Smart Transport

Michael Brown

Contents

1 Introduction

Smart transport is a vital system within a smart city. Efficient and safe movement of people and goods throughout a city is at the heart of what makes a city “smart.” However, enabling smart transport within a city is much easier said than done. Technologies are being introduced at a much faster rate than cities can adopt and city officials around the world are grappling with how to fund the deployment of smart transportation technologies while their existing infrastructure is underfunded and crumbling.

Even in the face of these challenges, we mustn’t give up as there is too much at stake. The World Health Organization reports over 1.25 million traffic related

---

M. Brown (✉)
Southwest Research Institute, San Antonio, TX, USA
e-mail: michael.brown@swri.org

S. McClellan (ed.), *Smart Cities in Application*,
https://doi.org/10.1007/978-3-030-19396-6_4

deaths worldwide annually [1]. Imagine the calamity and public outcry if a Boeing 737 carrying 143 passengers crashed once per hour somewhere around the world. Yet this is exactly the death rate we are facing on our roads every day. On top of the deaths and injuries caused by traffic accidents, we are struggling with mobility as residents of cities worldwide are stuck in congestion for multiple days of time annually [2]. This congestion negatively impacts cities both economically and environmentally.

Smart cities work to enable intelligent transportation systems (ITS) by piloting and deploying innovative solutions to these challenges. ITS is undergoing somewhat of a revolution due to emerging technologies such as connected vehicles, automated vehicles, and enhanced decision support systems. Information and communication technologies (ICT) are rapidly changing what is possible and opening up new opportunities for cities to leverage these solutions to enable smart transport.

2 Applications for Smart Transport

There are a wide variety of applications that a smart city can utilize to enable smart transport. These range from safety applications that allow vehicles to communicate with other vehicles and infrastructure to environmental and mobility applications such as transit signal priority. These applications also range in complexity and maturity. Some applications have only been identified and defined. Others have been deployed, tested, and refined. The following sections provide an overview of some example smart transport applications that a smart city can leverage.

2.1 Emergency Electronic Brake Lights (EEBL)

The EEBL application is a prime example of why vehicle-to-everything (V2X) communication is critical to realizing safety benefits. When a vehicle experiences a hard-braking event (>0.4 G deceleration), it will transmit a basic safety message (BSM) to nearby vehicles and infrastructure with an event flag set that indicates the presence of the hard-braking event. This allows surrounding vehicles to detect a hard-braking scenario from a vehicle that cannot be "seen" directly using onboard sensors. An EEBL scenario is depicted in Fig. 1, where the blue car ahead of the bus is quickly decelerating, and transmitting to nearby vehicles a BSM with an event flag indicating a "hard-braking" condition. The white car cannot directly "see" the blue car's context or braking event due to occlusion by the intervening bus.

While this may seem purely like a vehicle-to-vehicle (V2V) communication scenario on the surface, it is actually quite important to a smart city. With properly placed infrastructure to communicate with these connected vehicles, municipal

Fig. 1 Example of a basic safety message in a hard-braking event scenario

datacenters will also be able to receive the BSMs and monitor the data for detecting and responding to incidents as well as determining areas in which “hard-braking” events are common. In this fashion, cities can leverage such data to perform root cause analysis and possibly improve both the digital and physical infrastructure assets.

2.2 Queue Warning (Q-WARN)

Once a smart city has deployed roadside units (RSUs) in strategic locations, it can then use its communication backbone to notify upstream traffic of downstream hazards, or traffic queues. An example of a traffic queue is shown in Fig. 2 where slow or stopped vehicles (label 1) have queued up ahead due to some external problem. In the figure, RSUs aggregate slowed vehicle positions and provide context information to approaching vehicles (label 2).

This queue can be detected via several mechanisms including the BSMs that are transmitted from the vehicles and infrastructure-based sensing such as radar or cameras. A combination of these mechanisms provides a more robust queue detection mechanism which can reduce false positives. The warning of the upcoming queue can also be accomplished using a variety of communication mechanisms such as dedicated short-range communications (DSRC) [3], cellular vehicle-to-everything (C-V2X) [4], and/or 4th generation wireless telephony (4G LTE) [5].

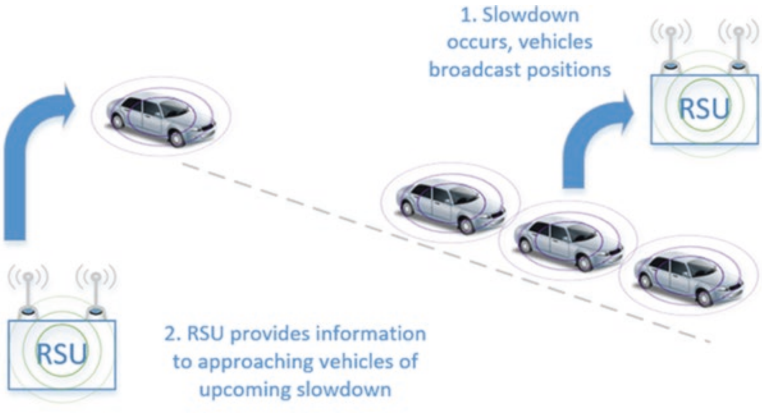

Fig. 2 An example of a traffic queue and Q-WARN system

2.3 Reduced Speed Zone Warning (RSWZ)

Construction is a reality for even the smartest of smart cities. Cities are constantly trying to maintain and repair their roadways while simultaneously trying to keep traffic moving. Work zones are difficult for AVs to navigate as the vehicles often depend on high definition maps to localize and navigate, and these maps are not updated at a frequency that would accurately reflect the work zone which can change frequently.

This is a great example of how a smart city can help to enable AVs that are not able to sufficiently deal with work zones. As part of a city's digital infrastructure, up-to-date maps can be transmitted to vehicles approaching a work zone to let it know about speed limit changes, lanes that are closed, and the appropriate route to take to navigate the work zone. An example of a construction zone with RSWZ is shown in Fig. 3. In the figure, the RSU broadcasts "reduced speed" warning signals to approaching cars.

Maintaining up-to-date maps of work zones is not an easy task. As a result, communications infrastructure will play an increasingly important role in monitoring traffic flow and communicating this information to upstream vehicles. This can help with work zones that are changing frequently or are very short-lived, and can help with situations such as temporary obstacles in the roadway.

2.4 Cooperative Situational Awareness

Breakthroughs over the last decade in the areas of deep learning and increased computational capabilities have led to a transition of intelligence in ITS to the edge.

The deployment of intelligent situational awareness hubs at key intersections allows vehicles to see pedestrians that are not detectable with sensors and to see

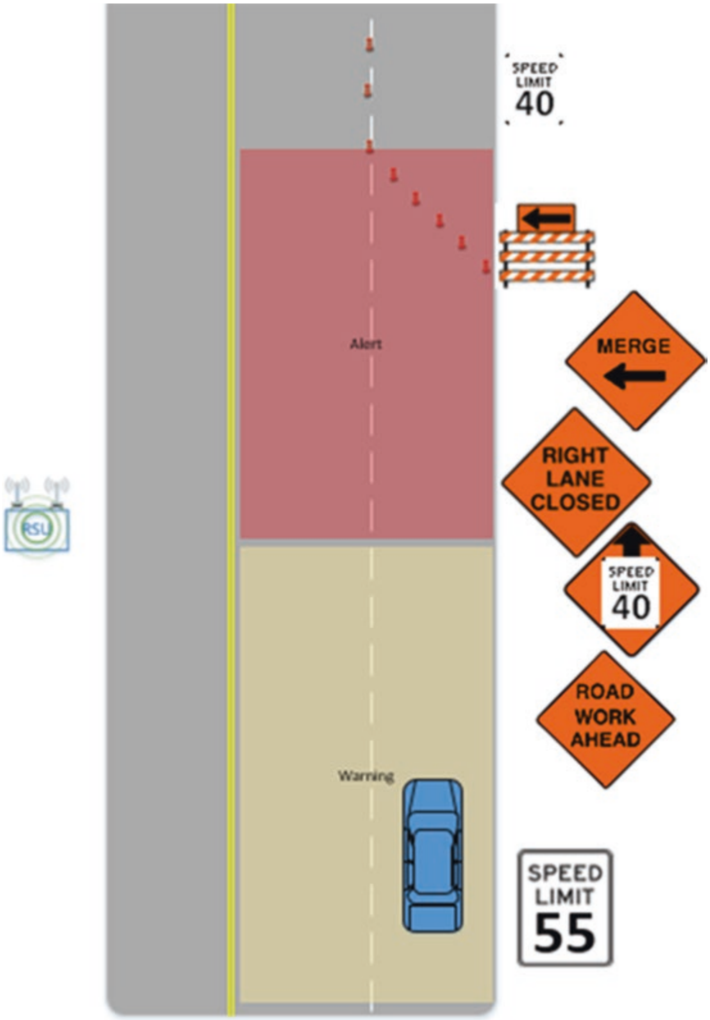

Fig. 3 Depiction of a reduced speed zone warning

around corners. This also allows complex computation to take place immediately where the data is received at the roadside and then information extracted from that data is exchanged with a traffic management center (TMC). This is in stark contrast to the traditional means of bringing all data back to the TMC and then dealing with it there. This capability can enable cooperative situational awareness for all users at the edge whether it is pedestrians, bicyclists, or vehicles. Figure 4 provides a descriptive perspective of cooperative situational awareness in a metropolitan area. In the figure, a situational awareness system located in/near a busy intersection aggregates information from cars, pedestrians, buses, and other transportation systems and communicates useful situational context to user systems.

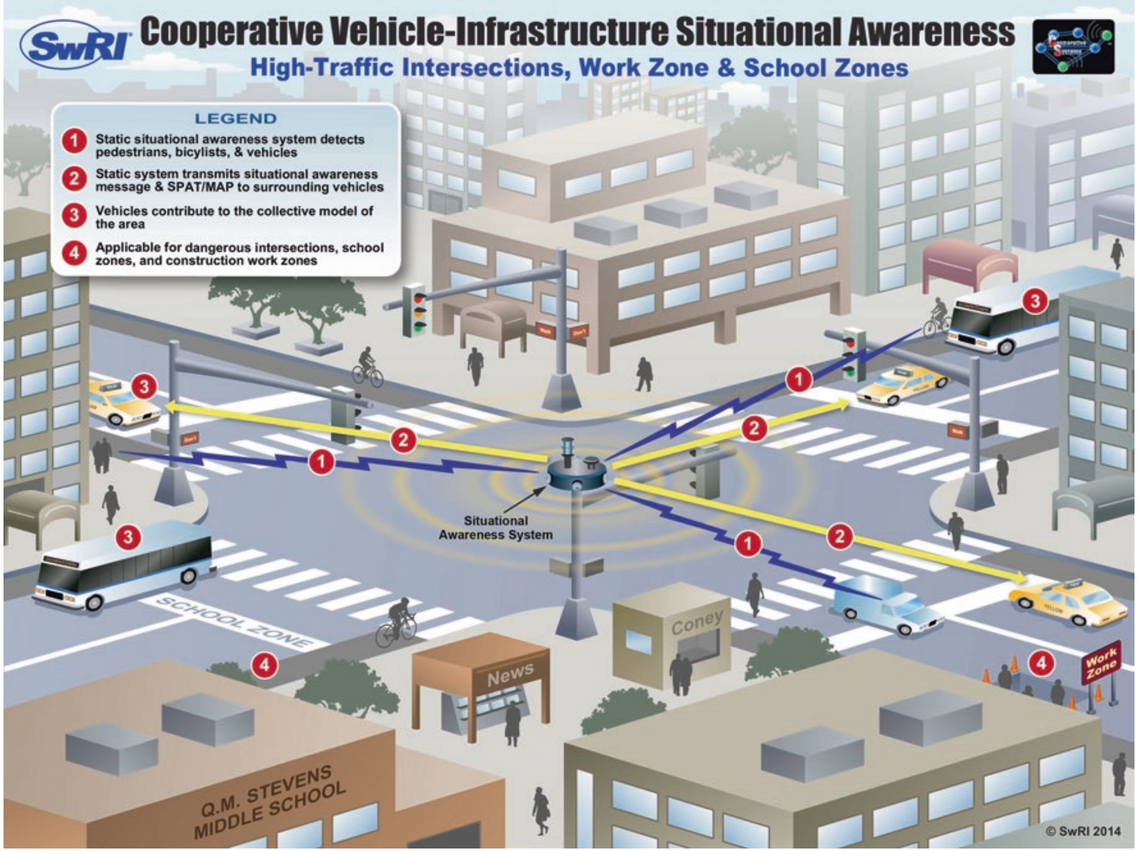

Fig. 4 Cooperative vehicle-infrastructure situational awareness

2.5 Integrated Corridor Management Systems

As ITS deployments become more mature and widespread, there is a growing need to augment these systems with decision support systems that regions can use to optimize the transportation network across modes. This capability is called integrated corridor management systems (ICMS) and is the wave of the future for smart transportation.

An ICMS collects data from a variety of public and private sector sources along a corridor, uses advanced modeling to predict the future state of the corridor if various actions are taken, and then takes the best course of action to optimize the flow of travelers along that corridor. Figure 5 provides an example of an ICMS in action. In the figure, accident detection and lane closures are used to redirect incoming traffic to alternate routes via connected-vehicle broadcast messages.

For example, consider the case shown in the following image in which a major accident has occurred on the freeway and traffic begins to back up significantly along the corridor. In an ICMS, the decision support system (DSS) will monitor the flow of traffic along the freeway and arterials, predict the future state of various potential scenarios (including rerouting traffic along arterials), then implement the best course of action. In this case the DSS routes traffic along the arterials while interfacing with the arterial signal systems to optimize the signal timing to allow the most traffic to flow along those arterials.

Following the event, the DSS can compare the impacts of the implemented response plan with the predicted impact. Machine learning techniques along with traffic engineering expertise can be utilized to tweak the capabilities of the system such that there is continual improvement in the ICMS in response to future events. This capability can be extended across many other modes including rail and buses.

2.6 Powertrain Optimization

The applications discussed so far illustrate the ability of smart transport technology to improve safety and mobility of travelers throughout the transportation network, but what about environmental impacts and fuel efficiency? There is a growing amount of research into this very question and it leverages the early work of the applications for the environment: real-time information synthesis (AERIS) program [6] along with other USDOT initiatives. ARPA-e (the DOE's advanced research projects agency) has initiated a $30M program investigating various techniques that would combine to enable CAVs to achieve at least a 20% fuel efficiency gain by optimizing the powertrain based on connected vehicle data. Imagine if your vehicle could get a preview of the traffic flow ahead and then optimize its powertrain accordingly. For example, the vehicle could more intelligently traverse a corridor based on the signal timing and other surrounding vehicles. Another example is the ability to optimize the power split in hybrid engines to utilize more battery and less fuel.

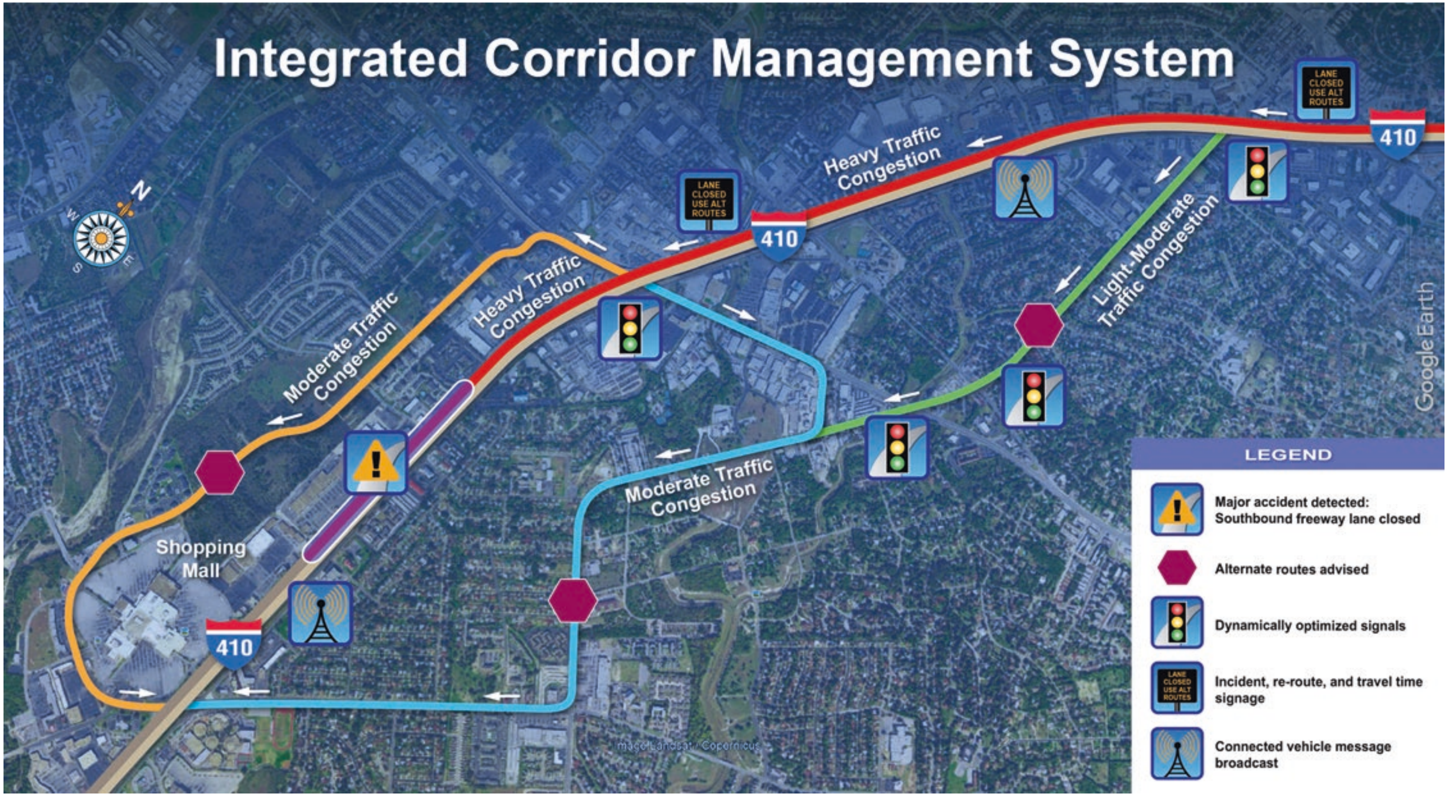

Fig. 5 Integrated corridor management system showing traffic diversions into alternate routes in response to an accident on the freeway

This capability is generating a lot of excitement not only in the passenger vehicle market but also in the heavy-duty vehicles. Large trucks and buses consume a significant amount of fuel and even a small savings can reduce their CO_2 emissions while simultaneously saving them significant amounts of money. Fuel is often the largest O&M cost for a fleet operator.

3 Enabling Technologies

So far, we've explored why smart transport is so vital to a smart city and what applications can be leveraged to improve transportation safety, mobility, and environmental impacts. Now let's look at "How?" What makes these applications tick and how can a city leverage these technologies without making investments in something that is quickly obsolete?

3.1 Navigating the Buzzwords

There are so many acronyms and buzzwords related to smart transport that it makes your head spin, e.g., ICT, IoT, 4G-LTE, DSRC, 5G, C-V2X, blockchain, cybersecurity, Wi-Fi, Li-Fi, OCC, NGV, 6G, deep learning, etc. The list is never-ending.

3.2 The Internet of Things

Let's begin to break these technologies down by starting at the highest level with communications systems architecture. For decades, smart transport systems have employed a strategy in which each agency deploys a certain amount of field equipment along the roadways and builds the network infrastructure to communicate with each device. Data from these field devices is collected and rolled up at the "center" level which typically refers to the building(s) that host the servers and communications equipment connecting the computer networks to the field networks.

This is how a traffic management center communicates with the cameras, message signs, traffic sensors, environmental sensors, and traffic signals that it maintains. The protocols used for this center-to-field (C2F) communication is sometimes proprietary but most often standardized in a National Transportation Communications for ITS Protocol (NTCIP) standard [7]. These protocols utilize a variety of existing communications media including fiber, cellular, Bluetooth, Wi-Fi, etc. The NTCIP C2F protocols are often based on older standards, such as the simple network management protocol (SNMP) [8]. Data that is collected from each center can be exchanged with other centers via the NTCIP center-to-center (C2C) protocol which

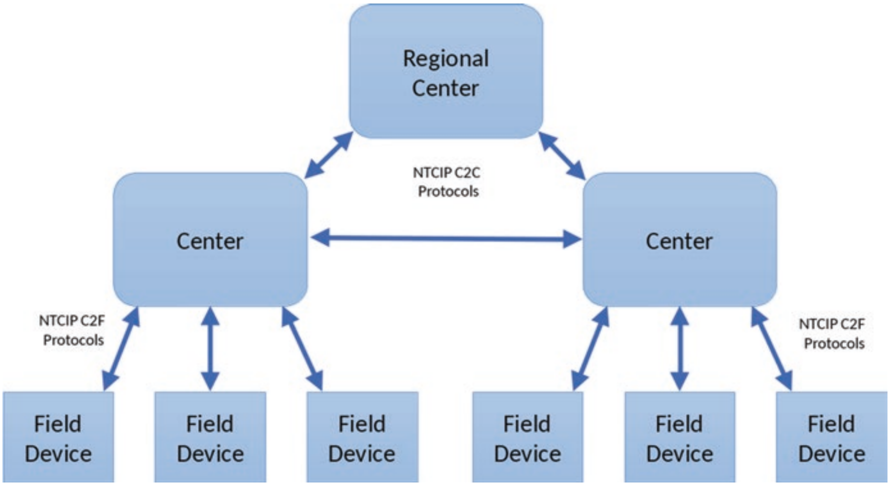

Fig. 6 Architecture showing how traffic management centers communicate with each other and with field devices

utilizes simple object access protocol (SOAP) [9] exchanging messages formatted in extensible markup language (XML) [10] compliant with the traffic management data dictionary (TMDD) [11]. This architecture is shown in Fig. 6, where the TMC locations communicate using "center to center" protocols, and field devices communicate with the TMCs using "center to field" protocols.

The term internet of things (IoT) simply refers to everything being connected to the Internet. Internet protocol version 6 (IPv6) allows an enormous set of available addresses such that even the tiniest of devices can have its own IP address and be accessible by any other device or system around the world. This increased addressing capability along with more and more communications bandwidth is facilitating a shift in communications systems architecture from this hub-and-spoke type model to a much more decentralized model. This architecture will realize itself soon by allowing systems to "share" resources such as ITS field equipment. For example, imagine a scenario in which a traffic management center has deployed traffic sensors along a corridor up to the point where another center has deployed its traffic sensors. To be able to calculate the travel time from one city to the other, a city must use the data collected from its traffic sensors along with data from the other center's sensors transmitted via the NTCIP C2C protocol. In a more decentralized architecture, each center can access the other centers' sensors directly to calculate the travel times that it needs to convey to those traveling along the corridor. A decentralized, interconnected communications architecture is shown in Fig. 7, where two field devices near the boundary of TMC centers communicate with both TMC sites.

This is just the tip of the iceberg, as sensors can be accessible to each center as needed allowing everything to communicate with everything. Furthermore, the

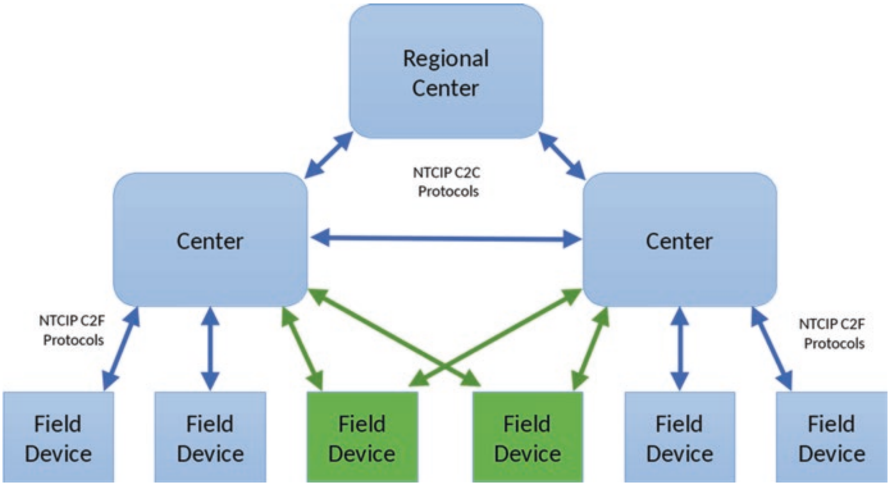

Fig. 7 Decentralized architecture where field devices are connected to multiple TMC sites

sensors are extending beyond just traditional traffic and environmental sensors and now even include mobile elements in the transportation system such as vehicles, bicycles, and pedestrians.

3.3 Vehicle-to-Everything

Modern vehicles are rolling sources of rich sensor data and can communicate this data with infrastructure as well as directly with other vehicles and road users. This is called vehicle-to-everything (V2X) communication and includes vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), and vehicle-to-pedestrian (V2P) communications. This capability extends the traditional intelligent transportation system from one that communicates with ITS field equipment to one that can collect data directly from vehicles and can communicate information directly to vehicles.

The communications media used for V2I communications can range from satellite and cellular for information that is not time critical to dedicated short-range communications (DSRC) and cellular V2X (C-V2X) for more time critical safety information that is localized. V2V communications is typically low-latency, small packets for higher reliability using DSRC or C-V2X. There are emerging technologies that utilize optical camera communications (OCC) which is a form of visible light communication (VLC) that modulates LEDs at a frequency higher than that visible to the human eye to transmit data from one source to another. Also, the evolution of DSRC is resulting in the development of next generation vehicular (NGV) communications which will support much higher data rates and packet reliability than DSRC.

3.4 Security

For a smart transport system to be effective, it must be secure. Elements within the transportation system must be able to trust information from other sources and must be resilient to hackers. To implement this security, messages that are exchanged with other elements are typically signed with a certificate that is provided by a security credential management system (SCMS). Currently the USDOT makes available a prototype SCMS that can be used for federal research pilots and there are also commercial alternatives emerging to support a full deployment. Some communications may contain personally identifiable information (PII) and often these data flows are also encrypted to ensure privacy. Other mechanisms are in place to ensure privacy by rolling over identifiers throughout the communications stack to ensure that vehicles or pedestrians are not able to be tracked for times longer than those critical to the safety applications.

Besides just the communications security of the transportation network, physical security of the ITS network is essential. Research that is combining all aspects of transportation system security is being conducted to develop guidance for state and local transportation agencies on mitigating the risks from cyber-attacks on the field side of traffic management systems (including traffic signal systems, intelligent transportation systems, vehicle-to-infrastructure systems (V2I), and closed-circuit television systems) and, secondarily, on informing the agency's response to an attack [12].

3.5 Standards

Standards are the key to enabling interoperability and system longevity in smart transport. We touched a little on NTCIP standards in communications between TMCs and with the field equipment but there are many other standards that have been developed or are being developed by standards development organizations (SDOs) for smart transport. Some of the major SDOs involved include:

- Institute of Electrical and Electronics Engineers (IEEE) [13]
- Society of Automotive Engineers (SAE) [14]
- International Organization for Standardization (ISO) [15]

Despite the significant amount of standards work that has been done to date in this area, there remains a lot of work to be done in the future. These standards will continue to evolve and adapt to allow new technologies to be introduced into our transportation system. The relationships between the elements of a smart transport system and the standards that facilitate interoperable communications between them are illustrated by the diagram in Fig. 8, which was created by the V2I deployment coalition [16]. The figure depicts a "logical view" of the standards context prescribed by the American Association of State Highway and Transportation Officials (AASHTO) [17].

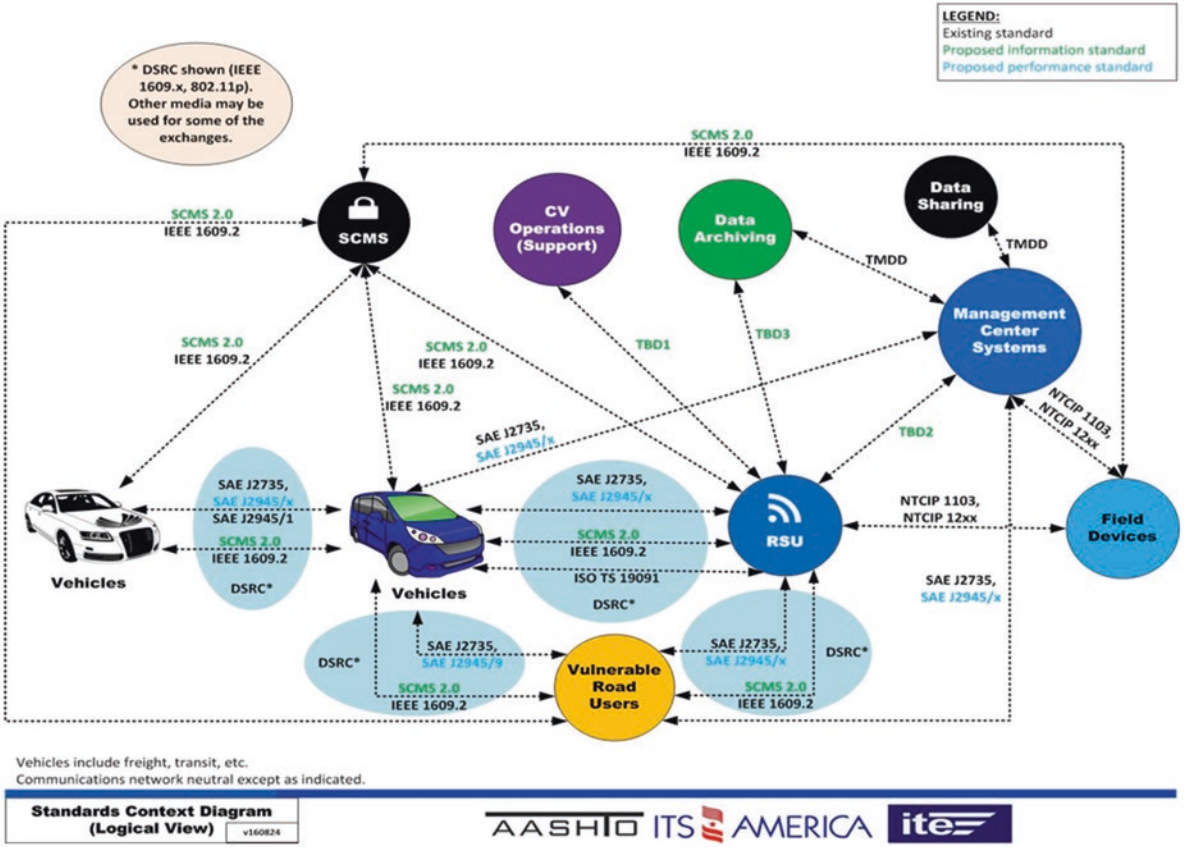

Fig. 8 Logical view of the AASHTO standards context

In the USA, several of the communications standards depicted depend on a 75 MHz band of wireless spectrum (5850–5925 MHz) that was set aside in 1999 by the FCC for ITS safety. This spectrum is currently under review by the FCC as the cable companies are pushing to have it opened for increased Wi-Fi access. In parallel, there is an on-going battle between competing technologies for V2X communications (DSRC and C-V2X) that currently has the ITS industry reliving the days of VHS and Betamax. Only time will tell if this critical portion of wireless spectrum will remain available for smart transport and which standards will be utilized for V2X. What we do know is that while we are sitting around and waiting, we are losing lives.

4 Conclusion

Smart cities around the world are continually working to deploy technologies that enable applications that can save lives, improve mobility, and reduce environmental impacts. Despite the many technical and funding challenges facing smart transport today, the resolve of this industry will prevail over time and we will see increasingly smarter transportation systems in the future. As we've explored the various aspects involved in smart transport, even though the "What?" and "How?" aspects remain somewhat fuzzy, the "Why?" aspect is crystal clear.

References

1. World Health Organization. Global status report on road safety 2015. http://www.who.int/violence_injury_prevention/road_safety_status/2015/en/
2. INRIX Global Traffic Scorecard. http://inrix.com/scorecard/
3. Kenney J (2011) Dedicated short-range communications (DSRC) standards in the United States. Proc IEEE 99:1162. https://doi.org/10.1109/JPROC.2011.2132790
4. Kinney S (2018) What is C-V2X? RCR Wireless News
5. Hill S (2018) 4G vs. LTE: the differences explained. Digital Trends
6. US Dept. of Transportation, Intelligent Transportation Systems Joint Program Office. Applications for the environment: real-time information synthesis (AERIS) program. https://www.its.dot.gov/research_archives/aeris/index.htm
7. National Transportation Communications for ITS (NTCIP). https://www.ntcip.org/
8. RFC 1157. A simple network management protocol. https://tools.ietf.org/html/rfc1157
9. W3C (2007) SOAP version 1.2 part 1: messaging framework. https://www.w3.org/TR/soap12/
10. W3C. Extensible markup language (XML). https://www.w3.org/XML/
11. Institute of Transportation Engineers. Traffic management data dictionary (TMDD) and message sets for external traffic management center communications (MS/ETMCC). https://www.ite.org/technical-resources/standards/tmdd/
12. National Academies of Science. Cybersecurity of traffic management systems (NCHRP 03-127). http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4179

13. Institute of Electrical and Electronics Engineers (IEEE). https://www.ieee.org/
14. Society of Automotive Engineers (SAE). https://www.sae.org/
15. International Organization for Standardization (ISO). https://www.iso.org/home.html
16. National Operations Center of Excellence. Vehicle to infrastructure deployment coalition (V2I DC). https://transportationops.org/V2I/V2I-overview
17. The American Association of State Highway and Transportation Officials (AASHTO). https://www.transportation.org/