
Safer Mobility Through V2X Communication

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Keynote: ScooterLab Workshop 2026

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University of Texas at San Antonio

Outline

- V2X basics: terminology, what it is
- What is V2X for? How does it work? Do we need it?
- Safety and VRUs
- V2X and VRUs. The V2X deployment challenge

A Word About Toyota InfoTech and Me

Toyota InfoTech Labs

We are: An applied research division of
Toyota Motor North America R&D

Vision: Creating a connected mobile society

Location: Mountain View, CA, US

Established: April 2001

John Kenney

- Joined Toyota 2007
- Focus: V2X Communication
- Activities include:
 - Research (V2X, Congestion Control, Protocols, Performance)
 - Standardization (IEEE, SAE, ETSI),
 - Industry (ITS America, Alliance for Auto Innovators, Car2Car Communications Consortium)
 - Government: (FCC, US DOT, US Congress)



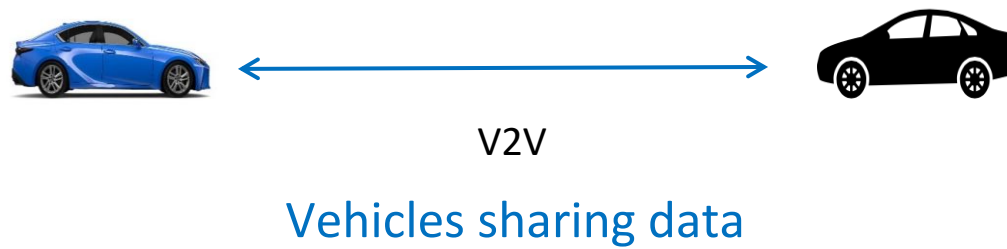
Start with an idea:

- What if vehicles could communicate with each other (wirelessly)?
- What if vehicles could use communication to improve awareness?
- What if awareness led to safer and more efficient roadways ...
... and facilitated automated driving?
- What if vehicles could COOPERATE with everything in their environment?

- We'll call this Cooperative Intelligent Transportation Services (C-ITS)

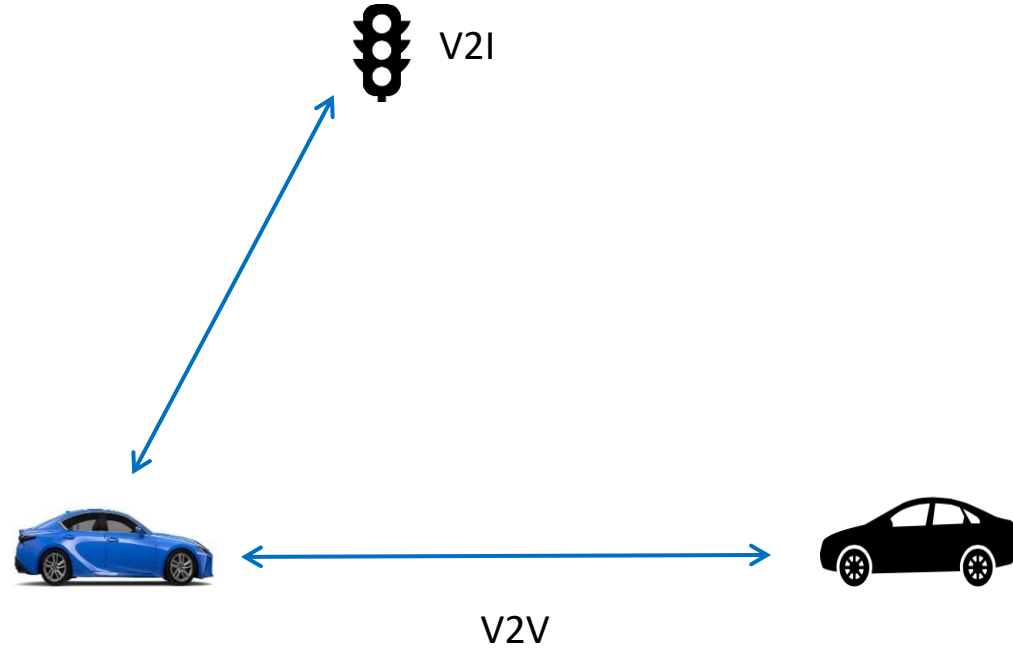
V2X is ...

V2X system on a vehicle is called an On-Board Unit (OBU)



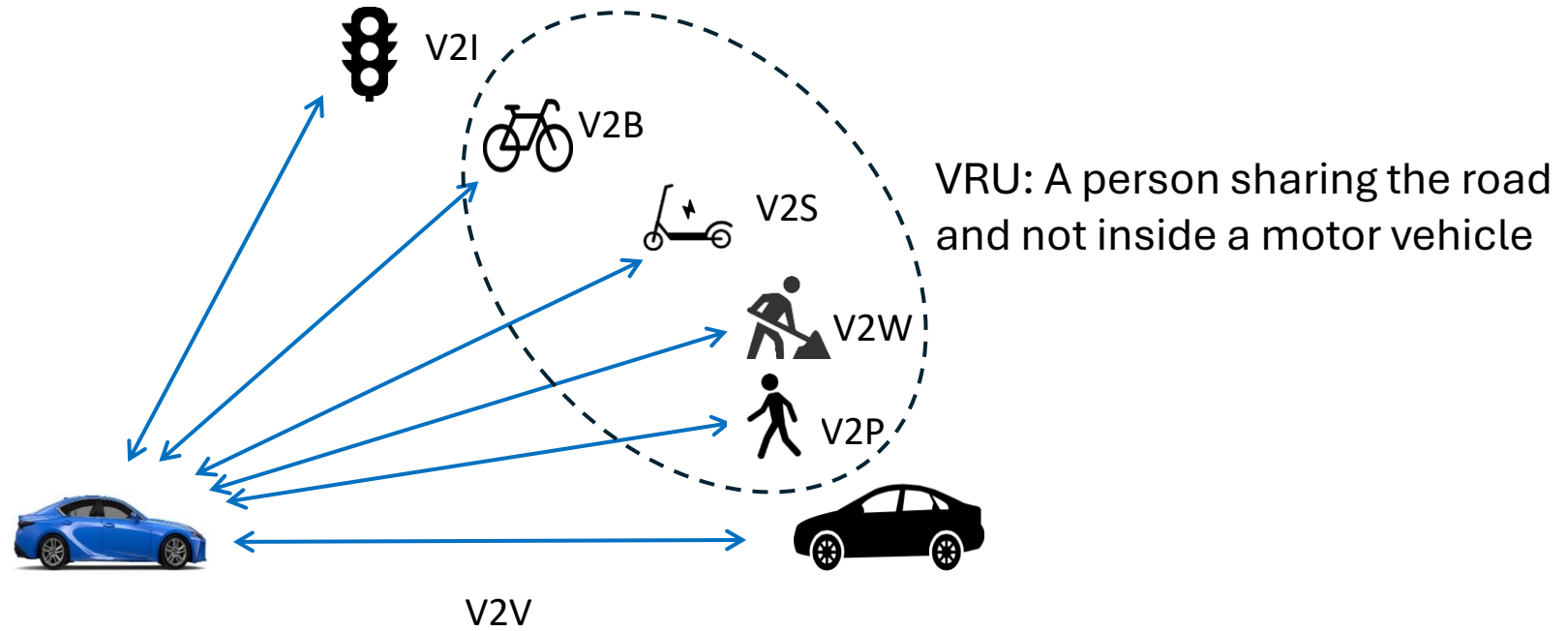
V2X is ...

Infrastructure V2X system is called a RoadSide Unit (RSU)



Vehicles communicating with roadside infrastructure

V2X is ...

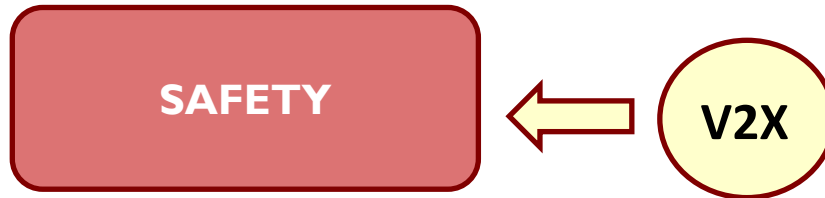


Vehicles communicating with Vulnerable Road Users (VRUs)

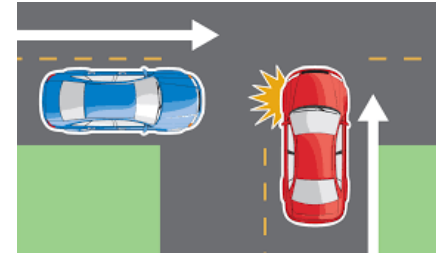
V2X is good for ...

Example Applications

V2X addresses 80% of crash scenarios - USDOT



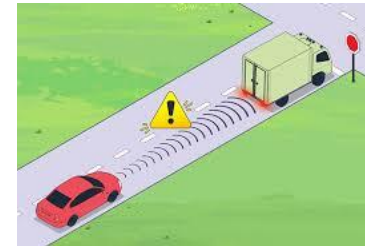
IMA: Intersection Movement Assist



LTA: Left Turn Across traffic



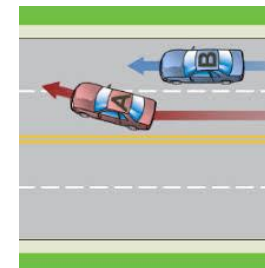
FCW: Forward Collision Warning and
EEBL: Emergency Electronic Brake Lights



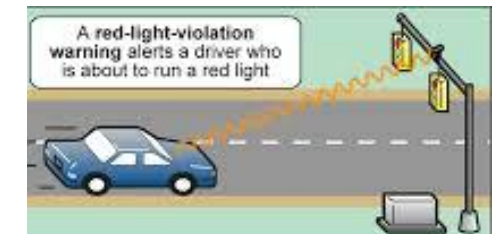
DNPW: Do Not Pass Warning



BSW: Blind Spot Warning



RLVW: Red Light Violation Warning



All are V2V except RLVW (I2V)

V2V Safety Paradigm (using US terms)

- **Transmit:** Each vehicle broadcasts *Basic Safety Messages (BSMs)* frequently in all directions.
- **Assess:** Receiving vehicles assess collision threats
- **Warn:** Warn driver or take control of car

SAE J2735 Basic Safety Message

Core BSM contents:

Position & Time

Speed

Heading

Acceleration

Brake Status

Size

Path history & prediction

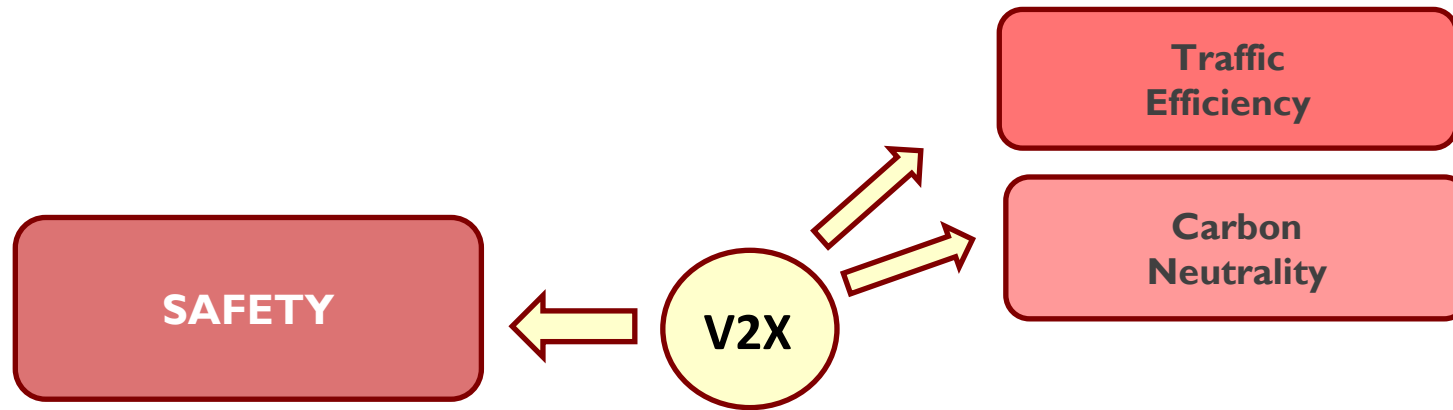
Event flags

The BSM supports all of the V2V collision avoidance applications on the previous slide



V2X is good for ...

Improving traffic goes hand-in-hand with reducing emissions

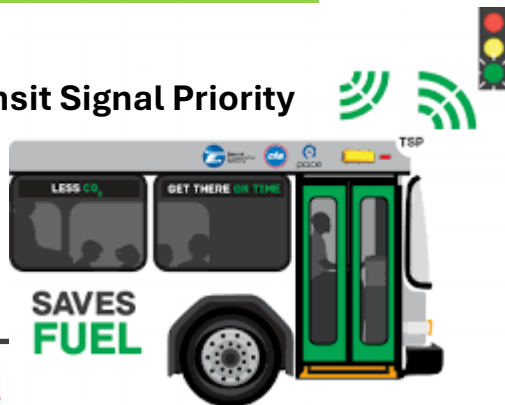


C-ACC: Cooperative Adaptive Cruise Control

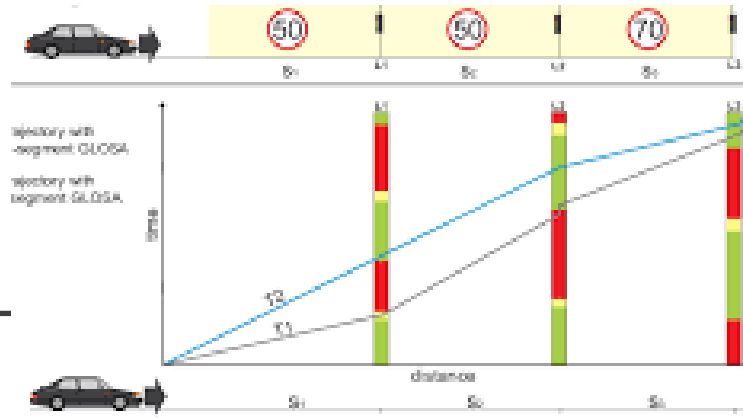


Example Applications

TSP: Transit Signal Priority



GLOSA: Green Light Optimal Speed Advisory

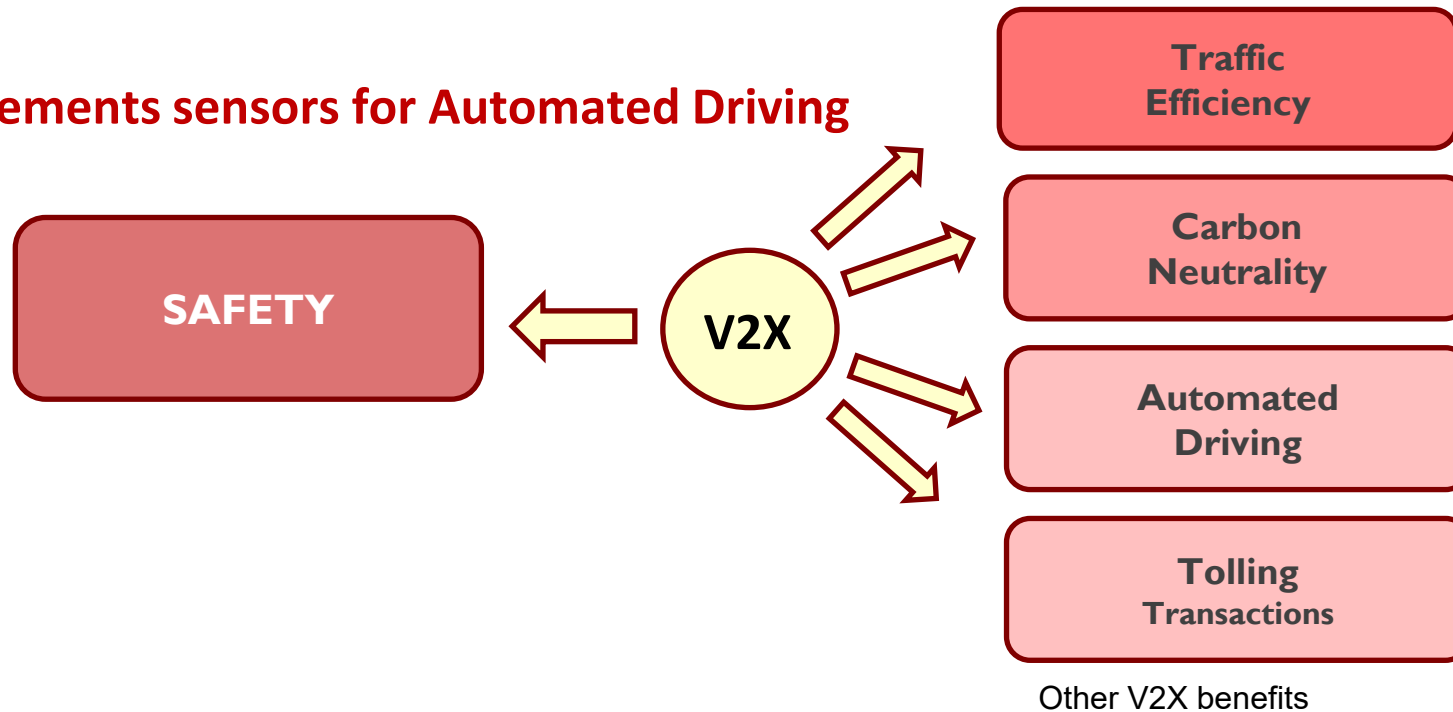


Platooning



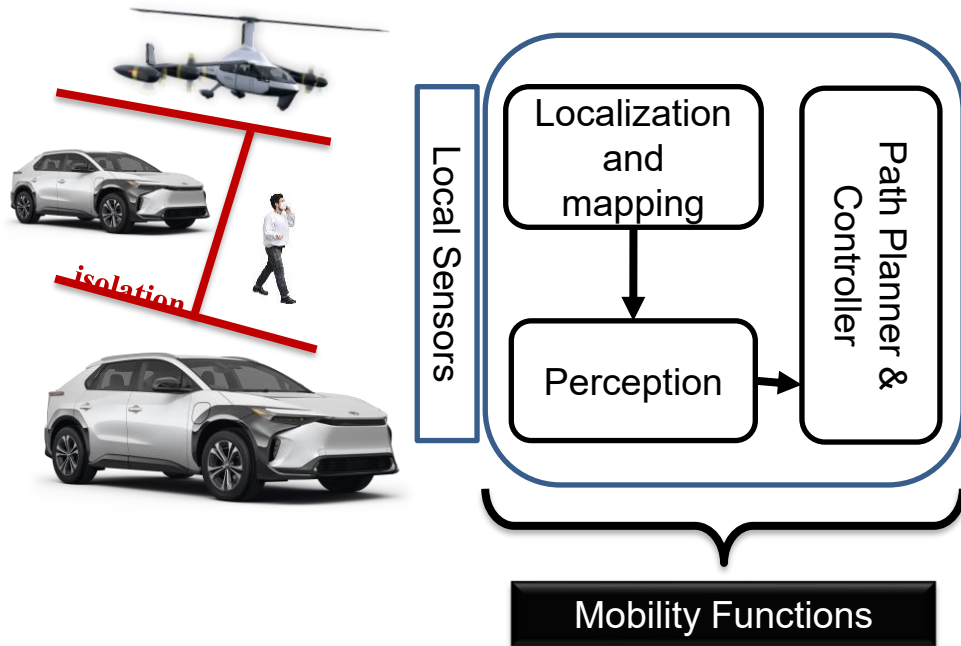
V2X is good for ...

V2X also complements sensors for Automated Driving

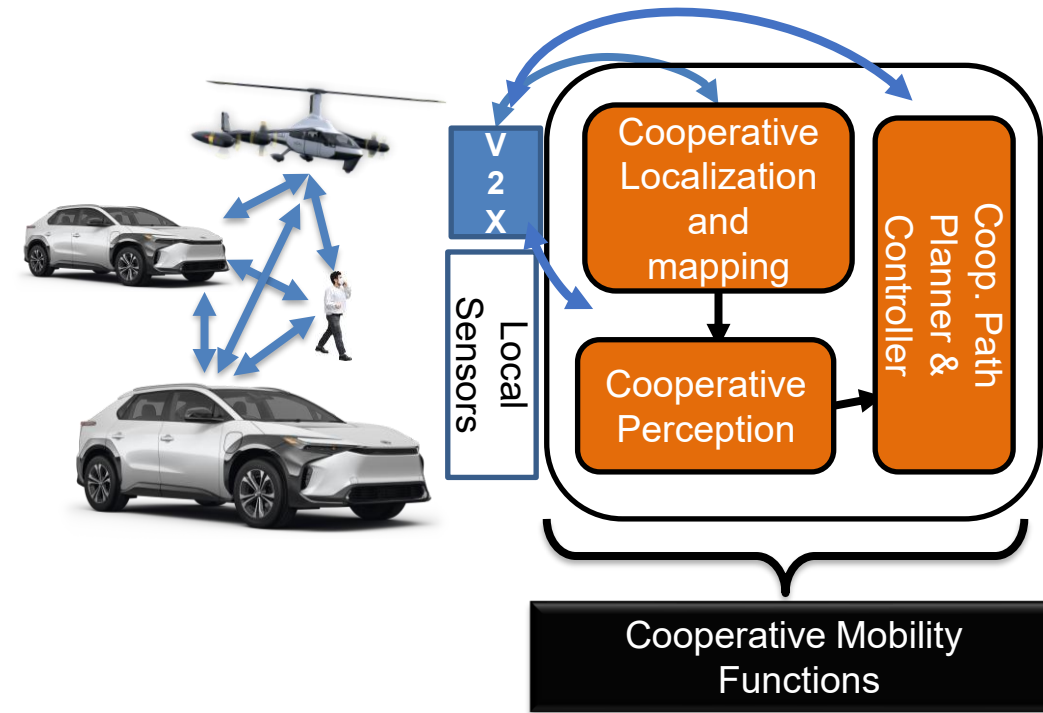


Key automated driving functions can be enhanced with Cooperation

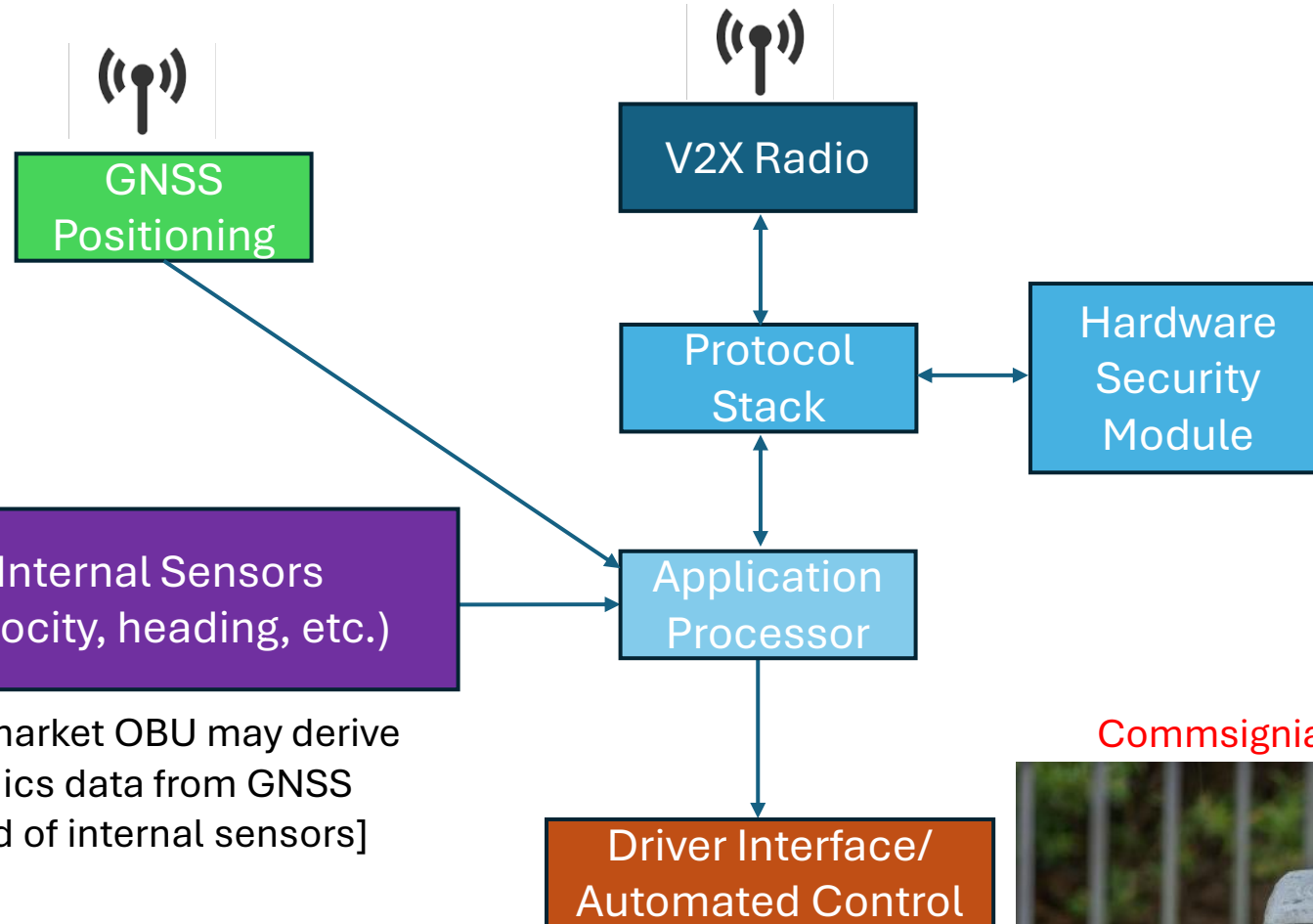
Traditional AD Approach



Cooperative AD Approach



How does V2X work? Components of an OBU



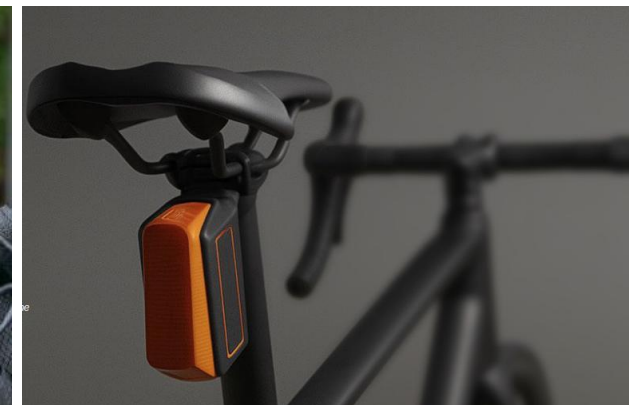
[Aftermarket OBU may derive dynamics data from GNSS instead of internal sensors]

- A VRU device might be simpler
- Example: if only broadcasting and not receiving
- Pedestrian might participate through smartphone capable of using V2X spectrum band

Commsignia: [OBU Lite](#)



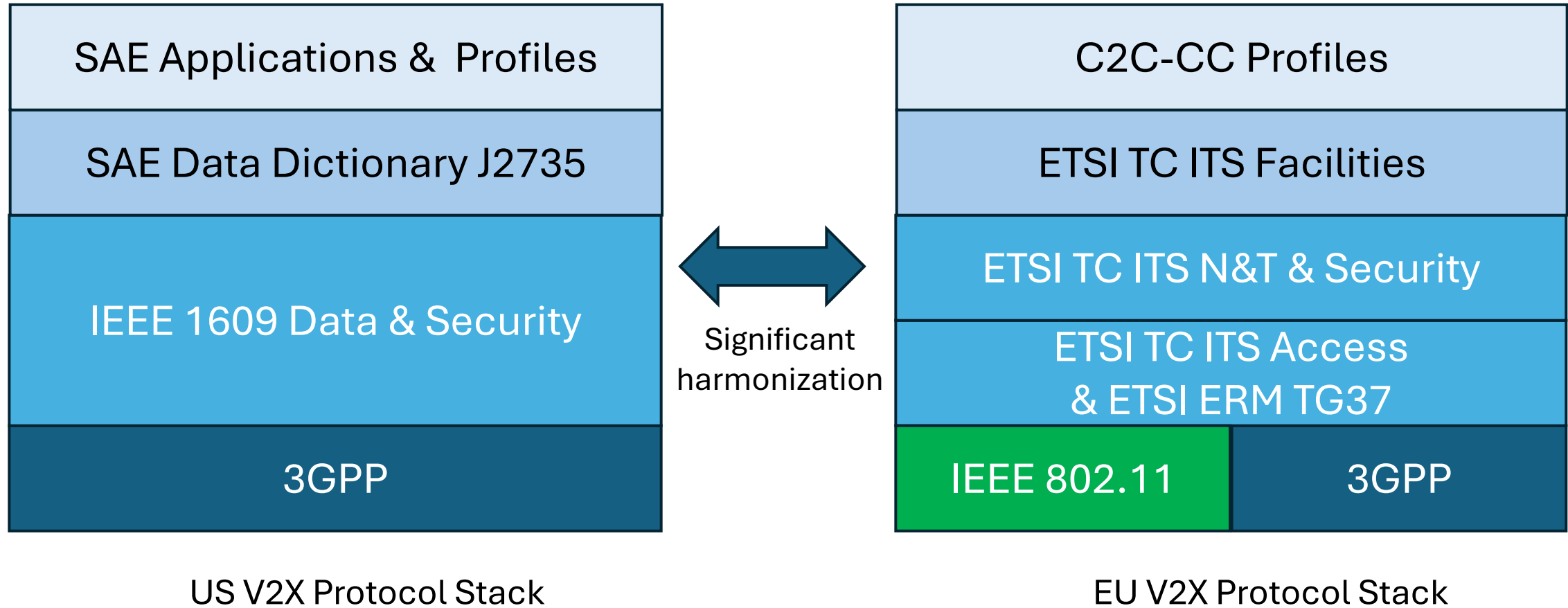
Spoke Safety: [Zone](#)



V2X Standards

- Communication protocols require standards to achieve interoperability across suppliers
- Examples:
 - IEEE 802 for LANs (Ethernet, Wi-Fi),
 - 3GPP cellular: 3G, 4G LTE, 5G New Radio, and now 6G generations
 - IETF for Internetworking standards (IP, TCP, UDP, Routing, etc.)
- The requirement for standards in V2X is even more acute because V2X communication is **ad hoc**, not centrally managed or controlled (no base station, no access point)
- Typically the transmit behavior is standardized, and the receive behavior is left open for implementation flexibility
 - Example: we standardize sending BSMs but not what a receiving vehicles does with them

V2X Protocol Stacks for US and Europe



In addition, there are test and certification specifications not shown

C2C-CC = Car2Car Communications Consortium, ETSI = European Telecommunication Standards Institute

Families of low layer V2X Technology

Japan
Europe

IEEE

- Reuses Wi-Fi protocols
- Modified to omit Access Point

Two generations:
802.11p – 2010
802.11bd - 2023

Known as **ITS-G5** in Europe

US
China

3GPP 4G

- Reuses LTE protocols
- Modified to allow device-device “sidelink”

Release 14 - 2017
(with Rel. 15
enhancements)

Possible future use
in Japan and Europe

3GPP 5G

- Reuses “New Radio” protocols
- Modified to allow device-device “sidelink”

Release 16 - 2020
(with Rel. 17-19
enhancements)

Collectively known as **Cellular V2X (C-V2X)**
though the protocols cannot interoperate or coexist

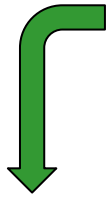
Note: No V2X work is planned as part of 6G

Interesting
Evolution
Challenges

V2X relation to other technologies: Complementary



V2X complements



ADAS

Sensor-based safety

V2X complements ADAS with:

- Non-line-of-sight
- Longer Range
- Higher Accuracy
- Future Intent

V2X complements



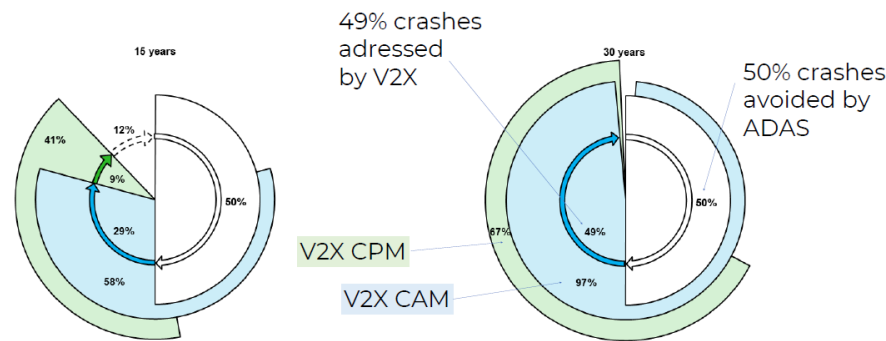
Connected Services
Long range cellular-based

V2X complements long range with:

- Extremely low latency communication
- Free communication
- Scalable communication
- Privacy-by-design

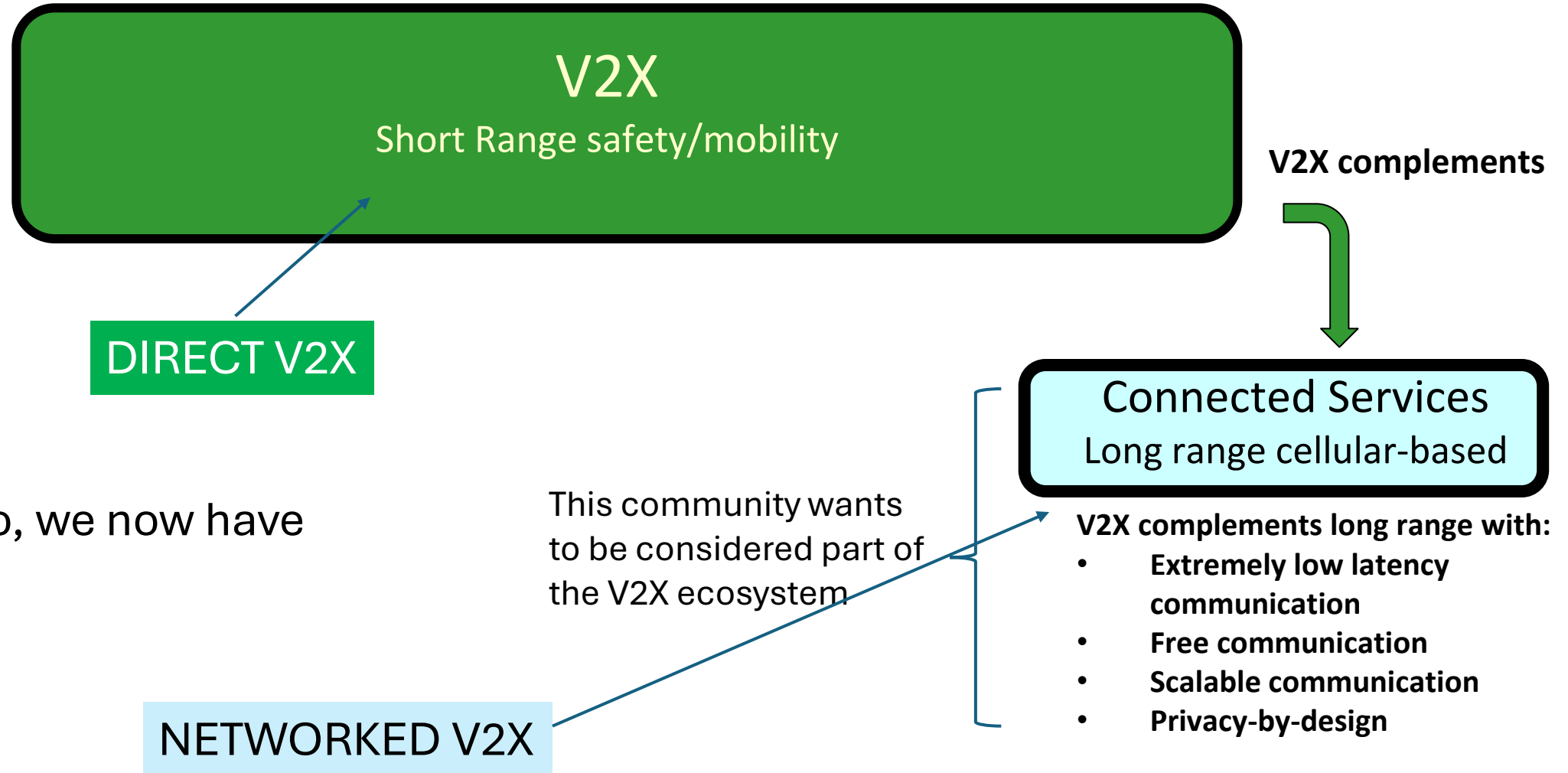
Continental Study

V2X can close the safety gap
Vehicle vs vehicle crashes studied in Germany, USA, Japan



Source: [REDUCING FATALITIES IN ROAD CRASHES IN JAPAN, GERMANY, AND USA WITH V2X-ENHANCED ADAS](#), Harald Feifel, Bettina Erdem, Dr. Marc Menzel, Robert Gee, paper on Enhanced Safety of Vehicles International Technical Conference 2023

Further refinement of V2X Terminology



V2X Security & Privacy

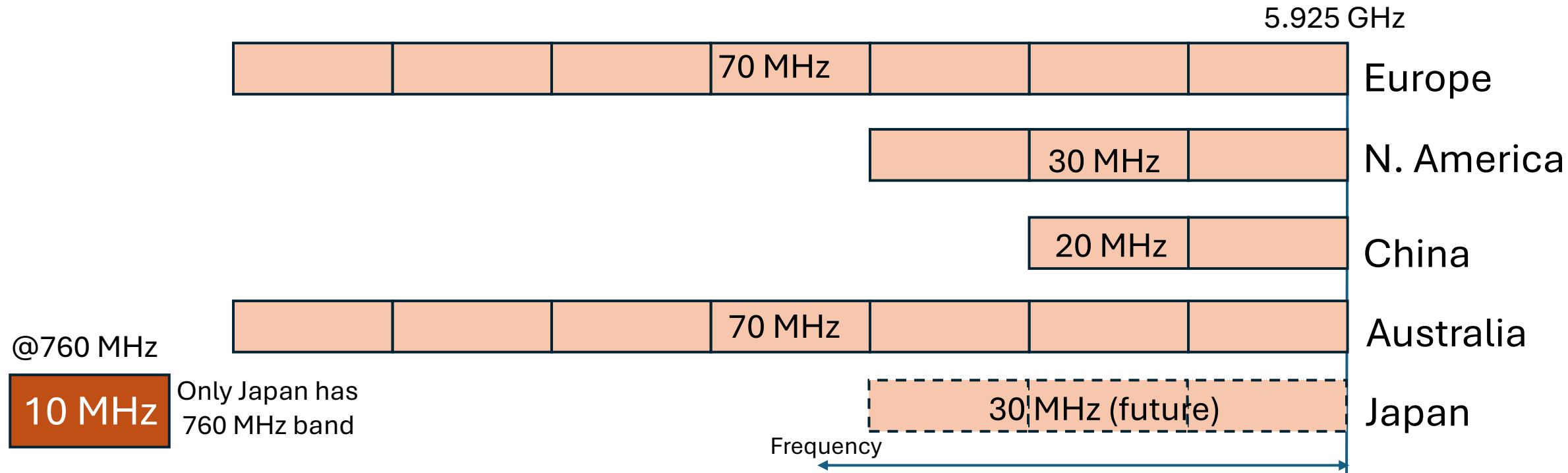


Privacy is
Essential

- V2X devices share potentially sensitive data (location, speed).
- They do this anonymously to protect driver & vehicle privacy
 - No personal or vehicular identifying information in BSM, for example
- Privacy Goals:
 - No single message can be linked to a vehicle/driver
 - No pair of messages can be linked to each other if sent more than a few minutes apart
- But, a receiver needs to know that a message came from an authorized sender. So, we need both **Authentication & Privacy**
- Solution: Sender digitally signs outgoing message, using a private key. Sender also includes certificate with public key
 - This is traditional PKI, but the certificate is **pseudonymous**, a temporary ID
- Authentication: Receiver uses public key to authenticate signature, proving that the sender was authorized and the content was not modified after signature.
- To avoid long term tracking: Keys, Certs, and all IDs (e.g. addresses) are changed frequently to prevent tracking.

V2X Spectrum

The world is harmonized* on the “5.9 GHz” band for V2X



Putting V2X band size in perspective relative to Wi-Fi bands in many places

Let's talk about safety:

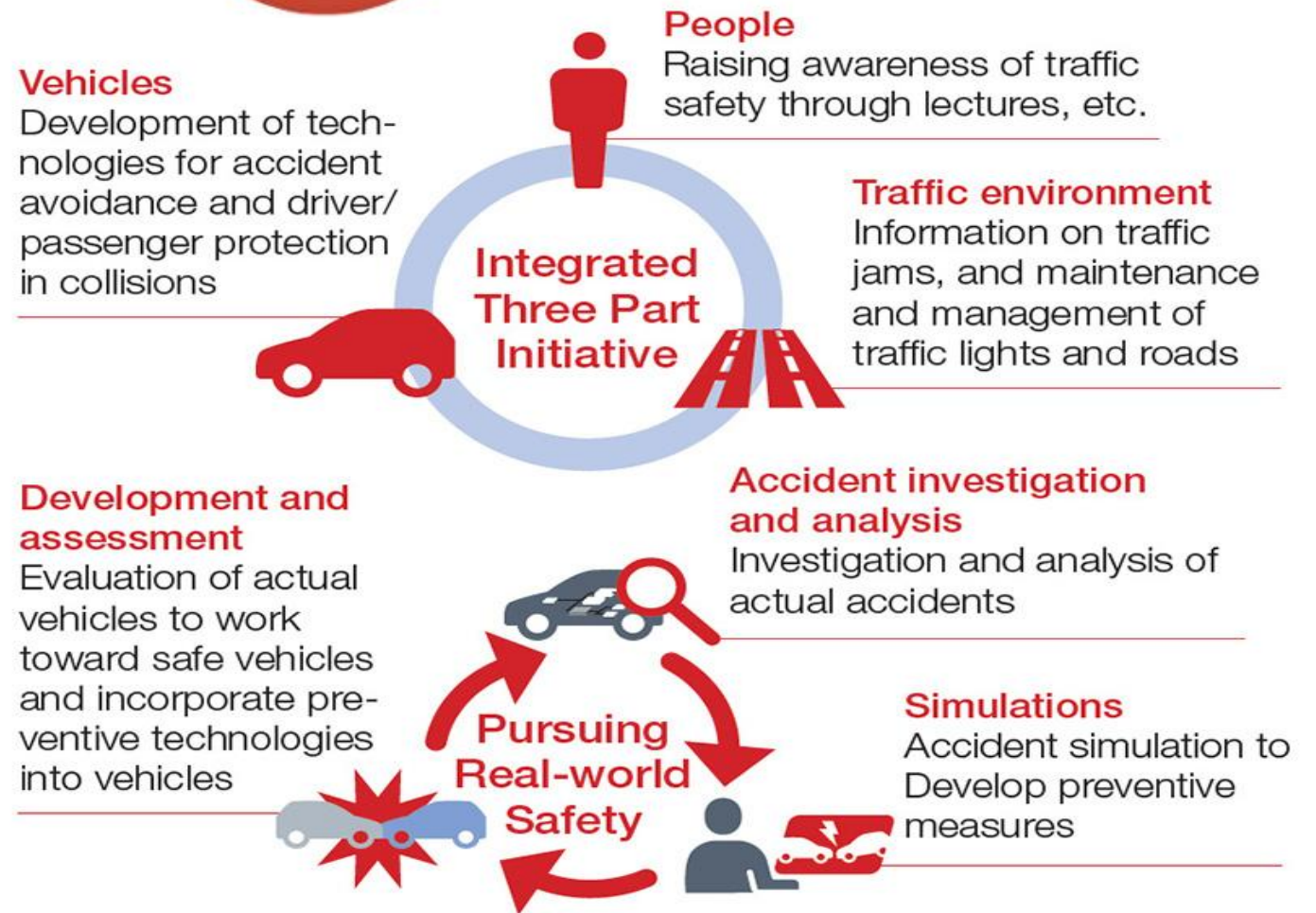
TOYOTA Vision Zero



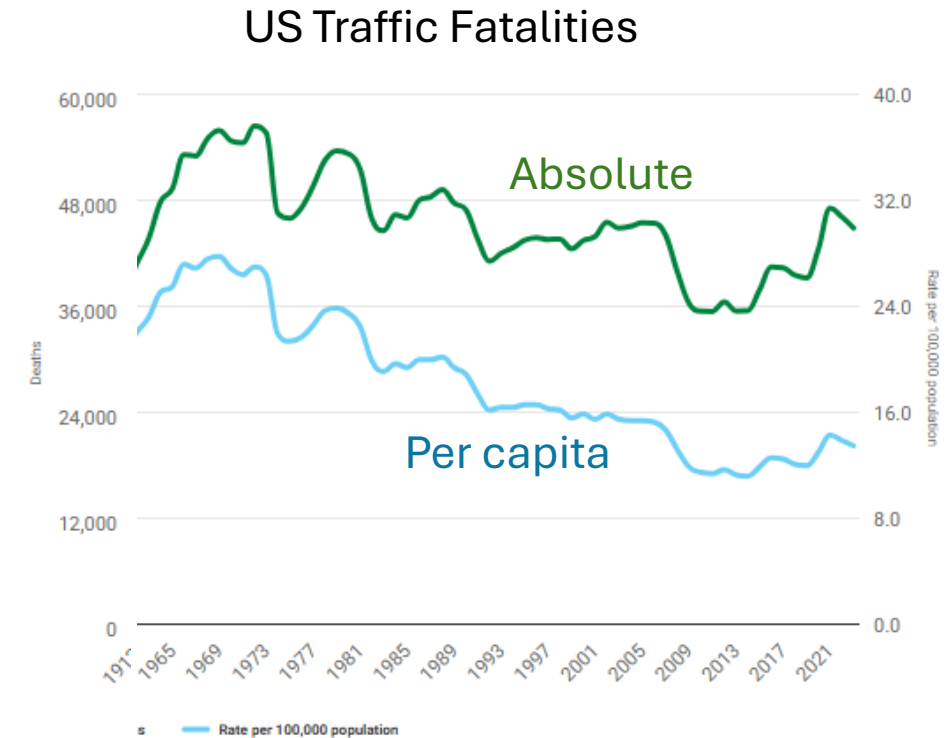
Ultimate Goal:
Elimination of Traffic Accident Casualties

Toyota's Safety Approach
Integrated Safety: Vehicle-Traffic-People

How do we do it?
Sensing, Communication, and Cooperation



We need to do more – Safety improvements stagnating

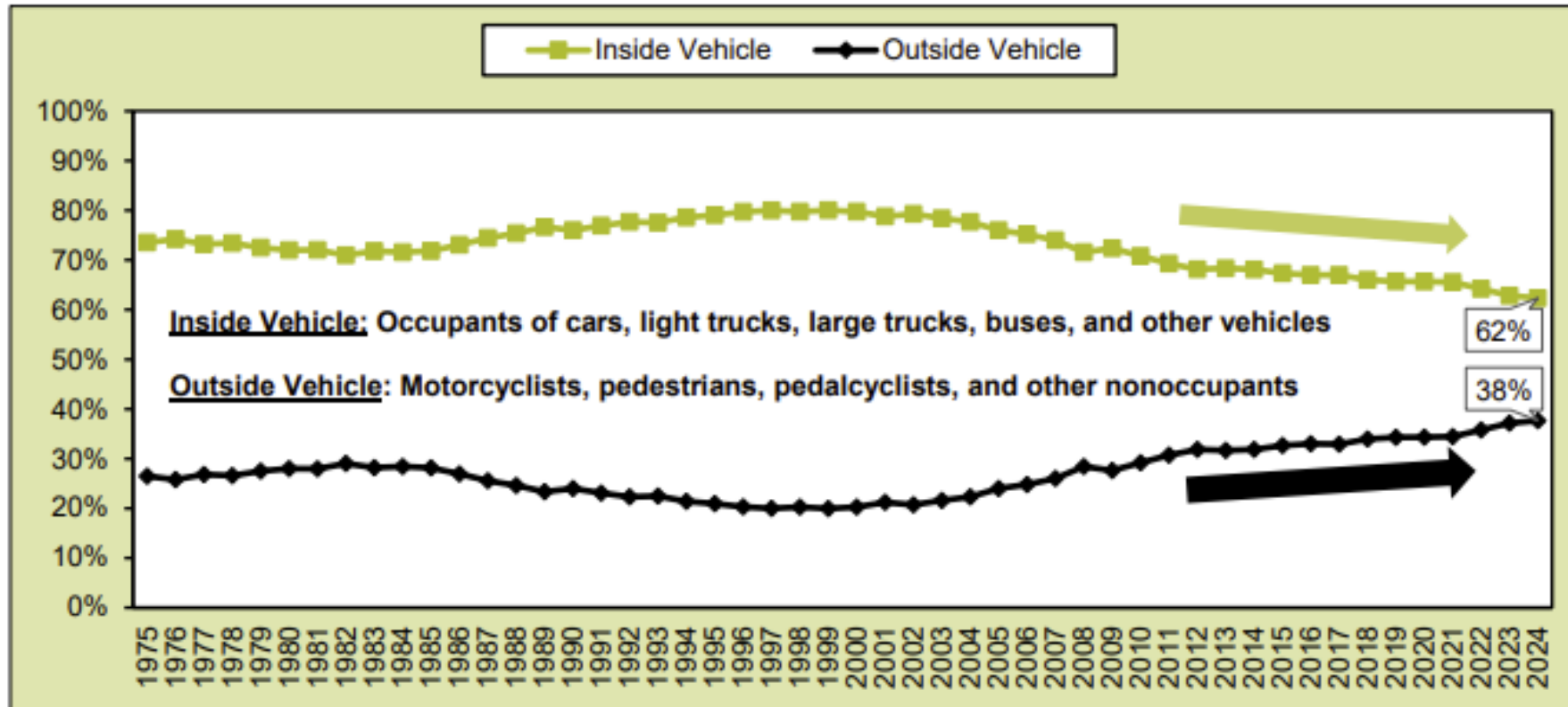


<https://injuryfacts.nsc.org/motor-vehicle/historical-fatality-trends/deaths-and-rates>

Despite progress since 2022, fatality rates are still too high and leveling off.

And VRUs account for higher percentage each year

Figure 3. Proportion of Traffic Fatalities Inside/Outside Vehicles, 1975-2024



Source: FARS 1975-2023 Final File, 2024 ARF

<https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813791>

Scooter injuries are increasing, and tend to be serious



Micromobility Products-Related Deaths, Injuries, and Hazard Patterns: 2017–2022

Key stats:

Accidents involving powered scooters led to **169,300 ER visits & 111 fatalities**

<https://www.cpsc.gov/s3fs-public/Micromobility-Products-Related-Deaths-Injuries-and-Hazard-Patterns-2017-2022.pdf>



Key stat: Serious scooter injuries: 2023 = 69,329;

2024 = **118,485 [71% increase]**

<https://www.usatoday.com/story/news/nation/2025/08/04/e-scooter-safety/85347698007/>



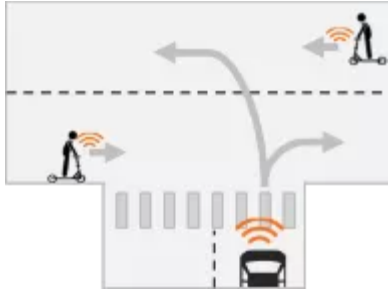
Key stat: Scooter-related injuries are **increasing at 45% per year** in Michigan

<https://www.michiganautolaw.com/blog/2025/06/16/electric-scooter-accidents/>

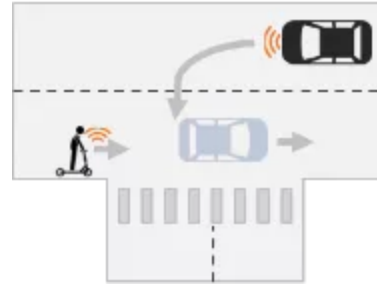
Can V2X help? Almost certainly

Returning to Vehicle-to/from-Scooter use cases

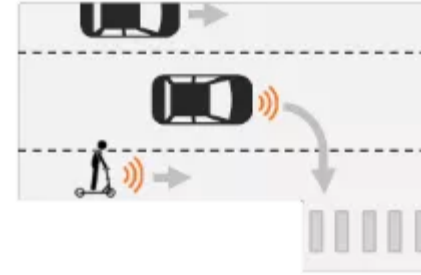
Source: Qualcomm/Autotalks - <https://auto-talks.com/products/tekon3-bike/>



Intersection Collision Warning



Left Turn Assist



Right Turn Assist



Rear Collision Warning

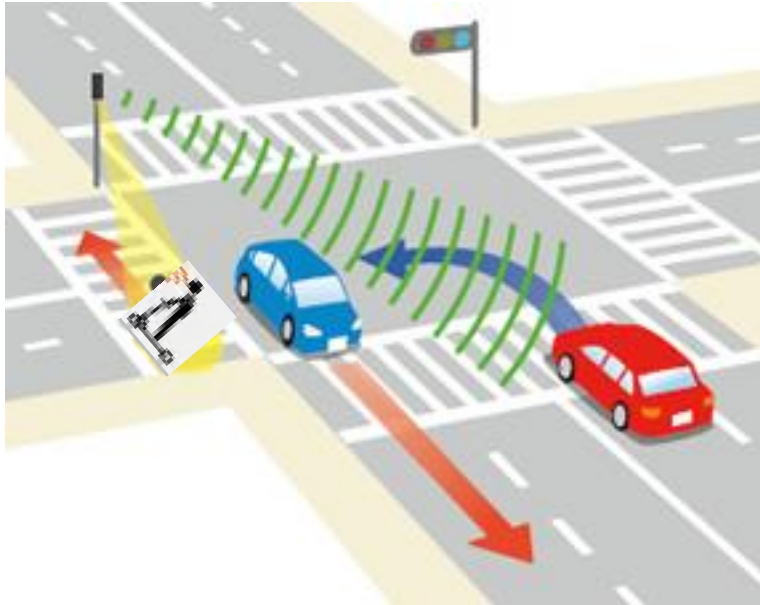
In each use case, awareness of Scooter is achieved through **message broadcast**

- Either a specialized version of Basic Safety Message
- Or a purpose-standardized VRU awareness message
SAE Personal Safety Message (PSM), ETSI VRU Awareness Message (VAM)

VRU/Scooter could also receive and process vehicle BSMs, but that increases complexity and cost of VRU device

An alternative approach to VRU protection: Proxy

1. Equip intersection with VRU sensors (camera, lidar)
2. When infrastructure knows a vehicle is on a path that intersects a VRU, RSU sends the vehicle a warning I2V
3. Thus, the infrastructure speaks for the VRU as a proxy, even if the VRU is unconnected



This is already used in Japan

SAE is standardizing this approach via:

J3224 – Sensor Data Sharing Message (SDSM)

J3224/1 – Profile for Infrastructure Sensor Sharing

Source: ITS Connect https://www.itsconnect-pc.org/en/about_its_connect/service.html

V2X Deployment Status

- **Europe** is leading the way (began 2019):
 - More than 2.5 million equipped vehicles. About 10,000 Roadside Units (RSUs) via C-ROADS consortium
 - Regulations are technology agnostic. **ITS-G5 (IEEE)** is deployed
- **Japan** has More than 700,000 equipped vehicles (began 2015)
 - Uses **IEEE** technology @ 760 MHz
- **China** has ~100k active equipped vehicles
 - Uses **3GPP LTE V2X**
- **United States** has thousands of RSUs and very few vehicles
 - FCC changed from IEEE to **3GPP LTE V2X** in 2024 – more below
- **Australia** moving toward deployment (will follow EU standards)
- ... Other regions are serious (India, Korea)

More on US Deployment: *“The first shall be last ...*



2012: All is good. 75 MHz ITS Band. Successful large scale field trial. Kumbyah



2013: Wi-Fi says “we want most of your spectrum”. FCC sympathetic.



2014: GM announces intent to deploy in 2017

NHTSA decides to pursue V2V mandate based on 802.11p



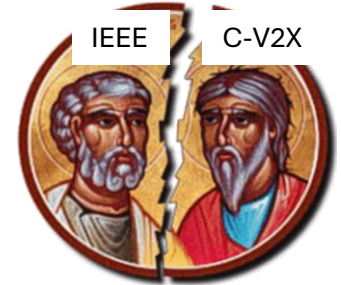
2015-16: Mandate momentum slows

2017: Mandate dies. GM deploys. LTE V2X Release 14 standard complete

Technology Schism



2018: Toyota announces intent to deploy 802.11p in 2021. FCC Criticizes Toyota
5GAA asks FCC to split spectrum into 802.11p, LTE V2X, and 5G NR parts.

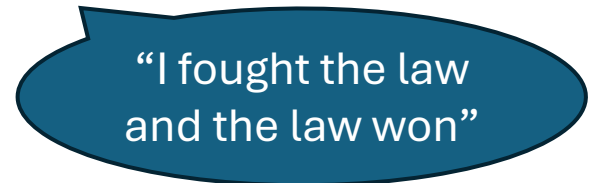


2019: Toyota pauses deployment plan due to “regulatory uncertainty” and OEM divisions

2020: FCC issues 1st new 5.9 GHz rules. Gives 45 MHz to Wi-Fi. 30 MHz remain for V2X.
Switching from 802.11p to LTE V2X in 2nd rulemaking



2024: FCC issues 2nd and final 5.9 GHz rules. Regulatory certainty
USDOT issues V2X deployment plan with RSU and OBU goals



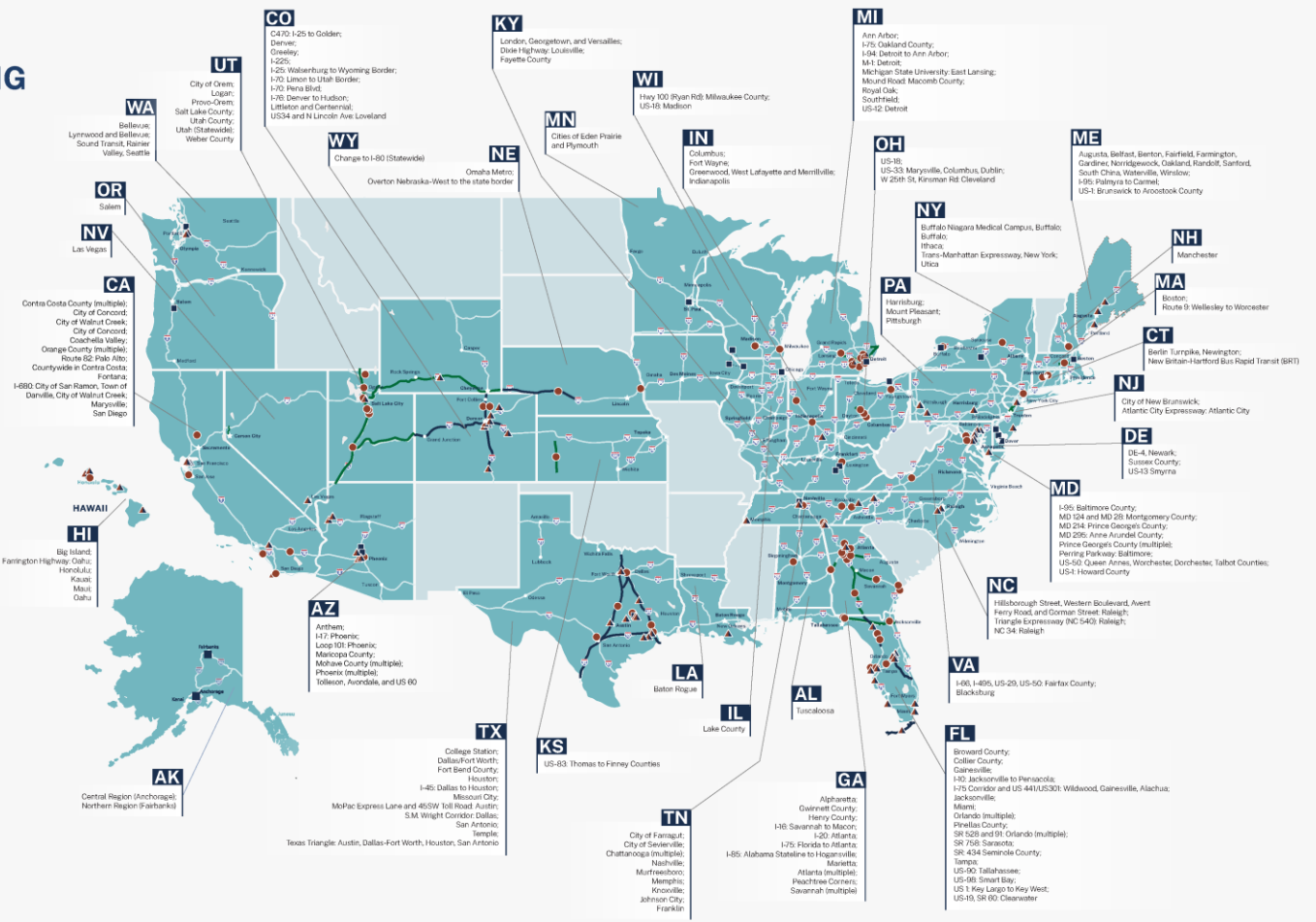
US RSU deployment starting to recover

ACCELERATING VEHICLE-TO-EVERYTHING (V2X) DEPLOYMENTS

Last Updated March 2026

KEY

- STATES WITH V2X DEPLOYMENT
- DIRECT V2X
- NETWORK V2X
- NETWORK V2X AND DIRECT V2X
- CORRIDOR - DIRECT V2X
- CORRIDOR - BOTH DIRECT & NETWORK V2X



Deployment is in the tri state border area of the below hvys/counties:

- Dubuque County, IA (US Hwy 20, 52, 61, and 151);
- Jo Davis County, IL (US Hwy 20);
- Grant County, WI (US Hwy 61, 161)

31 US states have some Direct V2X

U.S. Department of Transportation **March 2026**

USDOT RSU and OBU goals

By year	Inter-sections	OEMs
2028	20%	2
2031	47%	
2036	75%	6

Recent USDOT plans about updating: Saving Lives with Connectivity: A Plan to Accelerate V2X Deployment USDOT, August 2024



Static Map: <https://www.its.dot.gov/scrc/#/technology-areas/v2x/map>

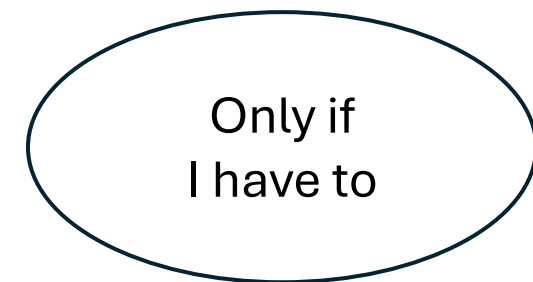
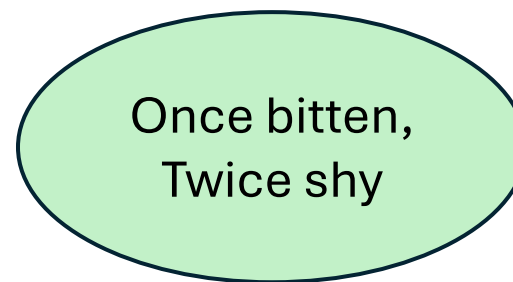
Dynamic Map: <https://maps.dot.gov/portal/apps/experiencebuilder/experience/?id=38c9701360df435c9e8db53511fa8b5f&page=V2X-Deployments>

Deployment Challenges for Cooperative ITS

Fundamentally different from non-cooperative technology

- Cost model is easy. Benefits to our customers are significantly unknown and changing over time. **Depend on decisions of others.**
- First-to-market advantages are missing
- Regulators can and have disrupted deployments
- New technologies (sensors, cellular services) impact analysis

A model for OEM attitudes after FCC changed 5.9 GHz rules



Deployment strategies

Mandate Model

- No decisions needed
- No competitive disadvantage

Strong Incentives Model

- NCAP
- If-Equipped Std
- Strong funding

All Jump Together Model

- MOU among stakeholders
- Shared risk
- Funding from Gov't
- Time frame known, reduces supplier risk

Leader jumps first Model

- Leader best able to absorb risk
- Chain reaction as risks fall and incentives grow
- Funding from Gov't

You're on your own Model





This is where we seem to be in most regions

How do VRUs change the deployment picture?

Old Thinking:

- VRU devices very cost sensitive
- Hard to deploy V2X in VRUs until we have high vehicle penetration
- Automaker deployments will be compelling to VRU community eventually

New Thinking:

- Micromobility is exploding.  #VRU devices  #VRU injuries/fatalities
- Some VRU stakeholders pushing to get into V2X *now*:
 - Example: Coalition for Cyclist Safety (C4CS): <https://coalitionforcyclistsafety.org/>
- Suppliers working on low cost VRU devices
- V2X needs VRUs and VRUs need V2X

An opportunity for ScooterLab members!

VRU Safety Initiatives: US

USDOT: under HSIP (Highway Safety Improvement Plan), USDOT requires states to submit VRU Safety Assessments



- USDOT and US Congress are serious about VRU safety
- V2X angle: SAE and USDOT discussing how to fund VRU safety standard

https://highways.dot.gov/sites/fhwa.dot.gov/files/2024-07/HSIP%20VRU%20Fact%20Sheet_508.pdf

<https://highways.dot.gov/safety/pedestrian-bicyclist/data-tools-and-resources-vulnerable-road-user-safety-assessment>

<https://www.transportation.gov/briefing-room/us-department-transportation-announces-new-guidance-improve-safety-vulnerable-road>

VRU Safety Initiatives: Europe



European
Commission

ITS & Vulnerable Road Users

- Horizon Europe Project V4SAFETY (ongoing)
 - Vehicles and VRU Virtual eValuation of Road Safety
- EC Project SAFE-UP (2020-2023)
- European Transport Safety Council
 - Study focused on E-Scooters
- ETSI and C2C-CC VRU Safety Work items



Links:

https://transport.ec.europa.eu/transport-themes/smart-mobility/road/its-directive-and-action-plan/implementation-its-action-plan/its-vulnerable-road-users_en

<https://cordis.europa.eu/project/id/101075068>

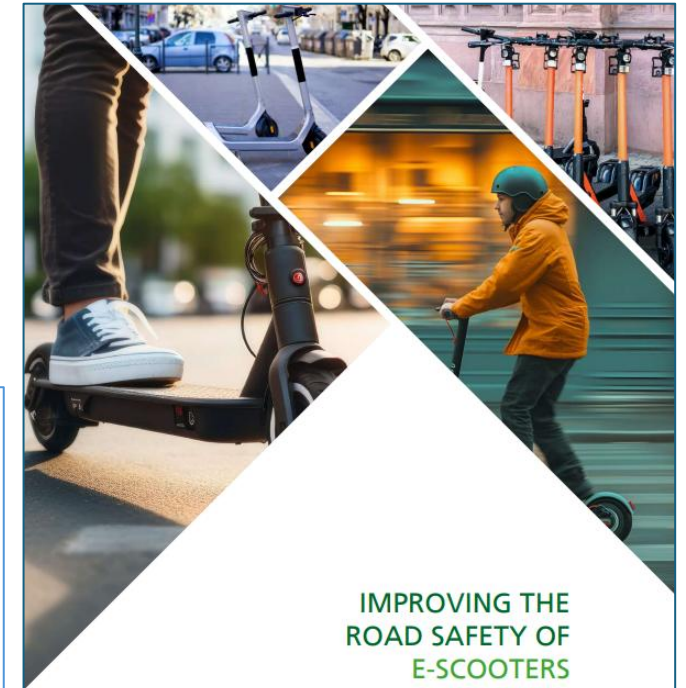
<https://www.safe-up.eu/>

<https://horizoneuropencpportal.eu/sites/default/files/2025-01/etsc-improving-the-road-safety-of-e-scooters-2024.pdf>

<https://www.etsi.org/newsroom/news/1852-2020-11-etsi-experts-complete-specifications-for-vulnerable-road-users/>

<https://www.car-2->

[car.org/fileadmin/documents/General_Documents/C2CCC_WP_2087_VRU_Awareness_Study_V1.0.pdf](https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_WP_2087_VRU_Awareness_Study_V1.0.pdf)



IMPROVING THE
ROAD SAFETY OF
E-SCOOTERS

PIN Flash Report 47

November 2024



Closing message

- When we say we strive for Vision Zero we have to mean it
- Cooperative ITS (V2X) is a necessary tool to reach that goal, as a complement to sensor-based safety and longer-range network-based communication
- VRUs are an increasingly critical part of the V2X ecosystem.
- Most of all we need **leadership, courage, and optimism**
- “Optimism is not naïve, it is hope. Optimism is true moral courage”
– Jacinda Ardern (NZ Prime Minister)