive and its business partners through a central system in the next five years. The communication of connected vehicles over a central system is planned to be provided by “Platform360” software developed by KoçDigital which is an IoT management system. Platform360 is a management system built on the IoT and it is planned to manage the data of 45 thousand connected vehicles in the next five years.

It is of great importance that the communication technologies used within the scope of C-ITS projects operate with full efficiency, seamlessly, and fast. In this context, it is important to make effective use of 5G technology. In 2017, 5G Open Test Site Cooperation was initiated with the protocol signed between ICTA, Hacettepe University, İhsan Doğramacı Bilkent University, Middle East Technical University (METU), TURKCELL Inc., Türk Telekom Inc (Avea Communication Services Inc.) and Vodafone Telecommunications Inc (BTK, 2017). The aim is to create an environment where applications and technologies related to 5G and beyond can be tested in the area between Hacettepe University’s Beytepe campus, Bilkent and METU (Middle East Technical University) campuses, and ICTA headquarters in Ankara. Within the scope of C-ITS, a very important step has been taken in the testing and development of C-V2X communication to realize long-distance communication and minimize latency. It is an important project where C-ITS applications can be tested at the 5G Open Test Site before they are put into practice, and where it can be tested that communication latencies are minimized and safe travel is provided.

SECTION VII

7. STANDARDS USED IN C-ITS STUDIES IN TÜRKİYE

In this section, information about the standards used in C-ITS-related projects carried out in Türkiye and the classification and definitions of standards followed in C-ITS studies are presented. In Table 4, the standards used by some organizations are listed.

Table 4. Standards Used by Organizations in Türkiye for C-ITS Studies

Institution	Standards Used		
EMRA	TS62196-2	TS62196-3	ISO/IEC 27001
DGH	EN302637-2	ISO 19091	EN302571
	EN302637-3	TS 102 440	TS 103 701
MoTI –Directorate General of Transportation Services Regulation	UNECE 2014/165	UNECE 2016/799	
ANADOLU ISUZU	ETSI TS 102 894-1	ETSI TS 136 133	UNECE R155
	ETSI TS 102 894-2	ETSI EN 302 665	UNECE R156
	ETSI TS 102 941	ETSI EN 302 637-3	UNECE R10
	ETSI TS 136 101	ETSI TS 102 942	
ADASTEC	IEEE 802.11-2012	ETSI ES 202 663	SAE J2735
	IEEE 802.11p		
OTOKAR	ISO11898	UNECE R156	ECE-15800
	ISO14229-1	ISO 8855	ECE-15900
	ISO15765-2	SAE J1939	ECE-16000

	ISO 4926	ECE-4807	EEC-2021/535
	ISO/SAE21434	ECE-2021/1341	ECE-14101
	ISO 26262	EEC-2021/1958	ECE-14201
	UNECE R155	ECE-15100	
TURKCELL	NB-IoT	CAT-M	
TEMSA	SAEJ1939		
TÜRK TELEKOM	IEEE 802.11p		
ULAK COMMUNICATIONS	ETSI EN 302 637-2	ETSI EN 302 637-3	ETSI EN 302 895
	ETSI TS 102 894-2	IEEE 802.11p	ETSI TS 102 636-4-1
	ETSI TS 102 636-4-2	ETSI TS 102 636-5	ETSI TS 102 636-6
	ETSI EN 302 665	ISO 16750-4	ISO 16750-3
	ETSI 301 489-1	ETSI EN 302 571	EN 62368-1
	ETSI EN 303 413	ETSI EN 301 908-13	ETSI EN 301 908-25
	UNECE R10	UNECE R155	UNECE R156

The standards used in C-ITS studies are classified under five headings. These headings comprise standards for (i) C-ITS, (ii) software, hardware, design, and parts of vehicles, (iii) communication technologies, (iv) electric vehicles, and (v) tachographs. The standards included in this section include the works of different institutions such as the Turkish Standards Institute (TSE), European Standards (EN), International Organization for Standardization (ISO), International Telecommunications Union (ITU-T), Institute of Electrical and Electronics Engineers (IEEE), European Telecommunication Standards Institute (ETSI), United Nations Economic Commission for Europe (ECE), the European Economic Community (EEC) and the Society of Automotive Engineers (SAE).

7.1. Standards for C-ITS

EN Standards

EN 302 637-2 : Includes features of the Cooperative Awareness core service. The Cooperative Awareness core service supports a core set of road safety applications and practices. This standard includes detailed message processing capability and syntax and semantic definitions of Cooperative Awareness messages. Cooperative Awareness messages are messages sent between the ITS network and ITS stations to improve the performance of vehicles by increasing awareness and cooperative performance (European Telecommunications Standards Institute (ETSI), 2019c).

EN 302 637-3 : This standard contains the specifications of the Decentralized Environmental Notification Basic Service (DEN) that supports the implementation of Road Hazard Warnings. More specifically, it specifies the syntax and meaning of "Decentralized Environmental Notification Message" (DENM) and the DENM protocol. DEN can be implemented in a vehicle ITS station, roadside ITS station, or a personal ITS station (European Telecommunications Standards Institute (ETSI), 2019d).

ISO Standards

ISO 19091 : It defines messages, data structures, and data elements to support data exchange between roadside equipment, and vehicles to address applications to improve safety, mobility, and environmental efficiency. A systems engineering process has been applied that traces use cases to requirements and requirements to messages and data concepts to verify that the defined messages will meet these applications. This standard also covers the interface where communication between roadside equipment and vehicles takes place (International Organization for Standardization (ISO), 2019).

TS Standards

TS 103 701 : It specifies specifications for IoT products that are recognized as safe within the scope of IoT applications. The conformity assessment methodology for IoT devices, their relevance to associated services, processes related to other IoT standards, complementary, mandatory, and recommended methods, and test scenarios and evaluation criteria for all these methods are also included under this standard (European Telecommunications Standards Institute (ETSI), 2021c).

ETSI Standards

ETSI EN 302 637-2 : Includes features of the Cooperative Awareness core service. The Cooperative Awareness core service supports a core set of road safety applications and practices. This standard includes detailed message processing capability and syntax and semantic definitions of Cooperative Awareness messages. Cooperative Awareness messages are messages sent between the ITS network and ITS stations to improve the performance of vehicles by increasing awareness and cooperative performance (European Telecommunications Standards Institute (ETSI), 2019c).

ETSI EN 302 637-3 : This standard contains the specifications of the Decentralized Environmental Notification Basic Service (DEN) that supports the implementation of Road Hazard Warnings. More specifically, it specifies the syntax and meaning of “Decentralized Environmental Notification Message” (DENM) and the DENM protocol. DEN can be implemented in a vehicle ITS station, roadside ITS station, or a personal ITS station (European Telecommunications Standards Institute (ETSI), 2019d).

ETSI TS 102 894-1 : It contains architectural and functional specifications for the facility layers of ITS stations. It builds on previous work performed within the "ETSI TC ITS WG1" on the Core Applications Set.

ITS applications use multiple ITS stations to share information using wireless communication. Core Applications Set is defined by the "ETSI TC" as a set of ITS applications that can be reasonably deployed within a time frame of three years after the completion of standardization. The specifications set out in this standard comprise the minimum functionalities, services, and data needed to ensure the interoperability and basic functioning of ITS applications (European Telecommunications Standards Institute (ETSI), 2013).

ETSI TS 102 894-2 : It defines a set of data elements and a repository of sets of data elements, specified as data frames, that are commonly used in ITS applications and facility layer messages. Each data element is identified by an attribute that allows that data element to be described from several perspectives. For example, identifier name, ASN.1 definition, data definition, minimum data granularity requirement, etc. This regulation focuses on the data elements of the Cooperative Awareness service (European Telecommunications Standards Institute (ETSI), 2014).

ECE Standards

UNECE R10 : It includes threats that affect the direct control of the vehicle and may adversely affect the safety of the driver, passengers, and all users of the road, requirements for data functions that may cause driver confusion, specifications for the control of malfunctions caused by electrical or electronic equipment or accessories that may be retrofitted to the vehicle (United Nations Economic Commission for Europe, 2021a).

ECE 2021/1341 : It provides a reference scale to be used by manufacturers to measure driver fatigue in tests involving human participants. Where manufacturers choose to use an alternative measurement method, it should be duly documented and equivalence to the reference scale proposed in this standard should be ensured (European Union Law, 2021b).

ECE 15900 : It is used for the approval of vehicles in the M2, M3, N2, and N3 categories concerning the onboard system created to detect and notify the driver of the presence of pedestrians and cyclists in the near-front blind spot of the vehicle. If deemed necessary according to the manufacturer's strategy, the onboard system warns the driver of a possible collision (United Nations Economic Commission for Europe, 2021f).

EEC Standards

EEC 2021/1958 : This regulation contains the general requirements for intelligent speed control systems and intelligent speed limit (ISL) systems. The following systems are also included in this standard (European Union Law, 2021c):

- ISL systems that provide visual and cascading audible warnings to the driver.
- ISL systems that provide visual and gradual kinesthetic warnings to the driver.
- ISL systems that provide fully kinesthetic alerts to the driver.
- ISL systems that automatically reduce vehicle speed.

7.2. Standards for Software, Hardware, Design, and Parts of Vehicles

SAE Standards

SAE J1939 **:** It is the protocol that sets the standards for CAN providers. It is a protocol used extensively in industrial diesel engines designed for heavy vehicles, agricultural vehicles, construction vehicles, etc. (Society of Automobile Engineers, 2023).

ISO Standards

ISO/SAE 21434 **:** Includes engineering requirements for cybersecurity risk management related to the concept, product development, production, operation, maintenance, and decommissioning, including components and interfaces of electrical and electronic (E/E) systems in road vehicles (International Organization for Standardization (ISO), 2021).

Defines requirements for cyber security processes and a common language framework for managing cyber security risk.

ISO 16750-4 **:** Applies to electrical and electronic systems/components in the context of road vehicles. It describes potential environmental stresses and specifies recommended tests and requirements for specific installation locations on/in the road vehicle. This standard specifically defines climatic loads (International Organization for Standardization (ISO), 2023b).

ISO 16750-3 **:** Applies to electrical and electronic systems/components in the context of road vehicles. It describes potential environmental stresses and specifies recommended tests and requirements for specific installation locations on/in the road vehicle. This standard specifically defines mechanical loads (International Organization for Standardization (ISO), 2023a).

ISO 8855 : Defines the basic terms used for road vehicle dynamics. The terms apply to passenger cars, buses, and commercial vehicles with one or more steered axles and multi-unit vehicle combinations (International Organization for Standardization (ISO), 2011a).

ISO 4926 : This document specifies the composition and properties of a reference fluid used for compatibility testing of hydraulic brake systems and components installed on-road vehicles (International Organization for Standardization (ISO), 2020b).

ISO 26262 : Designed to apply to safety-related systems installed in mass-produced passenger cars containing one or more electrical and/or electronic (E/E) systems and having a maximum gross vehicle mass of up to 3,500 kg. This standard addresses potential hazards arising from faulty behavior of E/E safety-related systems, including the interaction of these systems (International Organization for Standardization (ISO), 2011b).

ECE Standards

UNECE R156 : Includes specifications on who should perform software updates for vehicles in categories M, N, O, R, S, and T, compatibility requirements, and permissions for these software updates (United Nations Economic Commission for Europe, 2021d).

ECE 4807 : Applies to vehicles of categories M and N and trailers (Category O) regarding the installation of lighting and light-signaling devices United Nations Economic Commission for Europe, 2020c).

ECE 14101 : Includes evaluation and approval processes for tire pressure monitoring systems installed on Category M (under 3,500 kg), N, and O vehicles (United Nations Economic Commission for Europe, 2021b).

ECE 14201 : Applies to vehicles in categories M, N, and O regarding the mounting of tires. Includes specifications on the use of temporary spare parts, tires with increased mobility, tire pressure control systems, etc. (United Nations Economic Commission for Europe, 2020a).

ECE 15100 : Applies to the blind spot information system of N2 vehicles of 8 tons and over and vehicles of category N3. Vehicles of category N2 (maximum technically permissible mass ≤ 8 tons), M2, and M3 can be approved upon the request of the manufacturer (United Nations Economic Commission for Europe, 2020b).

ECE 15800 : Includes specifications to ensure that drivers have adequate visibility of the bumper and sides of vehicles to improve traffic safety (United Nations Economic Commission for Europe, 2021e).

ECE 16000 : Aims to establish uniform specifications for the approval of motor vehicles in Categories M and N regarding Event Data Recorders. The specifications relating to the collection and storage of motor vehicle collision event data and the preservation of data after a collision (United Nations Economic Commission for Europe, 2023a).

EEC Standards

EEC 2021/535 : Sets forth the specifications on the establishment of a uniform procedure and technical specifications for the EU type-approval of systems, components, and separate technical units as well as vehicles in categories M, N, and O (European Union Law, 2021a).

EN Standards

EN 62368-1 : It applies to the safety of electrical and electronic equipment in the field of audio, video, information, and communication technology and business and office machines with a voltage not exceeding 600 V. This standard does not include requirements for the performance or functional characteristics of the equipment (International Electrotechnical Commission, 2020).

7.3. Standards for Communication Technologies

ISO Standards

ISO 11898 : It contains specifications for exchanging digital information between modules implementing the CAN data link layer. The CAN is a serial communication protocol that supports distributed real-time control and multiplexing for use in road vehicles and other control applications (International Organization for Standardization (ISO), 2015).

ISO 14229-1 : Specifies data connection independent requirements for diagnostic services that allow diagnostic testers to check vehicle electronic control unit functions such as electronic fuel injection, automatic transmission, antilock braking, etc. Specifies generic services that allow the tester to stop or resume non-diagnostic message transmission over the data link (International Organization for Standardization (ISO), 2020a).

ISO 15765-2 : In CANs, it includes a transport protocol and network layer services tailored to meet the requirements of vehicular network systems. It is defined according to the diagnostic services established in other ISO regulations but is not limited to this use, and is also compatible with most other communication requirements for in-vehicle networks (International Organization for Standardization (ISO), 2016).

ISO/IEC 27001 : It is an international standard for information security. It specifies the specifications required to create an information security management system (IT Governance, 2022).

IEEE Standards

IEEE 802.11-2012 **:** It is a revision of IEEE 802.11. It includes technical corrections and clarifications to IEEE 802.11 for WLANs, as well as enhancements to existing medium access control (MAC) and physical layer (PHY) functions (IEEE Standards Association, 2012)

IEEE 802.11p **:** It is a standard published as an amendment to IEEE 802.11 to add wireless access technology to inter-vehicle communication systems. It defines Wi-Fi enhancements to support ITS applications. It includes specifications for data exchange in the 5 GHz ITS frequency via V2I communication between vehicles and road infrastructure (IEEE Standards Association, 2012).

ETSI Standards

ETSI ES 202 663 **:** Provides the European profile standard for communication in the 5 GHz bands. The functionality specified in the standard is called "ITS-G5" and distinguishes several frequency ranges. It covers the specifications for the physical layer and parts of the data link layer (European Telecommunications Standards Institute (ETSI), 2009).

ETSI TS 102 941 **:** It includes the management of the security and privacy of communication technologies used in the context of ITS. Based on the security services defined in ETSI TS 102 731 and the security architecture defined in ETSI TS 102 940, it defines the trust establishment and privacy management required to support security in an ITS environment and the relationships that exist between them. It also defines and specifies security services for the establishment and maintenance of identities and cryptographic keys in an ITS. It aims to provide the functions by which trust and privacy systems can be established (European Telecommunications Standards Institute (ETSI), 2021b).

ETSI TS 136 101/ TS 136 133	**:**	These standards are a comprehensive set of standards covering the performance and requirements of radio frequencies for Advanced Universal Terrestrial Radio access (European Telecommunications Standards Institute (ETSI), 2020b)
ETSI EN 302 665	**:**	It includes the global communication architecture for ITS. This version is created in the context of road transportation. It specifies mandatory and optional elements and interfaces of ITS. Some elements of ITS applications are also taken into account, especially those directly related to ITS stations (European Telecommunications Standards Institute (ETSI), 2010).
ETSI TS 102 636-4-2	**:**	Specifies environment-dependent functions for Geo Networking as defined in ETSI EN 302 636-4-1 over ITS-G5 (European Telecommunications Standards Institute (ETSI), 2020a).
ETSI TS 102 636-5	**:**	Specifies the ITS Basic Transport Protocol for transporting packets between ITS stations in the ITS ad hoc network. Provides an end-to-end, connectionless, and unreliable transport service (European Telecommunications Standards Institute (ETSI), 2011a).
ETSI TS 102 636-6	**:**	Specifies the transmission of IPv6 packets over the ETSI GeoNetworking protocol via a protocol adaptation sublayer referred to as GN6ASL (GeoNetworking-IPv6 Adaptation Sublayer). The scope of this standard is limited to GN6ASL (European Telecommunications Standards Institute (ETSI), 2011b). (IPv6 is the latest version of the internet protocol that allows computers to identify and locate other computers and devices (V2 Cloud, 2022)).
ETSI TS 301 489-1	**:**	Concerning electromagnetic compatibility, it specifies measurement methods and technical specifications for related auxiliary equipment,

excluding radio equipment and broadcast receivers (European Telecommunications Standards Institute (ETSI), 2019a).

ETSI EN 302 571	**:**	Specifies technical specifications and measurement methods for radio transmitters and receivers operating in the frequency range 5855 MHz to 5925 MHz (European Telecommunications Standards Institute (ETSI), 2017a).
ETSI EN 303 413	**:**	Specifies technical specifications and measurement methods for global navigation satellite system user equipment (European Telecommunications Standards Institute (ETSI), 2017b). This user equipment receives radio signals from one or more global navigation satellite systems for the determination of the position, speed, or other characteristics of an object by the radio or obtaining information about these parameters through the propagation characteristics of radio waves.
ETSI EN 301 908-13	**:**	This standard applies to User Equipment for Enhanced Universal Terrestrial Radio Access. It defines the frequency bands in which this equipment can operate (European Telecommunications Standards Institute (ETSI), 2019b).
ETSI EN 301 908-25	**:**	It is the User Equipment standard for NR (New Radio) as defined by ETSI (European Telecommunications Standards Institute (ETSI), 2021a).
ETSI TS 102 942	**:**	It includes authentication and authorization services to prevent unauthorized access to ITS services. It also specifies measures to ensure the necessary level of security and confidentiality for the transmission of ITS messages (European Telecommunications Standards Institute (ETSI), 2012)

SAE Standards

SAE J2735	**:**	Specifies message sets, data frames, and data elements for specific use by applications that aim to use 5.9 GHz short range communications for

wireless access in vehicular environments (Society of Automobile Engineers, 2009).

ECE Standards

UNECE R155 : Concerning cyber security, it applies to vehicles in Categories M and N. It also applies to vehicles in Category O equipped with at least one electronic control unit. It also applies to vehicles in Categories L6 and L7 if equipped with autonomous driving technologies from level 3 onwards. This standard focuses on cyber security and cyber security management for vehicles of these types (United Nations Economic Commission for Europe, 2021c).

EN Standards

EN 302 571 : It specifies technical specifications and measurement methods for radio transmitters and receivers operating in the frequency range of 5.855 MHz to 5.925 MHz. This frequency range has been selected as the 5 GHz ITS frequency range (European Telecommunications Standards Institute (ETSI), 2017c).

TS Standards

TS 102 440 : ECMA-354 specifies XML protocols that can be used to establish and manage application sessions independent of Application Session Services, and transport layer protocols. TS 102 440 includes web services and a simple object access protocol connection for Application Session Services defined in ECMA-354. Application Session Services allow applications to establish and maintain a relationship with servers, called application sessions. The web services specified here allow service requesters and service providers to establish and maintain such Application Sessions (European Telecommunications Standards Institute (ETSI), 2012).

Other Standards

NB-IoT : NB-IoT is developed to enable a wide range of new IoT devices and services and includes low-power wide area network (LPWAN) technologies (GSMA, 2023). NB-IoT is an LPWAN radio technology standard developed by 3GPP for cellular devices, and services.

CAT-M : Includes specifications on bandwidth narrow operation (1.4 MHz); coverage enhancements utilizing A/B modes; support for half-duplex-communication; in-band operation mode; possibility to suspend/resume RRC (Radio Resource Connection) connection; sending data via the control plane, mobility support, and advanced power saving mode (Release 13)(Masek et al., 2019).

7.4. Standards for Electric Vehicles

TS 62196 is a booklet containing standards for plugs, sockets, vehicle connectors, vehicle inlets, and conductive charging of electric vehicles.

TS 62196-2 : It includes specific designs of plugs, sockets, socket outlets, vehicle connectors, and vehicle inlets specified in TS 62196. These are designed to ensure that products from different manufacturers are compatible with each other. It supports single-phase 16 and 32-amp and 3-phase 63-amp charging systems. In addition, three types of basic connector designs are also included in this standard (International Electrotechnical Commission, 2022a).

TS 62196-3 : A standard for the specific design of plugs, socket outlets, vehicle connectors, and vehicle inlets for rechargeable electric vehicles that can be charged with direct current. These designs are created to ensure that products from different manufacturers are compatible with each other. In addition, a sub-standard of this standard, TS-62196-3-1, provides specifications for all wired vehicle connectors and inlets containing small cross-section conductors under thermal management (International Electrotechnical Commission, 2022b).

7.5. Standards for Tachographs

UN ECE 2014/165 : It sets out the requirements and obligations for the construction, installation, use, testing, and control of tachographs used in road transport to verify compliance with the previous regulations of UNECE (United Nations Economic Commission for Europe, 2016).

UN ECE 2016/799 : It sets out the specifications necessary for the proper implementation of the following aspects concerning tachographs:

- Recording the position of the vehicle at specific points during the driver's daily working time,
- Remote early detection of possible manipulation or misuse of smart tachographs,
- Integrated interface with ITS,
- Administrative and technical requirements for type approval procedures for tachographs, including safety mechanisms. The construction, testing, installation, inspection, operation, and repair of smart tachographs and their components are covered by this standard United Nations Economic Commission for Europe, 2016).

SECTION VIII

8. C-ITS IN LEGISLATION, STRATEGY, AND POLICY DOCUMENTS OF TÜRKİYE

With the aim of steering the studies in the field of C-ITS in Türkiye, this section discusses the studies on the deployment of C-ITS infrastructure included in the top policy documents, legislation, and strategy documents, as well as action plans of ministries, public institutions, and international organizations.

In the "**Eleventh Development Plan (2019-2023)**" priority sectors are identified as chemicals, pharmaceuticals and medical devices, electronics, machinery, electrical equipment, and automotive and rail system vehicles.

In the context of ITS, the Eleventh Development Plan includes actions to develop communication technologies that will enable the integration of autonomous and connected vehicles into real life, establish infrastructures, and facilitate the production and development of these vehicles in Türkiye.

The relevant policy and measure items for the electronics and automotive sector in the Eleventh Development Plan are listed below:

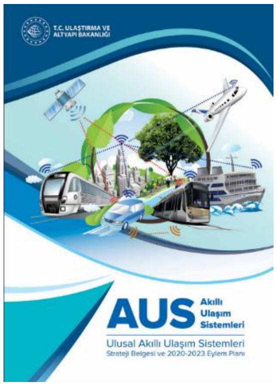
369.2. Domestic production and R&D activities will be supported within the scope of next-generation mobile communication technologies.

384. Emphasis will be given to the development of critical technologies such as environmental technologies, connected and autonomous vehicles, smart mobility within the framework of global developments, new technologies, and changing customer expectations to maintain and develop the competitiveness of the automotive industry.

385. Appropriate infrastructure will be established for new-generation vehicles.

385.2. Technical legislation and infrastructure requirements for the development and use of autonomous and connected vehicles will be determined.

385.4. Uncertainties in legislation and implementation regarding the collection and use of data from new-generation vehicles will be eliminated and their transformation into value-added services will be ensured.



In line with the **MoTI**'s ITS mission, i.e. "*To create a sustainable, productive, safe, efficient, innovative, dynamic, environment-friendly intelligent transport network which creates added value and integrated with all transport modes using the latest technology while making use of national resources*", strategic objectives included in the "**National ITS Strategy Document and 2020-2023 Action Plan**", which came into force after being published with a presidential decree on August 5, 2020, are as follows:

1. Development of ITS Infrastructure
2. Ensuring Sustainable Smart Mobility
3. Ensuring Road and Driving Safety
4. Creating a Livable Environment and Conscious Society

   Ensuring Data Sharing and Security.

When the National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan are examined, it is observed that there are actions that include testing ITS and C-ITS applications, creating an ITS architecture, and ensuring the integration of ITS applications. In addition, the importance of establishing the infrastructure that will enable autonomous and connected vehicles to operate uninterruptedly outside the test site is also emphasized. Related actions in the action plan under these strategic objectives are summarized below:

Action 1.2. Development and Publication of the ITS Architecture

A national ITS architecture will present a framework for planning, defining, deploying, and integrating ITS. The national ITS architecture will set out the relationship between ITS standards, services, functions, technologies, and data, and provide a roadmap for data sharing, management, and planning.

Action 1.8. Establishment of the Test and Application Corridor for C-ITS

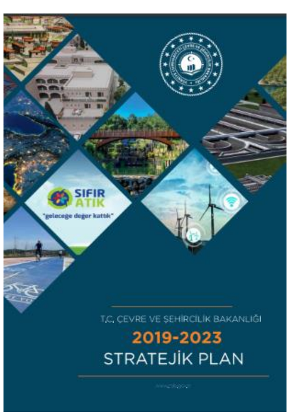
A C-ITS test and application corridor will be deployed to contribute to the transformation of solutions developed in line with the specifications of C-ITS technologies into final products.

Action 3.3. In-Vehicle Information and Communication System (IVICS)

A study will be conducted to determine the technical requirements for in-vehicle information and communication systems using cellular and wireless communication technologies and for data collection from these systems.

In addition, the National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan includes the following long-term targets:

- Carrying out preparatory work to make the existing infrastructure suitable for connected vehicles and autonomous driving, and developing and deploying fully autonomous vehicles in 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 transportation data and using it for the development of research and innovative implementations.



Within the scope of the "**2019-2023 Strategic Plan**" published by the **Ministry of Environment, Urbanization, and Climate Change**, work has been carried out to provide a suitable environment for the domestic and national production of the necessary components for the implementation of ITS and C-ITS applications in smart cities targeted to be created and to reach a sufficient level both infrastructurally and technologically for production. Within the scope of this strategic plan and in line with the "**National Smart Cities Strategy and Action Plan"**, the necessary competitive environment, technology infrastructure, and effective data security will be provided to create a healthy, comprehensive, and sustainable smart city ecosystem in our country and to develop domestic and national technologies in this field.

Within the scope of the "**2020-2023 National Smart Cities Strategy and Action Plan**" published by the **Ministry of Environment, Urbanization, and Climate Change**, it is aimed to make transportation systems smart in general and to increase and improve access, management, connectivity, and applicability of current technologies in this context. In line with the action of "*15.6. The maturity of Intelligent Transportation components will be increased*" in this strategy and action plan; the use of new generation vehicles and transportation models, supporting accessibility in transportation, improving transportation infrastructure, emergency and logistics management will be provided to increase the maturity of the Intelligent Transportation component determined by Smart City Maturity Assessment practices to ensure the Smart City transformation of cities by making use of the Smart City Technology Portfolio and National Smart City Solution Portfolio.

Within the scope of the "**2023 Industry and Technology Strategy Document**" published by the **MoIT**, it is aimed to find solutions to the mobility needs and demands in Türkiye by testing and making applicable especially autonomous and connected vehicle technologies, by implementing recent technologies. The related objectives in this strategy document are listed below: In Türkiye, a live test and development area for autonomous and connected mobility applications will be identified and initiatives will be developed to complete the infrastructure needs with support funds and make it available for use.

- Necessary support will be provided for the end-to-end identification of mobility needs and the evaluation of different business models, as well as product development for Türkiye's unsolved needs and for creating world-leading brands.

- The test center is planned to be structured not only for the current automotive industry but also for the next-generation mobility sectors.

"**Mobility Vehicles and Technologies Roadmap**" published by the **MoIT** in 2022 includes policies and action plans within the scope of connected, autonomous, and shared vehicles, as well as efforts to complete the technological and legal infrastructure of these vehicles and ensure their smooth implementation. With the implementation of these actions, specified vehicle technologies will be integrated into existing transportation systems seamlessly and uninterruptedly. The policies and actions within the scope of connected, autonomous, and shared vehicles in the roadmap are listed below:

M9. Infrastructure investments will be made required for the development of connected and autonomous vehicles.

M10. Test centers will be established to pilot connected, autonomous, and shared mobility vehicles and connectivity technologies.

M11. Necessary arrangements will be made for the use of connected and autonomous vehicles.

M12. Connected and autonomous vehicle investments will be encouraged and new investments will be promoted.

M13. "Türkiye's Autonomous Vehicles Program" will be launched.

M14. Software technologies will be developed at the "3rd Mobility Software and Hardware Development Center".

M15. Hardware technologies such as sensors, cameras, radar LIDAR, and telematics will be developed at the "Mobility Software and Hardware Development Center"

M16. The sector's transformation and product development in advanced technologies will be supported.

M17. Value-added service software will be developed.

Within the scope of the "*Establishment of Mobility Development and Test Centers*" project, which is among the "*Connected and Autonomous Vehicles Critical Projects*" recommendations under the "*Critical Projects*" heading of the "Mobility Vehicles and Technologies Roadmap" it is aimed to establish development centers that work in coordination with each other where future smart vehicle and transportation/road systems such as Smart Vehicle and Road Systems Development Center, Vehicle Communication Systems, ITS, Autonomous Vehicle Systems, and Highway Application Corridors can be designed, implemented and tested, and to establish a structure for the coordination and governance of the already established ones. At the same time, the systems planned to be used and tested in all test and development centers that will work in coordination with each other are as follows:"

- Autonomous and semi-autonomous vehicle systems,
- Driver assistance and safety systems,
- Accident and emergency management systems,
- Passenger information systems,
- Intelligent transportation/traffic management systems,
- Intelligent systems for public transportation,
- Electronic toll collection systems,
- Road-weather systems,
- V2V, V2I, V2X systems,
- C-ITS Day 1, Day 1.5 Services.

The "**2021-2030 Road Traffic Safety Strategy Document**" published by the **Ministry of Interior General Directorate of Security**, aims to establish a new system to prevent human-induced accidents that may occur in traffic and to improve road safety as a whole with this system. This strategy document aims to prevent fatalities and injuries through the establishment of efficient and strong communication systems and via "Sharing Responsibility in Traffic Safety" based on cooperation and coordination (T.C. Emniyet Genel Müdürlüğü Trafik Başkanlığı, n.d.).

One of the traffic enforcement activities included in the "**Road Traffic Safety Action Plan 2021-2023**" published by the **Ministry of Interior General Directorate of Security,** which is stated as the most effective intervention method in terms of ensuring that road users comply with traffic rules, is traffic control with "In-Vehicle Systems" within the framework of the safe system approach. Intelligent in-vehicle systems include tachograph, in-vehicle camera systems, Intelligent Speed Assistance (ISA) Systems, Following Distance Warning Systems, Seat Belt Warning Systems, Rear Collision Warning Systems, and ACC Systems. Each of these systems aims to prevent one or more risky driver behaviors. Actions planned in this context are summarized below:

1. Tachograph Control,
2. Traffic Control via In-Vehicle Camera Systems,
3. Traffic Control with Alcohol Interlocks (Alcolock), Event Data Recorders (EDR), and similar In-Vehicle Systems.

SECTION IX

9. INTERNATIONAL ORGANIZATIONS FOLLOWED BY TÜRKİYE

There are international organizations, which are followed by stakeholders working in the field of C-ITS in Türkiye, and various reports, architectures, and documents are published by these organizations. This section presents information about the international organizations and documents followed by C-ITS stakeholders in Türkiye.

The various C-ITS regulations published by the **European Commission** aim to increase C-ITS applications in Europe, to define the regulations, and to increase the traffic safety and efficiency of C-ITS (European Commission, 2023). The General Directorate of National Technologies of the MoIT harmonizes the regulations issued by the European Union in projects it carries out.

Car 2 Car Communication Consortium (C2C-CC) aims to get accident-free traffic as soon as possible. In addition, there are studies aiming to provide efficient and safe traffic conditions to the environment and end users with the lowest costs. The consortium was established by vehicle manufacturers to develop European standards for C-ITS to ensure the interoperability of systems that improve road safety and road efficiency. There are various regulations, technical reports, white papers, etc. published by this consortium on different areas of C-ITS (CAR 2 CAR Communication Consortium, 2023b).

The C-Roads Platform is a joint initiative of the member states of the European Union and road operators to test and implement C-ITS services in the light of cross-border compatibility and interoperability. Pilot projects are being implemented in various regions of Europe. Documents are published on topics such as safety, traffic impact, general evaluations, and operational test studies that are related to C-ITS projects implemented within the scope of this platform (C-ROADS, 2023a). The DGH considers the documents published by C2C-CC and C-Roads Platform in the scope of its projects.

The International Telecommunication Union (ITU) is the United Nations' specialized agency for information and communication technologies. Established in 1865 to facilitate international connectivity in communication networks, this organization develops technical standards that enable the seamless interconnection of networks and technologies (International Telecommunication Union (ITU), 2023).

The European Conference of Postal and Telecommunications Administrations (CEPT)'s main role is to provide a European forum for discussions and exchanges in the field of postal and telecommunications. In this context, it aims to facilitate and promote interoperability (Office of Communications (Ofcom), 2023).

The Electronic Communication Committee (ECC) is one of the three business committees of the CEPT. The ECC develops common policies and legislation on electronic communications and related applications for Europe and is a focal point for information on spectrum use The Electronic Communications Committee, n.d.). The ICTA, which is the institution that is the regulator of the telecommunications sector in Türkiye, considers the regulations of institutions such as ITU, and CEPT of which it is a member, as well as documents such as European Union decisions and relevant ECC reports.

The United Nations Economic Commission for Europe (UNECE) publishes an annual working report on the main regulatory developments and activities in the automotive sector in its forum for harmonization of vehicle regulations. It also publishes an annual status report on the EU's accession to UN regulations in the field of vehicle approval (United Nations Economic Commission for Europe, 2023).

CCAM (Connected, Cooperative, and Autonomous Mobility) Partnership aims to raise awareness and accelerate the implementation of innovative connected, cooperative, and autonomous mobility technologies and services. In this context, it aims to harmonize R&D studies in Europe. It aims to take advantage of all the systemic benefits (increased safety, reduced environmental impacts, and inclusion) of new mobility solutions provided by connected, cooperative, and autonomous mobility (CCAM - European Partnership on Connected, 2023). UNECE regulations and strategies, technical reports issued by CCAM Partnership, C-Roads Platform, and C2C-CC are used in the projects carried out by Marmara University VENIT Lab.

SECTION X

10. A SWOT ANALYSIS FOR THE WIDESPREAD DEPLOYMENT OF C-ITS IN TÜRKİYE

Within the scope of the increasing of C-ITS deployments in Türkiye, a SWOT analysis, as shown in Table 5, was conducted to identify the strengths, weaknesses, opportunities, and threats arising from the external environment, and strategic suggestions were made that can be used to shape the path that Türkiye will follow in the field of C-ITS. The SWOT analysis was created by using the answers to the questions on Türkiye's strengths and weaknesses in the field of C-ITS and the threats and opportunities arising from external factors within the scope of the surveys conducted with stakeholders.

In this section, in addition to the opinions of institutions and organizations competent in C-ITS, the opinions of cyclists, pedestrians, drivers, and vulnerable road users who stated that they did not have sufficient knowledge in the field of C-ITS were also evaluated.

When the SWOT analysis is examined, it can be observed that there are weaknesses such as the lack of legislation concerning the legal and testing process related to C-ITS, the big differences among regional infrastructures, and the loss of time and effort because of the increased number of institutions involved in the supervision and permission processes. However, in contrast to these, there are also strengths such as the existence of long-established organizations with knowledge and experience in the technology, the high proportion of the young population, and the rise in R&D studies on C-ITS components in recent years.

At the same time, the fact that the other countries are more advanced than Türkiye in the area of C-ITS compared to Türkiye and that Türkiye is slightly behind in the domestic production of C-ITS components carries the risk of foreign dependency in the domestic and national deployment of C-ITS applications. In addition, the loss of a skilled young population willing to utilize opportunities abroad also poses a risk for Türkiye. On the other hand, there are also several opportunities in the field of C-ITS. The fact that the technologies used in this field are being developed in Türkiye, the studies of international organizations are closely followed, and the experiences gained in international projects make it easier to catch up with the developments in the world. Since C-ITS is still in the process of development in the world, Türkiye has the potential to play a pioneering role in C-ITS applications by making timely decisions and completing the legislative gaps.

Table 5. SWOT Analysis

STRENGTHS

- Providing rapid adaptation to developing technologies in Türkiye which has a highly young population.
- Türkiye is a member of many different commercial, economic, military and political international organizations and has strong relations due to its geographical location and geopolitical duty so that C-ITS developments can be closely kept up.
- The presence of well-established organizations and experts with knowledge of transportation and communication technologies in Türkiye.
- The launch of Togg production and the infrastructure created will contribute to the R&D activities.
- With the increasing population density in cities, C-ITS can always find a place in urban planning implementations.
- Strong and developing transportation infrastructure and increasing interest in C-ITS studies.
- Laying the right and solid foundations with international collaborations established through R&D and pilot studies carried out in the field of C-ITS and thus having a strong position in the international arena.
- Promoting technology development activities in Türkiye.

WEAKNESSES

- There is a need for an umbrella organization that will guide stakeholders, supervise implementations, and increase the interoperability of the works carried out by different institutions.
- The social, economic, and infrastructural differences between the eastern and western regions of Türkiye.
- Communication infrastructures are not yet widespread for C-ITS applications.
- High costs of operation and maintenance of C-ITS components.
- The lack of national legislation to be followed by organizations that developmentproducts.
- Lack of regulations and legislation to determine those responsible in case of a problem (accident, incorrect information transfer, injury, etc.) that may occur within the scope of C-ITS applications.

OPPORTUNITIES

- C-ITS is still at the level of pilot studies and there is no widespread use (e.g., any improvements made will support meeting the current needs).
- Having the potential to be a pioneer in the field of C-ITS by encouraging special incentives for universities, research organizations, and companies to increase and accelerate studies on C-ITS.
- With the widespread use of 5G, the applicability of C-ITS systems will increase.
- Thanks to the speed and quality of production in Türkiye, economic gains can be achieved through the export of C-ITS components.
- Due to the novelty of C-ITS applications, suppliers can develop local products for these applications and offer them to the market.
- Attracting investors from abroad in the development of projects due to affordable labor costs.
- Türkiye's ability to adapt quickly to scientific and technological developments in the world and its high adaptation capability.

THREATS

- The possibility of creating dependency on foreign products in terms of tools and equipment used with the widespread use of C-ITS.Lack of sufficient qualified human resources in Türkiye for C-ITS applications to become widespread.
- The risk of possible problems that may occur in the world causing delays in the supply chain and thus affecting C-ITS applications (For example, the chip supply problem experienced in the world). The tendency of the qualified and young population to decrease due to those who prefer to work abroad.

SECTION XI

11. CONCLUSION AND EVALUATIONS

Within the scope of the “C-ITS Türkiye Current Situation Analysis Report” prepared within the scope of the “Determination of Autonomous Driving Architecture and Connected Vehicle Traffic Test Scenarios Project”, the institutions and organizations operating in the field of C-ITS in Türkiye were investigated, and the steps to be taken to increase the quality and efficiency of the work of these institutions and organizations were revealed.

In the preparation of this report, an extensive literature review including theses, dissertations, articles, papers, and projects was conducted. In the literature review, it was observed that most of the studies focused on the development of communication technologies. In addition to these, there are studies on cyber security and the impact of C-ITS on traffic conditions. Moreover, face-to-face and online surveys were conducted with certain institutions and organizations active in the field of C-ITS to gather information on C-ITS studies conducted in Türkiye.

In the surveys conducted, it was observed that the C-ITS studies have generally reached the level of productization and commercialization; however, to make progress in this area, the process of transition to real environment testing needs to be accelerated. In this context, it is important to prepare regulations on test scenarios and general testing issues. It is recommended that these regulations be prepared by an umbrella organization under the MoTI, with a unifying mission, based on the cooperation of all relevant stakeholders and the sharing of information and data.

In the research conducted, it was observed that most of the prioritized topics and scenarios in the field of C-ITS aim to ensure traffic safety. Examples of scenarios that are evaluated and prioritized in this context include road work warnings, traffic congestion ahead warnings, and warnings of approaching emergency vehicles. It is possible to prevent traffic accidents and incidents that jeopardize the safety of passengers and drivers by implementing C-ITS applications that prioritize safety in Türkiye.

A SWOT analysis was conducted within the scope of this study for the widespread deployment of C-ITS in Türkiye by using the information and opinions obtained through literature review, research, and surveys. As a result of these analyses, the recommendations for improving the current state of C-ITS in Türkiye are summarized below and Türkiye can become an important player in the field of C-ITS, which is developing in the world and where research is currently ongoing, by taking the recommended strategic steps.

- The legislation to be used within the scope of C-ITS in Türkiye should be prepared as soon as possible within the scope of the works of an umbrella organization to be established by MoTI and the standards to be used should be determined. Carrying out these studies under the leadership of a single umbrella organization will have several advantages. Benefits such as all stakeholders being in contact with a single organization, sharing data and information, obtaining permissions from a single point, and minimizing the loss of time and effort will be obtained.
- Because of the social, economic, and infrastructural differences between the eastern and western parts of Türkiye, it is not possible to adopt C-ITS practices across the country. For this reason, it is crucial to identify the demands and needs for C-ITS in the eastern regions, which do not have sufficient infrastructure, by employing surveys, interviews, etc., and to make the necessary infrastructural measures in line with these C-ITS demands.
- Fast and seamless communication infrastructures, which are intended to be used for both development and field testing, should be expanded as soon as possible. In this way, the regions covered by the infrastructure and the connection quality should be analyzed, and the regions with poor connectivity should be focused on to form a seamless communication infrastructure.
- Incentives should be provided to support technological developments in the field of C-ITS and to prevent the young population aiming to work in this field from going abroad.
- To avoid issues in the supply chain, starting local mass production of C-ITS components will be an important step both in terms of economic gains and in terms of providing a solid foundation for C-ITS applications.
- Due to the high operation and maintenance costs of the components utilized in C-ITS, the development of hardware and software used in C-ITS with incentives will speed up and enhance domestic and national production.
- Preparing the regulations that will come into play in determining those responsible in case of a problem (accident, incorrect information transfer, injury, etc.) within the scope of C-ITS applications. These studies will be possible by examining a comprehensive historical data set,

forming a working group with experts from different disciplines (lawyers, police, transportation engineers, etc.), and examining the problems experienced. Since a large and comprehensive data set is needed, it is of utmost importance to carry out the C-ITS-specific tests in areas closed to the public, to store all kinds of data and to record the problems experienced. The boundaries of the pilot regions can be expanded by analyzing and making sense of the information and knowledge obtained. Thus, progress can be made step by step and on solid ground.

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APPENDIX

APPENDIX A

QUESTION SET			
SURVEY QUESTION SET WORK PACKAGE-1	1	1.0	Are there research, studies, or field applications in the field of C-ITS in your institution?
	2	2.1	What is the C-ITS equipment?
		2.2	What are the functions and purposes of the use of these equipment in the projects they are used in?
		2.3	Which C-ITS standards are used in these hardware?
		2.4	What are the software used in these hardware?
		2.5	What are the communication and data communication protocols used in the communication of these equipment with each other and with the roadside infrastructure?
		2.6	What are the gains from the use of these systems?
	3	3.0	Do you use communication technologies such as V2I, V2V, V2X, etc. in your field applications?
	4	4.0	In these C-ITS applications; what kind of a process do you follow to ensure that the information about the safety conditions can be conveyed to the drivers in a timely and reliable manner?
	5	5.0	What are your competencies in the field of C-ITS?
	6	6.0	What services do you think will be needed when using C-ITS systems?
	7	7.0	Do the reports, legislation, strategy, and/or policy documents prepared by your institution include issues related to C-ITS?
	8	8.0	What are the national-international reports, legislations, strategies, and policy documents that you consider in your C-ITS studies?
	9	9.0	Do you have products that were developed for use in the field of C-ITS, contributed to the literature by you, and/or have added value?
		9.1	When was the product in question developed?
		9.2	What was the product in question developed for?
		9.3	What are the gains obtained by using the product in question?
	10	10.0	What are your views on the strengths/weaknesses and opportunities/threats arising from the external environment within the scope of the deployment of C-ITS in our country?

TÜRKİYE'S CURRENT SITUATION ANALYSIS OF C-ITS