Autotalks

Vulnerable Road Users Protection

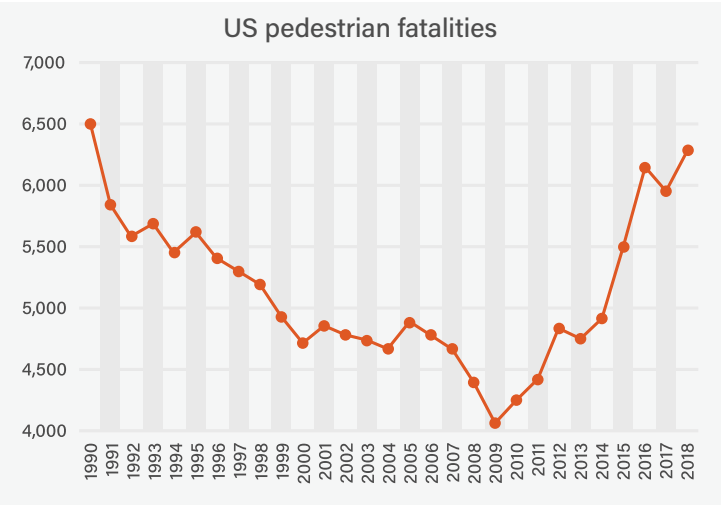
Overview

VRU accident statistics

Vulnerable Road Users refers to road users that are non-vehicle occupants: motorcyclists, cyclists, and pedestrians. In many countries, the number of non-vehicle occupants' fatalities is greater than vehicle occupants' fatalities. The pie chart shows the fatalities classification in Europe in 2018[1] .

In numbers, between 2010 and 2018, approximately 20,000 cyclists were killed in traffic accidents in the EU. More than 51,000 pedestrians were killed in road accidents during the same period. Roughly 5,000 motorcyclists die from crashes every year.

While vehicles are constantly increasing the occupants' protection, the same fatalities decrease trend does not apply to VRUs[2] .



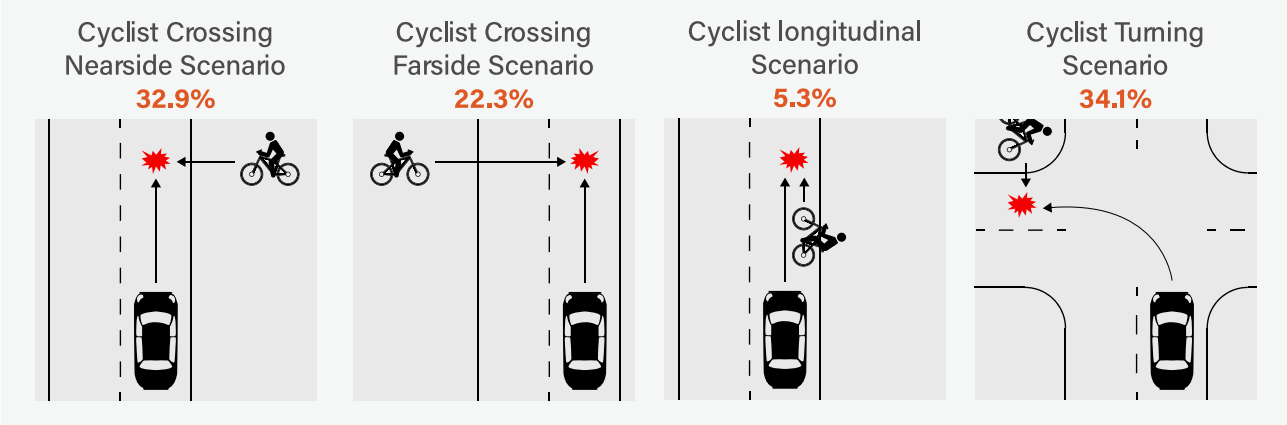
The conclusion is clear: the protection of VRUs should be a prime target. All stakeholders, regulators, OEMs, road operators, and road users should unite to make roads safer for non-vehicle occupants.

[1] 2018 road safety statistics: what is behind the figures?
https://ec.europa.eu/commission/presscorner/detail/en/MEMO_19_1990

[2] Cyclist and Pedestrian Deaths Skyrocket in 2018 as Motorists Stay Safe
https://usa.streetsblog.org/2019/06/18/cyclist-and-pedestrian-deaths-skyrocket-in-2018-as-motorists-stay-safe/

Reasons for accidents

Accidentology of bicycle accidents[3] reveals that most accidents occur when the cyclist crosses the street.



Most drivers direct their focus to the road and vehicles ahead. Bicycles are much smaller than vehicles, pose less threat to the drivers, and do not stand out from the environment. As a result, most often cyclists are not noticed. In the UK, 'Failure to look properly' was attributed to the car driver in 57% of serious collisions[4] .

Pedestrians are no different. They are most commonly hit when crossing the street.

The solution to VRU safety

Vehicle to Everything (V2X) communication is the safety network of all road users. V2X is a wireless safety sensor that prevents accidents by using reliable and secure data. V2X enables drivers to "notice" all road users. A road user transmits its location and other parameters like speed and direction of progress. All V2X road users in proximity learn about it. Since detection is based on wireless communication, it operates in any condition: day or night, fog, snow, or rain. V2X is the only vehicular sensor that can overcome obstructions and detect pedestrians and cyclists behind the corner, between parked cars, or hidden by other cars. This unique V2X property makes it an essential sensor for VRU protection.

V2X is already deployed in new vehicles, and the numbers of V2X vehicles is constantly growing. Since vehicles are already benefiting from V2X, it is only natural that the biggest transportation problem, VRU fatalities, should be addressed with V2X. Motorcycles are expected to include V2X first, then eBikes and eScooters, bikes, and eventually, pedestrians.

Vehicle alert consideration

V2X can alert the driver when a VRU's future route crosses the vehicle route. The alert will help the driver brake or steer the car to avoid an accident. With the continuous progress of ADAS (Advanced Driver-Assistance Systems), the V2X data will feed the vehicle decision unit. The vehicle would stop or steer automatically based on V2X data, as performed in response to any other vehicle sensor.

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[3] François Char, Thierry Serre. Analysis of pre-crash characteristics of passenger car to cyclist accidents for the development of Advanced Drivers Assistance Systems. Accident Analysis & Prevention, 2020, 136, 12p. ff10.1016/j.aap.2019.105408ff. ffhal-02483327f https://hal.archives-ouvertes.fr/hal-02483327/file/doc00031346.pdf

[4] Road Safety Factsheet - Cycling Accidents https://www.rospa.com/media/documents/road-safety/cycling-accidents-factsheet.pdf

Pedestrian movement is the hardest to predict. Extensive ML research is conducted to predict pedestrian trajectory, but future turns and speed changes cannot be predicted[5]. That implies that old data is pretty much useless. Data from 5 seconds ago, and even 3 seconds ago, cannot be used to alert a vehicle. The number of false alarms will be too high, making the entire system unusable and annoying. Up-to-date data should be used with minimal latency.

The same is true for cyclists. The prediction horizon is not more than 1.5 seconds[6], with trusted results only within 0.5 seconds. Therefore, V2X data latency and freshness are critical.

VRU alert consideration

eBikes and eScooters are the only VRUs that, theoretically, can automatically slow down when at risk. Other VRUs can only be alerted. The greatest challenge is avoiding distraction while alerting. For example, if a Smartphone is alerting a pedestrian or a cyclist, and the pedestrian diverts the attention toward the notification, or even worse, stops to grab it from a pocket, instead of moving aside to evade the endangering vehicle, then the damage is greater than the benefit. VRU alerts can be valuable, but must be applied only after a careful study of human behavioral aspects.

Like drivers, VRUs should not be bothered with false alarms. Therefore, alerts must not be issued prematurely, and data latency and freshness should be kept strictly low and high respectively.

Possible V2X VRU solutions

V2X primer

Two technologies are standardized for V2X: DSRC (Dedicated Short-Range Communication), based on WiFi, which was introduced first for directly connecting road-users, and C-V2X (Cellular V2X), based on cellular technology, which was introduced a few years later. In any given geography, only a single technology can be used to assure interoperability. C-V2X is the chosen technology in China and US, while DSRC was selected in Europe thanks to Volkswagen's mass deployment.

[5] End-to-End Pedestrian Trajectory Forecasting with Transformer Network. Hai-Yan Yao, Wang-Gen Wan and Xiang Li. https://www.mdpi.com/2220-9964/11/1/44/pdf

[6] Model-Based Prediction of Two-Wheelers. Florian Wirth, Tao Wen, Carlos Fernandez-Lopez and Christoph Stiller. https://www.mrt.kit.edu/z/publ/download/2020/Wirth_Bicycle_IV2020.pdf

The term "C-V2X" is confusing because it describes both direct communication over the PC5 interface and network communication over the Uu interface.

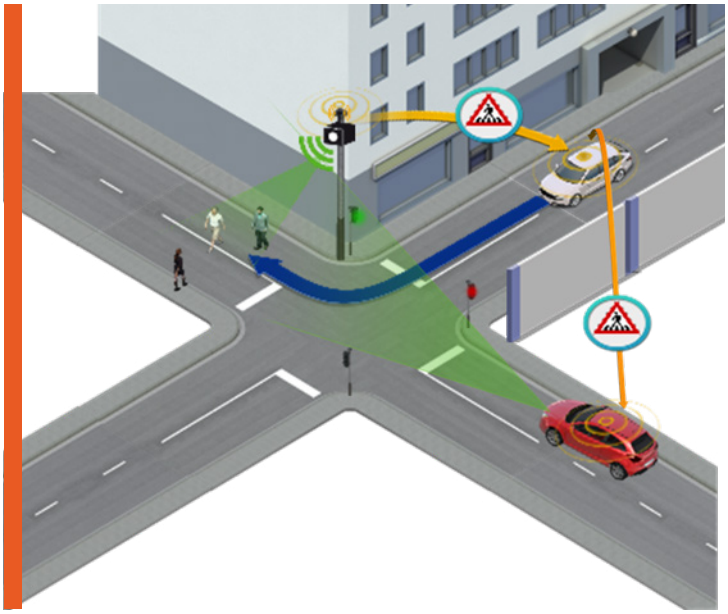
- Direct communication uses a dedicated channel, 5.9GHz worldwide, where road users exchange data with other road users in close proximity (up to 1km) without using the cellular network. Therefore, the data cost is zero, and there is no dependency on any infrastructure. Direct communication is secure, anonymous, and reliable enough to control the vehicle. Short latency is assured. The first C-V2X generation (Rel. 14) is based on LTE (4G), and the newest one (Rel. 16) is based on NR (5G).
- Network communication uses the cellular network, 4G or 5G, for long-range coverage.

In the context of this document, V2X refers to both DSRC and C-V2X direct communication.

V2X can be applied to VRUs in a variety of options outlined ahead. The options are not mutually exclusive, and can be applied concurrently.

Cooperative perception

With cooperative perception, vehicles share with other nearby vehicles the objects detected by their sensors. Cooperative perception is the major feature added to V2X Day2, which is the second phase of V2X deployment. An additional radio channel, adjacent to the existing one, is activated to carry the cooperative perception messages.



Courtesy of car2car communication consortium. Autotalks is a C2C-CC member

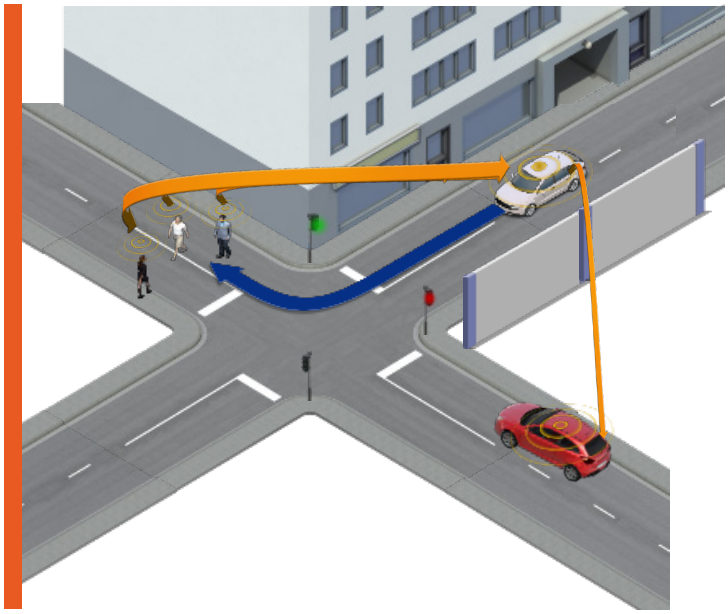
Cooperative perception dramatically increases the value of V2X as it adds unconnected road users, like VRUs and older vehicles, to the network. The unconnected road users get noticed, but cannot be alerted. In other words, a connected vehicle can detect an unconnected vehicle behind the corner, but the unconnected vehicle will not be aware of the connected one.

With cooperative perception, VRUs can be detected even without any active device. However, the detection is not perfect. Many bicycle accidents occur in smaller intersections. There is no guarantee that the cyclist will be detected by a nearby vehicle. The same is true for pedestrians. If the pedestrian was not noticed by the vehicle hitting it, then other vehicles, further away, do not have a greater probability of detecting the pedestrian.

Although not hermetic, the safety value is high. Most OEMs recognize the great value and are expected to move quickly from Day1 to Day2 in order to benefit from this gain.

V2X devices for VRUs

In a perfect world, all road users will have a V2X device. Every eBike computer, bicycle front light, smartwatch, or even a child's backpack will alert nearby vehicles.



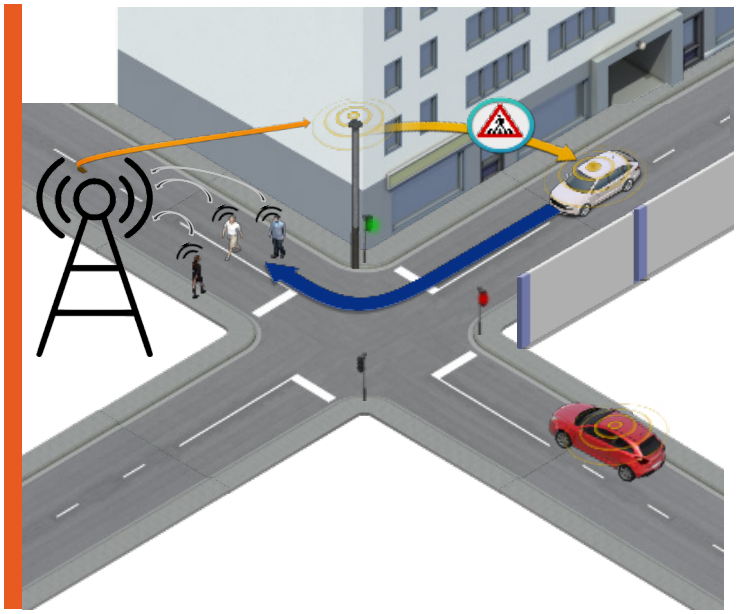
A connected vehicle will be able to avoid most of the accidents with VRUs. Since the latency is consistently short, VRUs can be alerted properly without distracting their attention.

A bicycle can embed V2X while placing the optimal positioning of the GNSS and V2X antennas and keeping the bike's elegant look. A vehicle can trust messages only if accurate and reliable, and integration can assure that. A smart eBike can even use the alert to automatically brake.

The challenges for pedestrian protection are similar. A dedicated device, like a safety tag embedded in a kid's backpack, can provide consistent positioning accuracy, compared with a smartphone placed in the pants pocket blocking most GNSS satellites.

V2X-enabled Smart infrastructure

In a less-than-perfect world, many road users will not have V2X. yet the goal is to increase road safety for all.



Smart infrastructure can detect VRUs and inform vehicles using V2X messages. VRUs are not alerted in case of a risk.

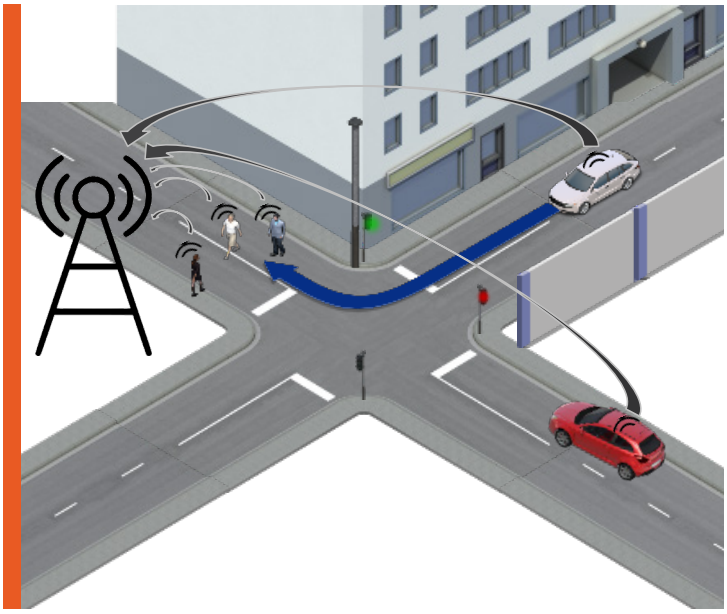
The detection can be performed in multiple ways, presented according to their likelihood:

- Camera, probably thermal, with image detection. The detection is limited to the field of view, requires a clear line of sight, and high camera installation. The camera must be maintained: it should be cleaned regularly to remove dirt and debris, and its surroundings must be cleared in order to assure that trees are not blocking its line-of-sight.
- A Bluetooth Low Energy (BLE) -enabled device can be used, yet requires installing multiple antennas in the intersection for triangulation, and keeping line-of-sight to each.
- A smartphone, sending its location to the cloud, which forwards the messages to the RSU is also an option. It requires short-latency, operation across multiple operators, and a resolution of the business case. The positioning accuracy of an arbitrarily placed smartphone is not trustworthy. In addition, a smartphone requires installing and activating an app, which is a great challenge.

Widespread infrastructure deployment is very costly. The electronic cost is the smallest factor. Permits, installation, road closures, power supply availability, and maintenance impose the greater challenge.

Cloud V2X

Cloud V2X does not use direct communication at all. Smartphones transmit the VRUs' locations and kinematics to the cloud. Vehicles do the same. The cloud analyzes the potential safety risks between all road users and sends the alerts back to the vehicles.



Anonymity and privacy should be maintained, conforming to the relevant regulations. For example, in Europe, Public Key Infrastructure (PKI) is specified for C-ITS (Connected intelligent transportation). PKI is not applicable in a cellular network.

All vehicles, of all brands, should be connected, regardless of their mobile operator. The processing latency should be consistently shorter than the prediction horizon. The latency aggregates the cellular communication latency, cloud access latency, and processing time. In order to shorten the cloud access latency, Edge Computing would be a necessity. The promise of edge computing is high, with predicted high growth, but the current deployments are sparse[7]. It does not come close to the required widespread coverage for reliable service. On top of that, the business case question remains: who will pay for the required computing and data?

The challenge of forcing an app installation and activation, as mentioned above, apply here as well. The positioning accuracy uncertainty, explained above, diminishes the viability of the scheme. It should be emphasized that vehicles do not use cellular data in ADAS due to security and reliability concerns. That would require a radical change in the design of Telematics Units.

[7] Mapping out edge computing: How dense is it? https://www.lightreading.com/the-edge/mapping-out-edge-computing-how-dense-is-it/d/d-id/771128

Data flow summary

In each of the schemes the VRU is detected differently, spanning from carrying an active device (V2X or Smartphone) to being detected by sensors. Except for when the VRU is carrying a V2X device, the detection is not direct, and involves an intermediate relaying entity. The top part of the table shows the detection path for each of the options.
The bottom part of the table indicates the path where the VRU can be alerted.

	Cooperative perception	VRU with V2X	V2X-enabled smart infrastructure	Cloud V2X
VRU detection path	Vehicle sensors ▼ Day2 V2X vehicles TX ▼ Day2 V2X vehicle RX	V2X in VRU ▼ V2X vehicle RX	Camera / BLE / Smartphone via cloud ▼ Road Side Unit ▼ V2X vehicle RX	VRU smartphone ▼ Collision prediction algorithm in edge ▼ Connected vehicle
VRU notification path	None	V2X vehicle TX ▼ V2X in VRU	None	Collision prediction algorithm in edge ▼ VRU smartphone

Advantages

	Cooperative perception	VRU with V2X	V2X-enabled smart infrastructure	Cloud V2X
Advantage	VRU doesn't need to carry any device to be protected	VRU device is automatically activated Assured positioning accuracy, latency and communication range	VRU doesn't need to carry any device to be protected	Utilizing existing Smartphones

Limitations

	Cooperative perception	VRU with V2X	V2X-enabled smart infrastructure	Cloud V2X
Limitation	The pedestrian or cyclist at risk may not be detected by any other vehicle	Achieving market penetration	Dependency in wide-spread RSU installations in intersections	App should be installed and activated
			Complicated installation and maintenance to cover with cameras the entire intersection or to install antennas for BLE triangulation	Dependency in wide-spread powerful edge computing deployment
			Uncertain positioning accuracy when using BLE or Smartphone	Uncertain positioning accuracy
				Requires solving ▪ Vehicle ability to use data ▪ Business model

Final thoughts

Out of the studied options, the 3rd option, V2X-enabled smart infrastructure, provides good value, but the value is too localized, depending on large infrastructure investment. The 4th option, V2X cloud, isn't viable at this time.

The 1st option, Cooperative perception, should be a key pillar in VRU detection. The network effect will be capable of protecting many VRUs shortly after Day2 V2X vehicles will reach the roads. OEMs should accelerate the introduction of V2X Day2.

Although the cooperative perception safety gain will become significant, there will still be gaps detecting cyclists and pedestrians. These gaps can be overcome by the 2nd option, equipping VRUs with V2X. Low-cost devices, embedded elegantly in products (e.g. micro-mobility vehicles, schoolbag tags, etc.), with assured performance would guarantee the VRUs' protection.

The combination of cooperative perception and V2X wearables will create a major impact on pedestrian road safety.