Module 16: ITS Emerging Opportunities and Challenges

Authored by **Eva Lerner-Lam**, F.ITE, M.ASCE, Palisades Consulting Group, Inc. Palisades Consulting Group, Inc., Tenafly, NJ, USA

Table of Contents

Purpose

This module describes key Fourth Industrial Revolution (4IR) technologies that are presenting new challenges and opportunities for the transportation professional. It explains how the rapid developments in data, computing, and telecommunications are changing fundamental assumptions in transportation demand, supply, and operational management, and why it is important that transportation professionals involved in intelligent transportation systems (ITS) not only keep up with those developments but take active roles in ensuring that ITS use cases are anticipated and properly defined, engineered, and implemented. The challenges are many, but the opportunities are great. With the nation's aggressive new efforts at the start of the second decade of the 21st century to fix and rebuild its infrastructure, transportation professionals have a truly unique opportunity to leverage 4IR technologies to innovate smarter, more resilient, and sustainable transportation systems for the future.

Objectives

This module will:

- Describe key Fourth Industrial Revolution (4IR) technologies and provide examples of ways in which they can be used to enhance ITS functions and performance.
- Identify key opportunities and challenges that these 4IR technologies present to transportation professionals as they seek to deliver the ITS solutions expected by policymakers and society at large. This module will focus on the weakest links in the connectivity chain that is ITS, and what it will take to strengthen them for success.
- Provide guidance to transportation professionals as to how best to facilitate the effective and efficient application of 4IR technologies in ITS planning, operations, and maintenance.

Introduction

The USDOT's ITS Joint Program Office (ITS JPO) is responsible for research, development, adoption, and deployment of ITS projects across the United States, and the ITS JPO's ITS Strategic Plan 2020-25 serves as its guide for ensuring ITS-related work is implemented in a consistent and efficient manner. Within the Strategic Plan, the ITS JPO Emerging Capabilities program initiatives "focus on future generations of transportation systems."[1]

Artificial Intelligence (AI)-enhanced traffic management systems, cellular-vehicle-to-everything communications (C-V2X) for automated driver assist systems (ADAS), 5th generation (5G) communication networks for low latency transmission of big data sets for edge and cloud computing by and for field devices and unmanned aerial systems (UASs) to relieve ground-level traffic congestion are just a few examples of how advanced technologies are changing the landscape of transportation policy, planning, and engineering. Generally referred to as elements of Fourth Industrial Revolution (4IR) or Industry 4.0[2], these technologies bridge our physical and digital domains with a wide range of 4IR sensors, computing architectures and telecommunication systems, all intended to work seamlessly to move data to help people make better, more informed decisions. When properly planned, designed, engineered, and secured, the ITS programs that utilize them can directly influence the effectiveness, efficiency, resilience, and sustainability of transportation systems. The better the transportation professional understands 4IR and engages with the momentum of 4IR, the more effective and efficient will be the ITS solutions they endeavor to develop and deploy for the markets that they serve.

The purpose of this module is to describe the intersection of the transportation sector with emergent 4IR technologies and to provide insights into the challenges and opportunities for transportation professionals to leverage those technologies in order to plan, design, build, operate, and maintain better transportation systems for the future. Other modules in the ITS Primer describe the stakeholders in the ITS ecosystem (travelers, vehicles, and infrastructure) and the interactions between and among them.[3] The USDOT recently released a Comprehensive Plan for Automated Vehicles.[4] Computing and telecommunications professionals are actively and aggressively defining their fundamental components in a 4IR world.[5] This module focuses on where these major domains intersect (see Figure 1).

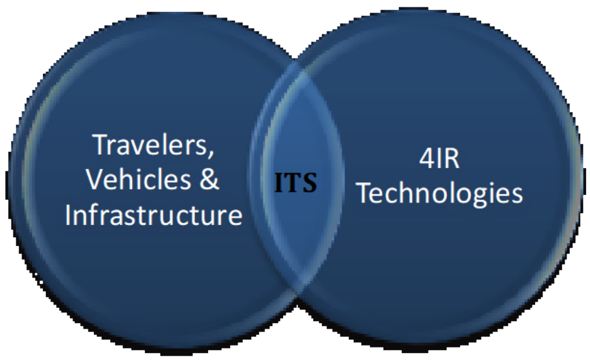

Figure 1. ITS is at the Intersection of Key Transportation Stakeholders and Fourth Industrial Revolution Technologies and is the Primary Focus of this Module

Key Components of ITS Integration of 4IR Technologies with Travelers, Vehicles, and Infrastructures

The USDOT National ITS Reference Architecture, Version 9.0[6] defines stakeholders in the following three categories:

- **Mobile** -- Onboard data sensing, collection, processing, and transmission devices for navigation and safety as well as serving as probes monitoring traffic and providing data and information for traveler information systems.
  - Individual travelers
  - Individual connected vehicles (cars, trucks, buses, bicycles, scooters, skates, etc.)
  - Fleet vehicles
  - Aerial drones (unmanned aerial systems (UAS))
- **Field/Infrastructure** -- Roadside data sensing, collection, processing, and transmission for traffic monitoring, safety, and control
- **Center** -- Regional data collection, pattern recognition, and traffic management

For the purposes of this module, this list of stakeholders will be grouped into three categories, generally along the industry sectors that equip and inform them: travelers, vehicles, and infrastructure. Following are characteristics and trends describing each one:

- Travelers
  - Smartphones, smart watches, and smart glasses will continue to connect the owners of such devices as nodes on the Internet of Things (IoT).
  - Integrated traveler trip planning and decision support will use artificial intelligence-based traffic and toll pricing prediction to plan multimodal navigation routes.
  - Mobility payment integration will gain momentum as app-based payment systems enable a societal trend toward a cashless economy.
  - Data collected by travelers will in and of itself become an asset for monetization by device manufacturers, app developers, and web service providers.
  - Mobility as a service (MaaS)[7] will provide gateways to ride hailing, ridesharing, carsharing, bike sharing, and e-scooters as well as traditional transportation services such as public transit and taxis using 4IR data, computing, and telecommunications innovations.
  - Mobility on demand (MoD)[8] will continue to evolve as integrated and multimodal transportation operators seek to interact and/or influence the supply and demand sides of transportation systems using 4IR data, computing, and telecommunications innovations.
  - Accessible transportation technologies[9] will enable wayfinding and navigation, pre-trip concierge and virtualization, safe intersection crossing, robotics, and automation functions to provide safe and reliable ITS innovations for people needing assistance with their transportation needs.

- Vehicles
  - Connected and automated vehicles will rely heavily on 4IR technologies in order to operate in connected and automated ways.[10]
  - Onboard data sensing, collection, processing, and transmission devices for navigation and safety will improve vehicle operations while simultaneously serving as probes to monitor traffic and provide data and information for other ITS stakeholders.
  - Internal combustion, hybrid, and plug-in electric automobiles, trucks, buses, trains; e-scooters; e-bikes; and urban aerial vehicles will all rely heavily on 4IR technologies for energy consumption monitoring and infrastructure capital investment.
  - Vehicles will become part of the decentralized edge for processing data utilizing 4IR technologies that dramatically reduce latency.
  - Electric vehicles equipped with onboard alternating current (AC)/direct current (DC) inverters will become mobile energy storage units that can deliver energy back into the electric grid on demand.
  - Digitization and system optimization of electric vehicle charging systems will help power generators and distributors manage electric grids with more robust analysis and control.
  - Data collected by vehicles will become an asset for monetization by public agencies and private enterprises.

- Infrastructure
  - Roadside data sensing, collection, processing, and transmission for traffic monitoring and control will become natural sites for edge computing of traffic and transportation management.
  - Key elements of communications networking architecture (dedicated short-range communications (DSRC), cellular vehicle to everything (C-V2X), third generation/fourth generation/fifth generation/sixth generation (3G/4G/5G/6G), wireless fidelity 6 (WiFi6), citizens broadband radio service (CBRS), etc.) and data interface requirements for optimized traffic monitoring and management, including National Transportation

Communications Interface Protocols (NTCIP), Transit Communications Interface Profiles (TCIP), General Transit Feed Specification (GTFS), will undergo enormous evolutionary changes as the sheer quantity of data will multiply to take up ever-increasing quantities of bandwidth in physically-limited frequency spectra.

- Digital signage for automated driver assistance systems (ADAS)-equipped and self-driving vehicles will evolve with a strong assist from a long-awaited update of the Manual on Traffic Control Devices, including a new section, Part 5 Automated Vehicles.[11]
- Vehicles will become part of the decentralized edge for processing data utilizing 4IR technologies that will dramatically reduce latency.
- Realtime, digital curbside management of ridesharing and freight loading zones will reduce urban street congestion.
- Adapting to urban aerial drone transport systems with rooftop and midlevel landing pads and loading zones will reduce ground-level transportation congestion but will also create new, three-dimensional (3D) challenges, including noise and wind buffering and traffic channelization.
- Market and policy forces will promote the use of electric vehicles but charging infrastructure (station locations and configurations) standards and coordination with the electric power generating and distribution companies and regulatory authorities are still in a nascent state.
- Interfacing with power companies for automated load balancing for electric power distribution and storage optimization will be critical but the appropriate policymaking bodies have yet to be convened.
- Data collected by the roadside infrastructure will become an asset for monetization by public agencies and private enterprises.

The original 2014 version of this ITS ePrimer module on ITS Emerging Opportunities and Challenges (updated in 2016) identified the following six primary trends and influencers:[12]

1. Declining levels of funding for transportation infrastructure (reduces the ability of the public sector to repair, maintain, and build infrastructure).
2. Rapid societal adoption of smart phones (increases end user access to traffic and transportation information).
3. Rapid developments in sensors and controls for automotive use (enables commoditization of automated driver assist systems (ADAS).
4. Technological advances enabling varying levels of so-called self-driving vehicles (reshaping urban areas).
5. Big data, extreme computing, internet of things enabling smart cities (technological breakthroughs have created fundamental, underlying foundations for smart cities).
6. Distracted drivers, bicyclists, and pedestrians increasing traffic fatalities.

Half a decade later, each of these prospective trends and influencers has been borne out, largely due to the rapid adoption of 4IR technologies that have enabled them individually and collectively.

This ITS ePrimer module focuses on those 4IR technologies that are most relevant for ITS professionals in 2021-26.[13]

Overview of Key 4IR Technologies Suitable for ITS

The accelerating deployment of 4IR technologies over the past several years has been breathtaking. Previously unimaginable advances in data sensing, collection, storage, sharing, and security, combined with increasingly fast computing speeds that enable robust analyses of big data sets and the ability to transmit enormous quantities of verifiable data and information using integrated and distributed telecommunications networks encompassing fiber, cellular, and wireless fidelity (Wi-Fi), are clearly redefining the ITS ecosystem.

This chapter provides an overview of three of the key elements that are enabling the rapid deployment of 4IR technologies that relate most directly to transportation stakeholders: data, computing, and telecommunications. Successful integration of 4IR with transportation stakeholders' use cases will greatly enhance the impact on national ITS programs such as USDOT's Accessible Transportation Technologies Research Initiative (ATTRI)[14] and its Complete Trip - ITS4 US Deployment Program,[15] as well as new mobility concepts such as mobility as a service (MaaS)[16] and mobility on demand (MoD)[17] that can be deployed at the regional and local levels.

Data

The advent of 4IR technologies greatly enhances the potential of ITS for its stakeholders because they enable travelers, vehicles, and control centers to generate, exchange, and process data. However, as the devices and infrastructures evolve to higher levels of technological sophistication, the underlying data definitions and application programming interface standards become ever more critical to the optimal functioning of the technologies.

Challenges Involving 4IR Data: A lot of data to collect, process, analyze, store, and use

As ITS systems began getting implemented around the nation over the past three decades, a strange thing happened, there was too much data. Sensors were everywhere and all sorts of data was getting collected. Data was streaming in from devices installed on-board vehicles or carried by the driver or passengers with their smartphones in those vehicles; data was sensed and transmitted from the field and dumped into data banks at regional traffic management centers. Regrettably, where data was not properly defined and/or organized, much of it required manual cleaning. Sadly, enormous data sets, having been transmitted along precious telecommunications channels and stored on hard drives at data centers, became examples of that dreaded computing industry characterization, “garbage in, garbage out.”[18]

Ensuring Common Definition of ITS Data and Use Cases

Transportation professionals must participate with 4IR developers to define relevant ITS use cases and conduct functional decomposition exercises specifically for those ITS use cases in order to define critical data elements, message sets, interface profiles and application programming interfaces. All of these should be standardized nationwide and made available to automotive, computing, and telecommunications original equipment manufacturers (OEMs) and device manufacturers to facilitate efficient and effective development of ITS applications.

Managing Cybersecurity Risks

Data security must be constantly monitored, not only for the privacy of data source owners, but for the safety and integrity of connected and automated vehicular operations.

Opportunities Involving 4IR Data

<u>Updating the Manual on Uniform Traffic Control Devices</u>

The Manual on Uniform Traffic Control Devices (MUTCD) provides the uniformity in traffic control devices necessary to ensure safe, efficient, and reliable use of transportation roadways by the public. Input from practitioners and all other stakeholders is critical in keeping the MUTCD current and relevant. USDOT is currently updating the MUTCD and among many of the new features will be a new Part 5 Automated Vehicles.[19]

Optimizing speed and accuracy of ITS data collection
If transportation professionals work together with other 4IR collectors of data and message sets (e.g., Waymo, Tesla, Uber, Cruise, municipal departments of transportation), the speed and accuracy of the data collection process can be optimized.

Collaborative partnerships in data access
Collaborative partnerships can mutually benefit all parties, with each party accessing data relevant to their individual business objectives across openly defined data and application programming interfaces (API's).[20]

Common data architecture, storage, and sharing
Major gains can be made in ITS efficiency and effectiveness if ITS professionals work together with 4IR innovators to architect data storage systems built, operated, maintained, and secured in the cloud, the fog, and at the edge.[21]

Development of USDOT Security Architecture
The USDOT is pursuing a "security by design" approach to developing the system architecture for connected vehicles; meaning that the entire connected vehicle system (vehicles, roadside components, and communications media) is being designed with the critical goal of cybersecurity in mind.[22]

Computing

Big data for ITS can be characterized by five Vs:[23]

1. **Volume**-- Processing high volumes of low-density, unstructured data such as highway vehicular traffic patterns.
2. **Velocity**-- Some Internet-enabled smart devices such as smart phones and connected vehicles (including scooters and bikes) at busy urban intersections operate in real time or near real time and will require real-time evaluation and action.
3. **Variety**-- Unstructured and semi-structured data types used by travelers, vehicles, and infrastructure, such as text, audio, and video, will require additional preprocessing to derive meaning and support metadata.
4. **Value**-- Finding value in big data for ITS requires insightful analysts, business users, and executives who ask the right questions, recognize patterns, make informed assumptions, and predict behavior.
5. **Veracity**-- How truthful is the data used by ITS applications?

Challenges and opportunities involving 4IR computing and ITS stakeholders include the following:

Challenges Involving Computing

Handling Big Data
Big data is defined as large, complex data sets, especially from new data sources. Until recently, these data sets were so voluminous that traditional data processing software had difficulty managing them, let alone analyzing them. However, with 4IR computing capabilities, these massive volumes of data can be used to address ITS applications, especially for vehicular safety and traffic management.

However, the computing network architecture necessary to optimally store and process big data has yet to be fully developed for ITS use. Allocating computing tasks and big data handling among and between cloud, fog, and edge components of computing networks will remain a big challenge as ITS innovations continue to emerge and demand more and more efficiency in the network architecture.

Opportunities Involving Computing

Increased CPU processing speeds

The increases in the speed of computing over the past half decade are truly remarkable. Although central processing unit (CPU) clock speeds began leveling off at between 2-3 GHz in 2015, dual, triple, and quad core computer technologies have fueled sustained increases in operating frequencies up to 5 GHz, and 4IR technologies are able to tap into these higher speed computing capacities.

Common IoT protocols and addressing schemes

Every electronic device in the 4IR world has, or soon will have, its own Internet protocol (IP) address, and each of those devices will become a node in the global Internet of Things (IoT). Once those billions of devices are connected via the Internet, it becomes possible to collect, store, and analyze massive amounts of static and dynamic data.

Travelers, vehicles, and infrastructure have many devices that connect via the Internet. Architecting, designing, building, operating, and maintaining how those devices process the data collected by those devices present significant opportunities and challenges for the transportation professional.

Efficient handling of big data with new advances in computations and data storage methods

Cloud, fog, and edge computing[24] are ways in which the handling of big data can be done efficiently, with computations that require low latencies handled locally (i.e., at the edge) and computations and data storage for applications not requiring such low latencies and bandwidth, including deep learning, handled in the fog or the cloud.[25]

Edge computing makes sense for safety features of ITS such as collision avoidance, while big data computing in the fog or the cloud makes sense for traffic planning, simulation modeling, and management systems.[26] (See Figure 2)

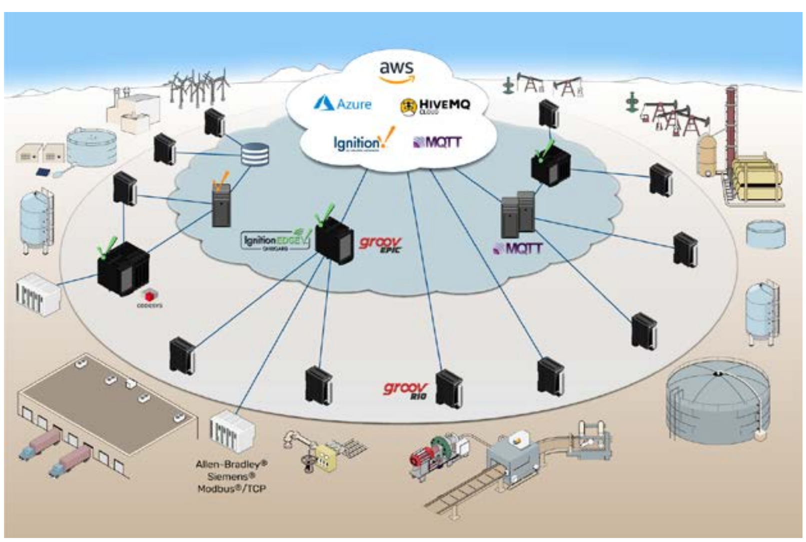

Figure 2. Edge, Fog, and Cloud Computing, Source: OPTO22.

Emergence of machine learning technologies

Augmented reality

Augmented reality (AR) is being tested in vehicles for enhancing night vision and other collision avoidance innovations.[27]

Virtual reality

Virtual reality (VR) can be a useful alternative in autonomous vehicle studies or simulations to avoid the risks of physical set-ups where people could be injured.[28]

AI technologies

Artificial intelligence (AI) (including machine learning) is now being used to process sensor data in centralized electronic control units (ECU) in vehicles to assist with driving scenario classifications or driver condition evaluations via data fusion from different internal and external sensors such as cameras, radars, Lidar, and IoT.[29]

Telecommunications

While recent advances in big data and computing speeds and capabilities have been extraordinary, so have advances in telecommunications. Challenges and opportunities involving 4IR telecommunications and ITS stakeholders include the following:

Challenges Involving Telecommunications

DSRC and C-V2X

In 1999, the Federal Communications Commission (FCC) dedicated 75 MHz of bandwidth at 5.9 GHz to be used for vehicle safety and other mobility applications.[30] Since then, advances in cellular telecommunications and Wi-Fi technologies have created additional ways in which vehicles can communicate with travelers, vehicles, and infrastructure. The resulting competition for frequency spectra needed for these new telecommunications advances has caused a shift in FCC policy away from DSRC to C-V2X.[31] The uncertainties related to FCC spectra allocation policies create significant challenges for traffic management agencies and vehicle manufacturers and their original equipment manufacturers (OEMs) to optimize their use of spectra.

One of the initiatives underway to address this challenge is being led by the National Electrical Manufacturers Association (NEMA). The National Electrical Manufacturers Association is seeking to enable the coexistence of multiple communication technologies between connected vehicles (CVs) and roadside infrastructure. Commissioned by the NEMA Transportation Management Systems Section, the new NEMA TS 10 Connected Vehicle Infrastructure-Roadside Equipment Standard is a harmonized technical specification for roadside connected vehicle devices.[32] (See Figure 3, where P2N is person-to-network, V2N is vehicle-to-network, P2V is person-to-vehicle, V2V is vehicle-to-vehicle, V2I is vehicle to infrastructure, RSU is roadside unit and BS is base station.)

More information about DSRC and C-V2X can be found in ITS ePrimer Module 13 Connected Vehicles.

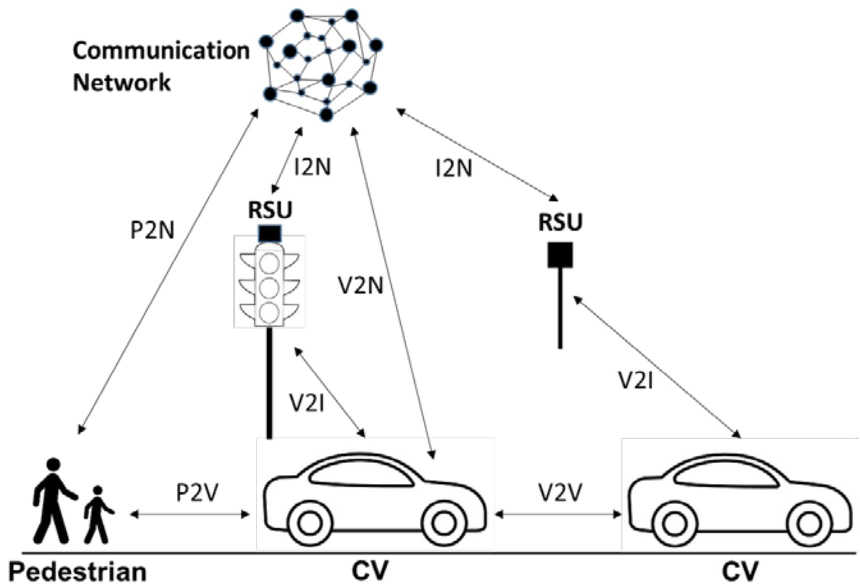

Figure 3. NEMA TS 10 Conceptual Connected Vehicle Diagram, Source: NEMA.

<u>Cost and infrastructure buildup of 5G networks</u>
5G evolution will be extremely rapid but will require significant, highly engineered infrastructure. The infrastructure must be dense, high-performance, cost-effective, and power-efficient for both indoors and outdoors, and support public and private networks with scalable and flexible networking equipment for diverse deployments across multiple industries and use cases.

Further complicating widespread deployment of 5G is that little is known of the health risk—real or imagined—posed by the radio waves propagated by 5G base stations. There have been very few peer-reviewed studies regarding the safety of prolonged exposure to beams formed by millimeter wave 5G devices, and public concern is rising.[33] Weighing the efficiency and productivity benefits of 5G against the public policy risks will become an increasingly challenging task for transportation planning professionals.

Opportunities Involving Telecommunications

<u>Evolution and economic impacts of 5G mobile networks</u>
The 5th generation (5G) wireless mobile Internet networks are truly foundational. Just as 1G provided the telecommunications foundation for the first generation of analog wireless cellular phones; 2G for digital wireless mobile phones, including texting; 3G for video calls and mobile TV; and 4G for mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, and 3D television; 5G will reduce latency, expand data pools, enable billions of IoT devices to communicate with each other, and support augmented reality (AR) and virtual reality (VR) functions for safety systems in transportation.

A wave of 5G network investments is underway across the United States. Network operators are racing to expand their wireless coverage and turn up new spectrum to bolster capacity, while simultaneously putting more miles of fiber down to connect those cellular networks. In 2017, Accenture projected that 5G would create up to 3 million jobs, generate up to $275 billion in new investment and economic growth of as much as $500 billion in the seven years between 2017 and 2024.[34]

Integration of 5G networks and communication systems for use by first responders
5G networks are supported by large area synchronized code-division multiple access (LAS-CDMA), orthogonal frequency division multiplexing (OFDM), multi-carrier code division multiple access (MCCDMA), ultra-wideband (UWB), network-LMDS (local multipoint distribution service), dynamic spectrum sharing (DSS), radio access networks (RAN) and IPv6.[35] Many, if not all of these communications systems are also used by transportation center operators, fire and emergency medical responders, fleet operators, and many other ITS stakeholders for low-latency, secure transmission of data and information needed for other purposes. Therefore, integration of efforts involving them will help to facilitate and optimize the deployment of 5G networks for ITS purposes.

General Opportunities

Standards Development for Data and Application Programming Interfaces

The successful functioning of ITS in the future depends on low latency exchange and accurate interpretation of data between and among modal applications and devices. ITS data, computing, and telecommunications standards are critical to achieving safe and reliable ITS implementations and operations.

Figure 5 illustrates the many standards development organizations that are actively and aggressively developing 4IR standards for vehicles (Society of Automotive Engineers (SAE)), mobile devices (International Electrical and Electronic Engineers (IEEE)), telecommunications (5G Automotive Association (5GAA)), physical infrastructure (American Society of Civil Engineers (ASCE)), edge and cloud computing (European Telecommunications Standards Institute (ETSI), big data analytics (International Standards Organization (ISO/ International Electrotechnical Commission (IEC) and the Internet of Things (IoT) (National Institute of Science and Technology (NIST) and International Telecommunications Union (ITU)).

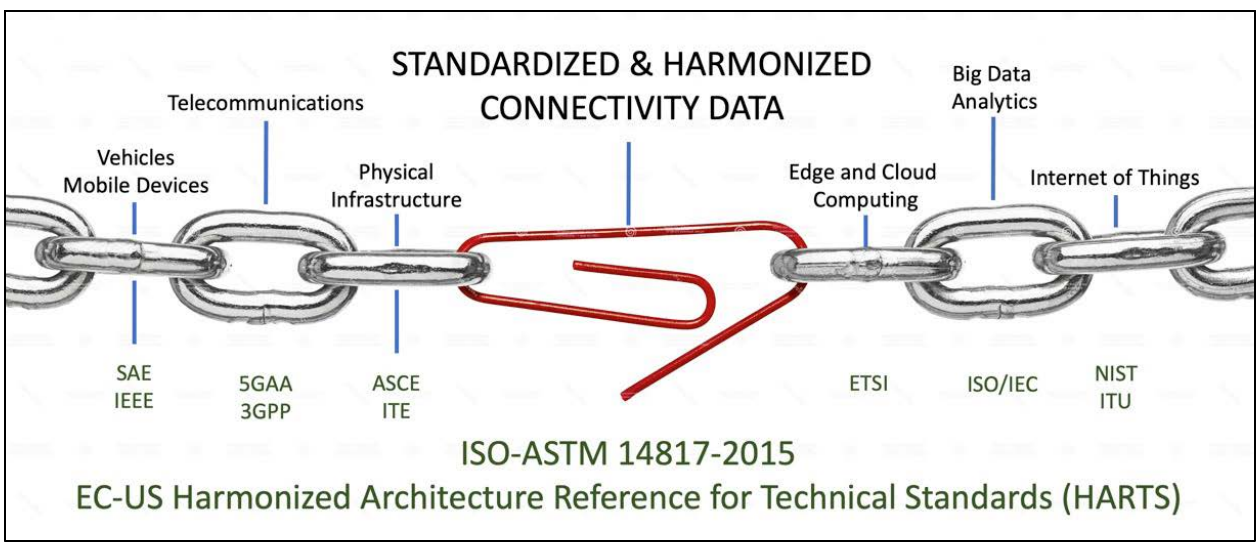

Figure 5. Avoiding Becoming the Weakest Link in the ITS Ecosystem, Source: Palisades Consulting Group, Inc.

At its core, ITS is all about acquiring, transporting, analyzing, processing, and making transportation decisions based on data. Getting everything else properly defined and standardized for connectivity and automation in the transportation domain will only work if the data is properly defined and standardized. The International Standards Organization Task Committee (ISO/TC) 204 for intelligent transportation systems has been leading efforts to standardize ITS data since 1992. ISO/TC 204 has published 296 ITS standards and is currently developing 78 more.[36] It has a strong community of domain experts in ITS and deserves continued, steadfast support from legislative bodies, transportation agencies, auto manufacturers, and 4IR technology companies.

ITS professionals have also developed Harmonized Architecture Reference for Technical Standards (HARTS) (see Figure 6). This was a significant undertaking initiated in the early 2010s involving the United States and the European Commission, and more recently, Australia.[37]

Figure 6. International Partners for ITS Cooperation, Source USDOT.

Of special significance was the HARTS initiative to conduct a Standards Gap Analysis for Cooperative ITS.[38] Table 8 in the HARTS report lists 112 HARTS Proposed Resolutions, categorized by resolution class, and provides the associated description and urgency for each proposed resolution. This effort was a major step forward toward the harmonization of data critical to enabling and facilitating connectivity and automation in transportation. It provides the frameworks for standardizing ITS data, and now ITS professionals must turn their attention to defining and harmonizing that data across device, computing, and telecommunications interfaces in ITS use cases.

Here is a simple example of how critical the definition and harmonizing of data is to successful implementation of ITS. Although many regions in the world use the metric system of linear measurement based on meters, some (including the United States) still use the Imperial system based on inches: 1 centimeter = 0.39370. If an automobile or field device contains storage, computing, or transmission devices that defines data in centimeters, that information can certainly be converted into inches. But, lacking a standard conversion factor, the data from one device using a non-standard data element might introduce rounding or truncation errors that would propagate throughout the ITS ecosystem. For example, if one device limits the calculation to a maximum of three decimal places to perform the conversion, should the conversion calculation use .393 (truncated fourth decimal place) or .394 (rounded to nearest third decimal place)? Depending on the use case, introduction of such non-standardized data can result in calculation errors that can propagate and cause ITS systems to malfunction and fail...the weak link that breaks the connectivity chain.

Development of such data standards is therefore essential to safe and reliable implementation of ITS. ISO/TC 204 has made remarkable progress with its relentless efforts over the past two decades to organize domain experts in a global effort to accomplish this enormous task. It deserves the strong support and active participation of all ITS professionals in making the data link as strong as all the other connectivity links in the chain.

Appendix 1 lists data standards development efforts that have direct benefit to ITS implementation.

Strategic Deployment of ITS - New Approaches and Perspectives

4IR technologies can help to build robustness, resiliency, and sustainability into the deployment of ITS applications by sensing levels and types of traffic, pedestrians/bikes, pavement conditions, work zones, weather, etc., and utilizing edge and cloud computing and artificial intelligence to bolster analysis, prediction, and response to transportation system effects. Fiber cabling, 5G, Wi-Fi6, open radio access networking (O-RAN) and virtual radio access networking (V-RAN) will dramatically reduce latency in data transmission, thus enabling more accurate and reliable connectivity between and among travelers, field devices, and control centers. The collection and analysis of massive amounts of big data will provide opportunities to monetize transactions that may be able to provide more stable funding for transportation infrastructure and operations. Agile software development platforms and database tools will power the delivery of MaaS and MoD transportation services, building a technological path away from service models to product models.[39]

All of the above will require creative scenario and strategic planning that draws on strong public-private collaborations and attention to the avoidance of system obsolescence. Society-wide trends, such as adoption of electric vehicles, will challenge not only the generation, storage, and distribution of electric power, but also the structural integrity and resilience of roadway pavements, viaducts, and bridges that were designed and built for much lighter vehicles. Tackling these challenges will require a commitment to professional capacity building that includes a willingness to look beyond the constraints of the past and present, and instead use creativity and insight to imagine a greener, more sustainable future. Leaders eager to embrace such change must also provide mentorship, invest in succession planning, and instill an atmosphere of aspiration and hope in workforce management.

What Challenges and Opportunities Do these 4IR Technologies Present to the ITS Professional?

Challenges

Rapid developments in 4IR

There are many moving parts in the 4IR world, each moving at a different pace, requiring very different domain expertise but relying on accurate and unambiguous data sensing, transmission, and analysis.

Multiple interactions and dependencies among multiple disciplines

The transportation professional must understand the interactions and dependencies among many disciplines--in particular, data, computing, and telecommunications; each with its own objectives, strategies, and tactics.

Many obstacles to standardized data

Non-standardized data elements, message sets, and application programming interfaces among different stakeholders pose a significant threat to the successful deployment of ITS projects that attempt to leverage 4IR technologies; yet the collaborative efforts necessary to achieve standardization of data remain sparse and slow-moving.

One important step forward would be a consensus-based set of application programming interfaces (APIs) that would not require standardization of data elements themselves, but rather only a set of defined rules that explain how computers or applications can communicate with one another in specific cases where data sharing is in the best interests of all.[40] [41]

Interoperability / integration with existing (legacy) communication systems
The pace of advancements in telecommunications seems to be accelerating, making it very difficult for devices and telecommunications to be interoperable without a high degree of coordination and cooperation between and among public agencies and private communications systems providers.

Deteriorating infrastructure and lack of stable sources of public revenues
Aging roadways, bridges, and tunnels combined with shrinking gas tax revenues are daily challenges to transportation agencies in their efforts to maintain basic, safe, and resilient transportation infrastructure. Against this backdrop, investments in ITS may simply not be tenable without substantial investment by private parties. So-called public-private partnerships (PPPs) are difficult to execute over time due to a general lack of transparency in fiscal reporting. Furthermore, the enforceability of terms and conditions of the PPP contracts over the decades-long durations of most PPPs is oftentimes elusive as project champions move on or retire.

National security threats from collection of data by ITS devices
Geopolitical and cyber security concerns involving 4IR technologies will continue to limit the availability of desired devices and software platforms. Specifically, ITS equipment, software, and service providers are increasingly based in foreign countries and the collecting of infrastructure and travel behavior data by sensors in devices used by travelers, vehicles, and infrastructure is an increasing threat to national security that requires attention and collaboration with national security experts.

Opportunities

Multidisciplinary understanding
The more the transportation professional understands the dependencies, objectives, strategies, and tactics of each 4IR discipline, the better the chance of progress and success.

Strengthen the weak links
Start with just one interaction/dependency and go from there. For example, begin with efforts to affirm that there is standardization of data elements and message set definitions for the use cases specified by infrastructure owner-operators (IOOs). Another example would be to engage with USDOT Federal Highway Administration's effort to update the Manual on Uniform Traffic Control Devices (MUTCD) to standardize fundamental vehicle-to-infrastructure and infrastructure-to-vehicle elements such as reflectivity of pedestrian crossing markings, physical and digital directional signage and icons representing electric vehicle charging station locations.[42]

Follow the money
Where is financial investment strongest? At the moment, it is 5G devices and networks. Investment is coming in from venture capital firms, the telecom industry, and chipmakers, among many others. How can ITS programs best leverage those investments?

New legislation for infrastructure projects
Stimulus spending proposed by the Biden Administration and the US Congress in 2021 includes substantial funding for transportation infrastructure projects. These funds, whether used to repair and maintain deteriorating infrastructure or to directly deploy new national digital infrastructure projects—or both—should be quickly contracted and spent.

Summary

ITS professionals must stay up to date with progress in 4IR technologies
Transportation professionals who understand the directions and pace of growth of 4IR technologies, particularly those related to data, computing, and telecommunications, will be able to plan more effectively, design, engineer, operate, maintain, secure, and update future ITS programs.

Willingness to engage in public-private partnerships will help leverage the private sector's investments and the public good in applying 4IR technologies in ITS
Public-private partnerships with 4IR technology companies and others have potential to help public agencies leverage 4IR technology capabilities to implement future ITS programs more effectively. Such collaborations can grow quickly in the fertile soil of 4IR standards associations such as 3GPP, 5GAA, IEEE, NTCIP, SAE, and others, and transportation professionals will find themselves welcome in these focused groups for their ability and willingness to help define specific domain use cases and requirements for all the data, computing, and telecommunications technologies that 4IR engineers are developing.

Key 4IR things to watch
The entire transportation industry is dramatically changing through the influence of 4IR developments such as the Internet of things (IoT), big data, artificial intelligence (AI), machine learning, 5G/Wi-Fi6, dynamic spectrum sharing/radio access network, and 4IR standards. Connected and automated vehicles (CAVs) and the field devices that will connect them to traffic management control centers will be driven by AI. Road construction will increasingly depend on drones and robots; video analytics are being used in maintenance and asset management; data systems are revolutionized by predictive analytics; commercial automated vehicle applications are improving safety and efficiency; IoT has connected and integrated different modes of transportation; and there are many implications for policy decision making.[43]

Post COVID-19 pandemic shifts in urban density and traffic
Key societal behaviors to watch include post-COVID-19 decentralization of cities and dispersion of populations, climate change impacts on residential and business location decision making, mobility as a service (MaaS) and mobility on demand (MoD). The planning, design, engineering, operation, maintenance, and updating of future transportation systems that take into consideration societal impacts on transportation demand and supply as well as low-probability, high-risk events such as the COVID-19 pandemic have the best chance for success.

Privacy and cybersecurity risks
The privacy implications of ITS technologies are becoming a bigger concern for many transportation organizations and further assessment of privacy protection mechanisms is needed for both public and private sectors. Federal and state privacy laws lag behind ever advancing ITS technologies, but privacy laws are likely to evolve in response to these innovative technologies.[44]

Every interaction between two devices in an ITS ecosystem risks cyber intrusion and hacking. This is a particularly serious threat to the safety and security of the traveling public that is increasingly dependent on sensing, computing, and telecommunication of data and information between and among devices connecting them to other moving people and vehicles. A single cyberattack that exposes a systematic weakness rather than a user error could cause critical setbacks to connectivity efforts and progress made.

Capacity Building (training and education)
Capacity building is needed for all of the above and with it comes the biggest opportunity of all, capturing the imagination and excitement of the next generation of transportation professionals. Seasoned transportation professionals can and should motivate and inspire young people who have grown up during the nascent years of 4IR technologies to think creatively and collaboratively to use those technologies to build a safer, more resilient, and sustainable transportation ecosystem. Our ability and commitment to educate and train the planners and engineers of the future to apply that knowledge and experience will be the measures of our collective success.

Appendix

List of Data Standards **Relevant to Intelligent Transportation Systems**

1. The Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) defines the standards used by road managers nationwide to install and maintain traffic control devices on all public streets, highways, bikeways, and private roads open to public travel. The MUTCD is published by the Federal Highway Administration (FHWA) under 23 Code of Federal Regulations (CFR), Part 655, Subpart F. It is currently undergoing a major revision and for the first time, will include a new Part 5 Automated Vehicles.[45]
2. The National Electrical Manufacturers Association (NEMA) developed the National Transportation Communications for Intelligent Transportation System (ITS) Protocol (NTCIP), a family of standards that provides both the rules for communicating (called protocols) and the vocabulary (called objects) necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system.
3. SAEJ2735 Basic Safety Messages specifies a message set and its data frames and data elements specifically for use by applications intended to utilize the 5.9 GHz Dedicated Short-Range Communications for Wireless Access in Vehicular Environments communications systems. Although the scope of this Standard is focused on DSRC, this message set and its data frames and data elements have been designed to also be of potential use for applications that may be deployed in conjunction with other wireless communications technologies. This Standard therefore specifies a definitive message structure and provides sufficient background information to allow readers to properly interpret the message definitions from the point of view of an application developer implementing the messages according to the DSRC Standards.
4. SAE J2945 On-Board V2V Safety Communications specifies the system requirements for an on-board vehicle-to-vehicle (V2V) safety communications system for light vehicles[1], including standards profiles, functional requirements, and performance requirements. The system is capable of transmitting and receiving the SAE J2735-defined basic safety message (BSM) over a dedicated short-range communications (DSRC) wireless communications link as defined in the Institute of Electrical and Electronics Engineers (IEEE) 1609 suite[46] and IEEE 802.11 standards [2] to [6].[47])
5. Transit Communications Interface Profiles (TCIP) standard specifies the rules and terms for the automated exchange of information in transit applications such as operations, maintenance, planning, management, and customer services.[48] Although TCIP has not yet been widely adopted, a recent study by ITS America found that while the technical aspects of the standard are sound, market forces and organizational challenges to its implementation and use have been difficult for individual transit agencies to overcome. The study's author recommends (1) a large-scale demonstration of TCIP, and (2) enhanced documentation and knowledge transfer of TCIP benefits, challenges, and interface engineering resources.[49]

6. General Transit Feed Specification (GTFS) is a data specification that allows public transit agencies to publish their transit data in a format that can be consumed by a wide variety of software applications.[50]
7. Collected naturalistic driving data from the Federal Motor Carrier Safety Administration's Onboard Monitoring System (OBMS) Field Operational Test (FOT) that enables analysis of safety-critical events (SCEs) and determination of factors related to the occurrence of SCEs.[51]

List of Data Standards Relevant to Computing

8. ISO 14817-1:2015 specifies the logical structure (framework) and the data content (substance) of intelligent transport systems (ITS) data dictionaries (DDs). Specifically, this part of ISO 14817 specifies the following:
   a. framework used to identify and define all data concepts
   b. meta-attributes used to describe, standardize, and manage each of the data concepts defined within this framework
   c. requirements used to record these definitions
   d. naming conventions for the data concepts
   e. a set of preferred data concepts within the ITS domain
   f. data modelling method for defining ITS data concepts, when used
9. ISO 14817-2:2015 ITS central data dictionaries — Part 2: Governance of the Central ITS Data Concept Registry

List of Data Standards Relevant to Artificial Intelligence

10. National Institute of Standards and Technology (NIST)[52]
11. Artificial Intelligence standards, International Standards Organization (ISO)[53]
12. IEEE Standards Association AR2020[54]

Internet of Things (IoT)

13. IEEE Standards Association 802.11, 802.15, 802.16 and 802.22[55]

Blockchain (Distributed Ledger Technology (DLT)

14. IEEE P2418.4 - Standard for the Framework of Distributed Ledger Technology (DLT) Use in Connected and Autonomous Vehicles (CAVs)[56]
15. ISO/DIS 23257 Blockchain and distributed ledger technologies — Reference architecture[57]

Telecommunications Standards

16. 5G Automotive Association (5GAA), a global, cross-industry organization of companies from the automotive, technology, and telecommunications industries (ICT), working together to develop end-to-end solutions for future mobility and transportation services
17. 3rd Generation Partnership Project (3GPP), Mobile Broadband Standard

Endnotes

[1] Intelligent Transportation Systems Joint Program Office, “Emerging Capabilities” program (n.d.). *ITS Research 2020-2025: Emerging and Enabling Technologies.* Retrieved from https://www.its.dot.gov/factsheets/emerging_tech.htm, retrieved April 9, 2021.

[2] Klaus Schwab, "The Fourth Industrial Revolution: What It Means and How to Respond” https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution December 12, 2015, retrieved May 31, 2021.

[3]United States Department of Transportation, ITS Joint Program Office, ITS Professional Capacity Building Program, https://www.pcb.its.dot.gov/default.aspx and https://www.pcb.its.dot.gov/t3_archives.aspx retrieved on March 29, 2021

[4]United States Department of Transportation, *Automated Vehicles-Comprehensive Plan* https://www.transportation.gov/sites/dot.gov/files/2021-01/USDOT_AVCP.pdf, retrieved on April 9, 2021.

[5]PWC, "The Fourth Industrial Revolution--Are You Ready?" https://www.pwc.com/us/en/library/4ir-ready.html, accessed March 29, 2021 and https://www.mckinsey.com/featured-insights/world-economic-forum/davos-agenda/perspectives/january-28-agenda, retrieved on March 29, 2021.

[6] United States Department of Transportation, National ITS Reference Architecture V.9.0 (March 11, 2021). *Architecture Reference for Cooperative and Intelligent Transportation*. Retrieved from https://local.iteris.com/arc-it/html/whatsnew/whatsnew.html, retrieved on April 2, 2021.

[7] Institute of Transportation Engineers, *MaaS/MoD ITE Initiative,* June 2019, https://www.ite.org/technical-resources/topics/maas-mod-ite-initiative/, retrieved on April 9, 2021 and BusinessWire "Global Mobility As A Service (MaaS) Market Size, Share, Trends Report 2020-2027 - ResearchAndMarkets.com" https://www.businesswire.com/news/home/20201215005699/en/Global-Mobility-As-A-Service-MaaS-Market-Size-Share-Trends-Report-2020-2027---ResearchAndMarkets.com#:~:text=The%20Mobility%20as%20a%20Service,the%20transportation%20and%20telecom%20industries, retrieved on April 9, 2021.

[8] Booz Allen Hamilton, *Mobility on Demand: Operational Concept Report,* September 2017, https://rosap.ntl.bts.gov/view/dot/34258, retrieved on April 9, 2021.

[9] Accessible Transportation Technologies Research Initiative (ATTRI) (n.d.)., *Accessible Transportation Technologies Research Initiative (ATTRI) Application Development*

Awards, http://www.its.dot.gov/factsheets/attri_baa_awards.htm, retrieved on April 9, 2021.

[10]United States Department of Transportation, Federal Highway Administration, "21st Century Operations Using 21st Century Technologies," https://ops.fhwa.dot.gov/publications/fhwahop17001/ch1.htm, retrieved on April 4, 2021.

[11] National Standards for Traffic Control Devices: Manual on Uniform Traffic Control Devices for Streets and Highways; PROPOSED RULE: Revision, https://www.regulations.gov/document/FHWA-2020-0001-0001, Discussion of Items 448-460, retrieved on April 4, 2021.

[12] Eva Lerner-Lam, E.L.L., Nathan E. Keyes, N.K. (n.d.), *Module 14: ITS Emerging Opportunities and Challenges*. https://www.pcb.its.dot.gov/eprimer/module14.aspx#major, retrieved on April 9, 2021. The original ITS ePrimer Module 14 will be replaced by this Module 16. The link provided in this reference is only viable through September 2021.

[13]United States Department of Transportation Automated Vehicles Activities https://www.transportation.gov/AV, retrieved on April 9, 2021.

[14] Accessible Transportation Technologies Research Initiative (ATTRI) (n.d.),*Accessible Transportation Technologies Research Initiative (ATTRI) Application Development Awards*. http://www.its.dot.gov/factsheets/attri_baa_awards.htm, retrieved on April 9, 2021.

[15]United States Department of Transportation, ITS Joint Program Office, Accessible Transportation Technologies Research Initiative (ATTRI) Application Development Awards https://www.its.dot.gov/its4us/index.htm, retrieved on April 9, 2021

[16] Institute of Transportation Engineers *MaaS/MoD ITE Initiative,* June 2019, retrieved from https://www.ite.org/technical-resources/topics/maas-mod-ite-initiative/, retrieved on April 9, 2021.

[17] Booz Allen Hamilton, (September 2017). *Mobility on Demand: Operational Concept Report*, retrieved from https://rosap.ntl.bts.gov/view/dot/34258, on April 9, 2021.

[18] Tech Terms, https://techterms.com/definition/gigo, retrieved on April 9, 2021.

[19]Manual of Urban Traffic Control Devices, https://mutcd.fhwa.dot.gov/, retrieved on July 15, 2021

[20] Intelligent transport systems — ITS central data dictionaries — Part 1: Requirements for ITS data definitions ISO 14817-1:2015, retrieved on April 9, 2021, and
EC-US Harmonized Architecture Reference for Technical Standards (HARTS), http://htg7.org/, retrieved on April 9, 2021

[21] IEEE Xplore® Cloud, Fog and Edge: Cooperation for the Future?" https://ieeexplore.ieee.org/document/7946409, retrieved on April 9, 2021.

[22] United States Department of Transportation (n.d.), *How the U.S. Department of Transportation is Protecting the Connected Transportation System from Cyber Threats* https://www.its.dot.gov/factsheets/cybersecurity.htm, retrieved April 9, 2021.

[23] Big Data for ITS, "Five Vs" (n.d.), *What is Big Data?* https://www.oracle.com/big-data/what-is-big-data.html, retrieved on April 9, 2021.

[24] Flavio Bonomi, et al.2014, *Fog Computing: A Platform for Internet of Things and Analytics* https://cse.buffalo.edu/faculty/tkosar/cse710_spring19/bonomi-bdiot14.pdf, retrieved on April 9, 2021.

[25] OPTO 22 (n.d.), Building Industrial IoT from Edge to Cloud.

https://documents.opto22.com/2348_White_Paper_Building_Industrial_IoT_from_Edge_to_Cloud.pdf, retrieved on April 9, 2021.

[26] Rabih Arzouni R.A., May 16th, 2019, *How Edge Computing Will Drive Intelligent Transportation*. https://www.smartcitiesworld.net/opinions/opinions/how-edge-computing-will-drive-intelligent-transportation#:~:text=Fortunately%2C%20edge%20computing%20is%20increasing,and%20intelligent%20solutions%20across%20cities.&text=%22Edge%20computing%20is%20increasing%20the,and%20intelligent%20solutions%20across%20cities.%22. retrieved on April 9, 2021.

[27] Lofti Abdi, L.A., Faten Ben Abdallah, F.B.A., Aref Meddeb. A.M. *In-Vehicle Augmented Reality Information System: A New Type of Communication Between Driver and Vehicle,* December 2015), https://www.researchgate.net/publication/291013097_In-Vehicle_Augmented_Reality_Traffic_Information_System_A_New_Type_of_Communication_Between_Driver_and_Vehicle, retrieved on April 9, 2021.

[28] J. N. Bailenson, et al., "The use of immersive virtual reality in the learning sciences: Digital transformations of teachers, students, and social context," J. Learn. Sci., vol. 17, no. 1, pp. 102–141, 2008.d https://vhil.stanford.edu/mm/2019/12/nascimento-aivr19-role.pdf, retrieved on April 9, 2021.

[29] Visteon (n.d.), "Machine Learning Algorithms in Autonomous Cars*,"* Retrieved from https://www.visteon.com/machine-learning-algorithms-in-autonomous-cars/, retrieved on April 9, 2021.

[30] Federal Communications Commission News, https://transition.fcc.gov/Bureaus/Engineering_Technology/News_Releases/1999/nret90

06.html, October 21, 1999, retrieved on May 31, 2021.

[31]Federal Communications Commission https://www.fcc.gov/document/fcc-modernizes-59-ghz-band-improve-wi-fi-and-automotive-safety-0 retrieved on June 3, 2021.

[32] NEMA (October 2019). *Connected Vehicles Infrastructure - Roadside Equipment.* https://www.ite.org/ITEORG/assets/File/Standards/NEMA%20TS%2010%20CV%20Infrastructure%20v20a%2020200318.pdf retrieved on April 9, 2021.

[33] https://blogs.scientificamerican.com/observations/we-have-no-reason-to-believe-5g-is-safe/, retrieved on March 29, 2021.

[34]"New Research from Accenture Strategy highlights Economic and Societal Impact of Investing in 5G Infrastructure" https://newsroom.accenture.com/news/new-research-from-accenture-strategy-highlights-economic-and-societal-impact-of-investing-in-5g-infrastructure.htm, January 12, 2017, retrieved on May 31, 2021.

[35] Tushar Gupta1, Amit Kumar Jha2 1,2Assistant Professor, IIMT College of Management, Greater Noida, Uttar Pradesh, India, Next Generation "5G Wireless Technology" https://adrjournalshouse.com/index.php/cloud-computing-web-applications/article/download/83/368/1952, retrieved on April 7, 2021.

[36]ISO/TC 204 Intelligent transport systems https://www.iso.org/committee/54706.html, retrieved on April 4, 2021.

[37] ISO 14817-2:2015(en) Intelligent transport systems — ITS central data dictionaries — Part 2: Governance of the Central ITS Data Concept Registry https://www.iso.org/obp/ui/#iso:std:iso:14817:-2:ed-1:v1:en, retrieved on April 4, 2021.

[38]Standards Harmonisation Working Group Harmonisation Task Group 7, Standards Gap Analysis for Cooperative Intelligent Transportation Systems, HARTS Website Overview, Document HTG7-4, Version: 2018-12, http://htg7.org/docs/HTG7-4.pdf, retrieved on April 9, 2021.

[39] "In a service-based business, customers purchase the skills of a service provider. Product-based businesses deliver physical products that are reasonably consistent in quality for each customer, making the customer experience fairly predictable," https://smallbusiness.chron.com/differences-between-productbased-businesses-servicebased-businesses-23372.html, retrieved on April 7, 2021.

[40] IBM Corporation, "What is an application programming interface (API)?" https://www.ibm.com/cloud/learn/api#toc-why-we-nee-i-O5lku5 retrieved on May 31, 2021.

[41] "Best API Development Software" G2, https://www.g2.com/categories/api-design, retrieved May 31, 2021.

[42]"National Standards for Traffic Control Devices; the Manual on Uniform Traffic Control Devices for Streets and Highways; Revision," created by the Federal Highway Administration, https://www.regulations.gov/docket/FHWA-2020-0001, retrieved on March 30, 2021.

[43]"Managing AI in Transportation," https://www.heinz.cmu.edu/programs/executive-education/managing-ai-in-transportation, retrieved on April 3, 2021.

[44] MDOT, CAR June 2012, Ethics of Government Use of Data Collected via Intelligent Transportation Systems. https://www.michigan.gov/documents/mdot/MDOT_EthicsDataCollectedITS_394489_7.pdf, retrieved on April 7, 2021.

[45] United States Department of Transportation, Federal Highway Administration, 23 CFR Parts 470, 635, and 655 [FHWA Docket No. FHWA–2020–0001] RIN 2125–AF85 National Standards for Traffic Control Devices; the Manual on Uniform Traffic Control Devices for Streets and Highways; Revision, https://www.govinfo.gov/content/pkg/FR-2020-12-14/pdf/2020-26789.pdf, retrieved on April 5, 2021.

[46]IEEE 1609 - Family of Standards for Wireless Access in Vehicular Environments (WAVE) https://www.standards.its.dot.gov/factsheets/factsheet/80, retrieved on April 9, 2021.

[47]IEEE 802,11TM Wireless Local Area Networks https://www.ieee802.org/11/, retrieved on April 9, 2021.

[48] ITS Standards Program (September 25th, 2015). *APTA TCIP-S-001 - Standard for Transit Communications Interface Profiles (TCIP).* https://www.standards.its.dot.gov/Factsheets/Factsheet/37#:~:text=The%20Transit%20Communications%20Interface%20Profiles,%2C%20management%2C%20and%20customer%20services, retrieved on April 9, 2021.

[49]The Adoption of Transit Communications Interface Profiles in the Transit Industry, Intelligent Transportation Society of America, April 4, 2016, https://static1.squarespace.com/static/596fb16003596e0fa70a232f/t/5a274eb2e2c483816e3b84ec/1512525491261/ITSA+-+The+Adoption+of+TCIP+-+Factors+and+Recommendations+-+final+-+AJS+040416.pdf, retrieved on April 5, 2021.

[50]GTFS: Making Public Transit Data Universally Accessible https://gtfs.org/, retrieved on April 9, 2021.

[51] FMCSA (n.d.), *Naturalistic Driving Study (OBMS Data Analysis).* https://www.fmcsa.dot.gov/research-and-analysis/research/naturalistic-driving-study-data-analysis, retrieved on April 9, 2021.

[52] NIST (April 12, 2019), *FAQs about NIST's role in planning federal engagement in AI standards development.* https://www.nist.gov/topics/artificial-intelligence/ai-standards/faqs-about-nist-and-ai-standards, retrieved on April 9, 2021.

[53] ISO/IEC JTC 1/SC 42 Artificial intelligence, https://www.iso.org/committee/6794475.html. retrieved on April 7, 2021.

[54] IEEE Standards Association, *Augmented Reality,* https://standards.ieee.org/initiatives/ar/index.html, retrieved on April 9, 2021.

[55] IEEE 802.11TM Wireless Local Area Networks, https://www.ieee802.org/11/, retrieved on April 9, 2021.

[56] IEEE Blockchain Standards https://blockchain.ieee.org/standards, retrieved on April 9, 2021.

[57] ISO (n.d.). *Blockchain and distributed ledger technologies - Reference architecture,* https://www.iso.org/obp/ui/#iso:std:iso:23257:dis:ed-1:v1:en, retrieved on April 9, 2021.