Autotalks

How to Add V2X to ADAS

Overview

Advanced driver assistance systems (ADAS) have been developed over a decade using Line-Of-Sight (LOS) sensors, namely cameras, radars, and Lidar. A lot of know-how was developed and gained based on deployed vehicles experience.

Vehicle-to-Everything (V2X) communication is posing new challenges:

- No redundancy: ADAS typically brakes after two different sensors have observed a risk. V2X can uniquely detect a risk even if it's obstructed, meaning no other sensor can corroborate the detection.

- Risk depends on road geometry: V2X detects road users from a distance. Assuming that self and target vehicles advance in the current trajectory, it can lead to a false alarm. An example of a false positive alarm is two vehicles approaching a bridge while the GNSS height indication is erroneous. A different example of a false negative is when a vehicle moving forward is about to turn left, and another vehicle is arriving from the opposite direction.

- New and accurate road-user information to use: The road users provide accurate speed and steering wheel information while existing sensors infer it and offer inaccurate future path prediction. In addition, path history can be used to match lanes only when a risk is suspected.

- New road data to use: Traffic light provides rich information, like Signal Phase and Timing (SPAT), and not just "light is now green".

- Different error types: As opposed to other sensors, V2X doesn't suffer from perception errors. V2X radio is trustworthy, but overall V2X system reliability is "Garbage In – Garbage Out". The integrity of data transmitted inside the V2X message, and the processing of that data determines the V2X usage reliability.
  - ASIL V2X transmitter: Despite continuous GNSS accuracy improvement (adding L5 band), the positioning may be erroneous.
  - Non-ASIL V2X transmitter: As opposed to ASIL V2X, data reliability isn't assured. In the rare event of hardware or software failure, V2X data is arbitrary.

The document aims to describe the flow of automatic braking based on V2X. ASIL V2X receiver assures reliable data processing for automatic braking. Non-ASIL V2X receiver isn't reliable enough to initiate braking, but many accidents can be prevented by warning the driver or activating pre-braking like building braking fluid pressure or tightening seat belts. More importantly, ADAS can decrease the perception threshold where the target vehicle is expected to enter the field of view. To illustrate the value, if ADAS would require 400mS to indicate the risk, with V2X, only 100mS will be needed, saving critical time for mitigating the risk.

Functional Safety V2X

Most sensors are developed as ASIL B for economical practicality and technical feasibility. V2X is no different. A V2X system contains GNSS, V2X radio and a processor. A system is ASIL only if all elements are ASIL.

Transmitter ASIL grade should be included in the V2X message. Standardization discussions are ongoing, most notably in ETSI (TR 103 917), as part of the overall functional safety concept. Message extension should be concluded by 2025/6.

ISO26262 is relevant only for road vehicles, potentially including trucks and motorcycles. Bicycles, which are a key part of V2X safety, aren't subject to ISO26262. Even Road-Side-Units (RSUs) aren't subject to ISO26262, but vendors are expected to adopt the similar IEC 61508 – the general Functional Safety specification, from which ISO26262 is derived. Those can't be excluded from automatic braking.

The following table lists the possible actions per ASIL level:

	V2X transmitter: No ASIL	***V2X transmitter: ASIL***
V2X receiver: No ASIL	**Warning or pre-braking**	**Warning or pre-braking**
V2X receiver: ASIL	**Braking:** • Validating GNSS correctness • Validating parameters' correctness	**Braking:** • Validating GNSS correctness

Position accuracy needs to be verified irrespective of the GNSS and V2X transmitter ASIL grade in order to meet SOTIF (Safety Of The Intended Functionality) compliance. When the transmitter isn't ASIL, all other parameters should be validated as well.

Furthermore, in cases where the transmitter lacks an ASIL rating, all pertinent parameters should also undergo validation.

V2X Data Verification

As mentioned above, ensuring the accuracy of GNSS is a prerequisite for any V2X based braking system. Furthermore, in cases where the transmitter lacks an ASIL rating, all relevant parameters should also be validated.

GNSS correctness is validated by two methods:

- Consistency – the current position, heading, and speed, should follow a normal movement course based on previous positions and kinematics values.
- Comparison with another data source – map data is an independent data source. The current position should follow a known road, and the transition between roads should follow a normal standard course of movement.

The comparison with the map is called "map matching". Road-level matching links the vehicle with the road that is most likely to be its current position. An accurate HD map can be used to perform "lane-level matching", where the position should follow a known lane. For that, the GNSS accuracy should be less than 1.5m, defined as "lane level accuracy". Other relevant V2X message fields are validated in a similar manner. For example, vehicle length should be consistent, meaning identical in all messages. Turning light, as another example, cannot appear only in a single message.

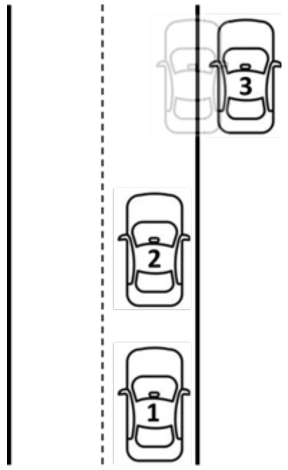
Braking can't be performed if conditioned by a parameter that can't be corroborated. This does not limit most of the use cases since position and movement vectors can be corroborated simply and reliably.

Filtering V2X Data

V2X surpasses all other sensors in the count of detected targets since it possesses the unique capability to identify obstructed road users within a full 360° radius around the vehicle. No other sensor is required to process ~200 targets. That can create a high processing load and high interface load on the ADAS. Filtering can be determined by considering the feasibility of the self-vehicle reaching the target vehicle and the time required for that.

Sample Scenarios

4 indicative scenarios are presented to illustrate false warnings using V2X:

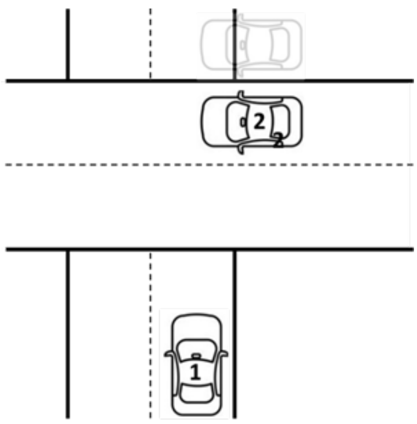


Stopped vehicle

Applicable on highways and urban roads, at high and moderate speeds.

V2X messages can indicate a slow vehicle ahead. The self-vehicle will dangerously brake if a risk is falsely detected in its lane.

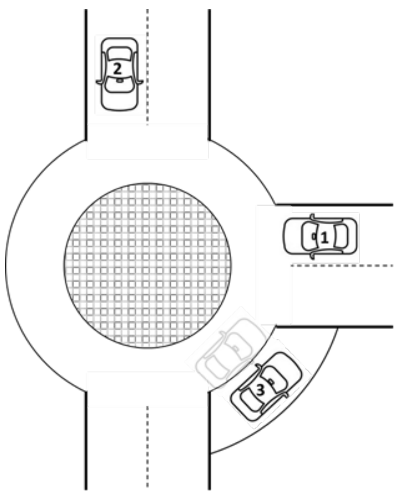
A stopped target vehicle entering the road from the side lane is the most challenging scenario. The target vehicle has no path history, and the initial positioning is the least accurate, complicating the lane matching.



Overpass (bridge)

Applicable on highways and urban roads, at all speeds.

V2X will falsely warn if the self-vehicle fails to recognize that target vehicle's road is on a different level.

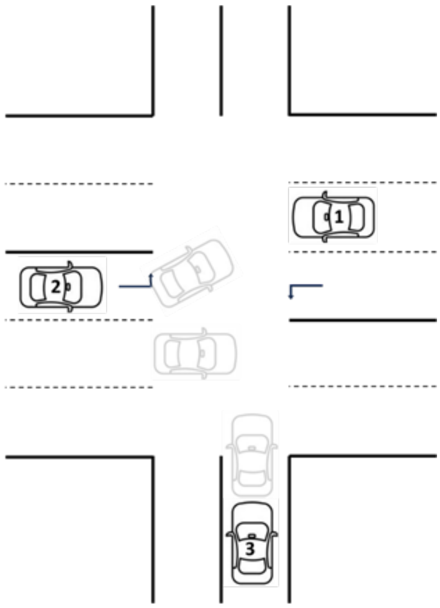


Roundabout

Applicable on urban roads, at moderate speeds.
When vehicles enter the roundabout, their trajectories may indicate a collision, but the drivers are about to steer away along the route and not collide.

On the other hand, vehicles inside the roundabout pose a threat even if their current trajectory doesn't indicate one. In such a case, the automated braking should not increase the risk, for example, if the emergency braking ends inside the roundabout, blocking the route.

A driver can be falsely warned if a target vehicle drives on a dedicated lane, bypassing the roundabout, even if it can't risk the self-vehicle.



Intersection

Applicable on urban roads, at high and moderate speeds.

V2X can uniquely mitigate intersection accidents. No other technology can warn of a target vehicle running a red light.

When the vehicle's left-turning light is on or is in a dedicated left-turn lane, it is possible to predict that a target vehicle will soon steer even if the wheels are still pointing forward. Having said that, the driver's behavior is never guaranteed to be logical.

If the positioning error is high, a target vehicle stopping point may falsely seem to be inside the intersection. Without proper decision logic, that can create a false warning.

V2X technology allows for the early identification of a target vehicle before it enters the intersection. The warning timing should be determined carefully to avoid unnecessary alerts of target drivers who stop late.

Prevent False Warnings

All the different potential false warnings in the various use cases have one answer: knowing the future routes of self and target vehicles can be used to determine the risk and action reliably. Map road-level or lane-level matching, conducted as part of positioning validation, provides route information as a supplementary outcome. The required path accuracy depends on the use case.

Matching	Relevant Scenario
Road-level	▪ Overpass ▪ Roundabout
Lane-level	▪ Stopped / slow vehicle ahead ▪ Determining the future route when an exit or turn lane exists

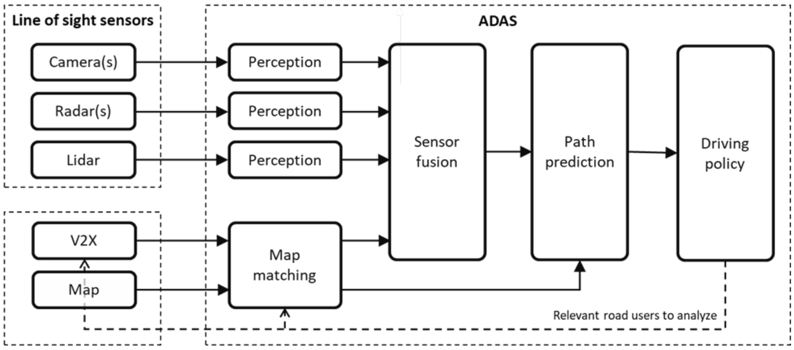
Adding V2X to the ADAS decision flow

The raw data of all line-of-sight sensors, camera, radar, or Lidar are processed by perception engines. Those convert raw data into objects. This function isn't used for V2X since the data is already describing objects.

All sensors are fused, corroborating each other. V2X is not different. V2X targets in sight should be aligned with the same object perceived by other sensors.

V2X technology allows for the early identification of a target vehicle before it enters the intersection.

Even if other sensors have successfully matched the target, incorporating V2X remains beneficial due to its capacity to enhance both the precision and the timeframe for predicting future paths. Like other sensors, V2X employs map matching for validating and contextualizing V2X data before triggering automatic braking, which typically requires the detection of risk by two or more sensors.



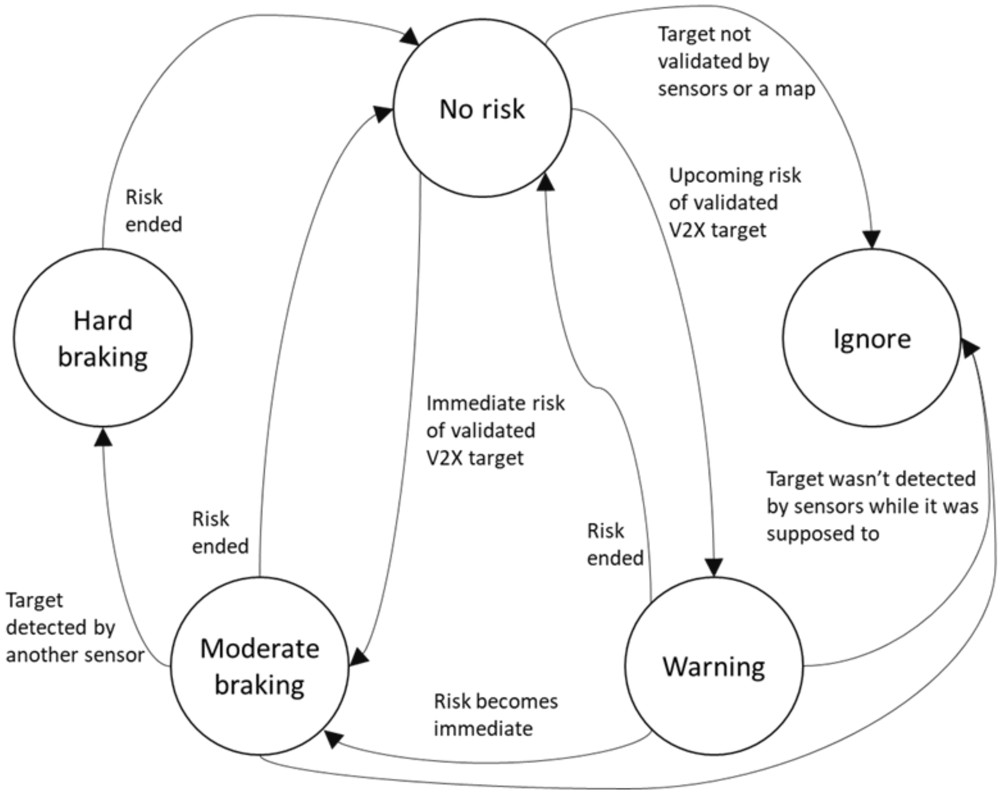
The rightmost block in the diagram 'driving policy' is responsible for establishing the required actions and can streamline the analysis of road users by specifying which ones to focus on. Other road users can be ignored or rarely scanned. Map matching should be applied only to pertinent road users as needed.

V2X Possible Actions

The V2X ASIL self-vehicle can take four possible actions when a V2X target is imposing a risk, as listed below. In contrast, a non-ASIL V2X can only issue warnings, initiate pre-braking procedures, and adjust ADAS detection thresholds.

- Ignore: The target is implausible. Positioning and other parameters can't be validated.
- Issue a warning (light or sound): Alerting the driver to an event several seconds away. A warning sound is only issued if the event is corroborated while a warning light can be issued more liberally.
- Initiate moderate braking: The hazard requires an immediate response, but only V2X detected it. The braking deceleration is set according to ASIL B.
- Initiate hard braking: The hazard requires an immediate response and is detected by multiple sensors. The braking deceleration is set according to ASIL D.

The transitions between the four possible actions are shown below:



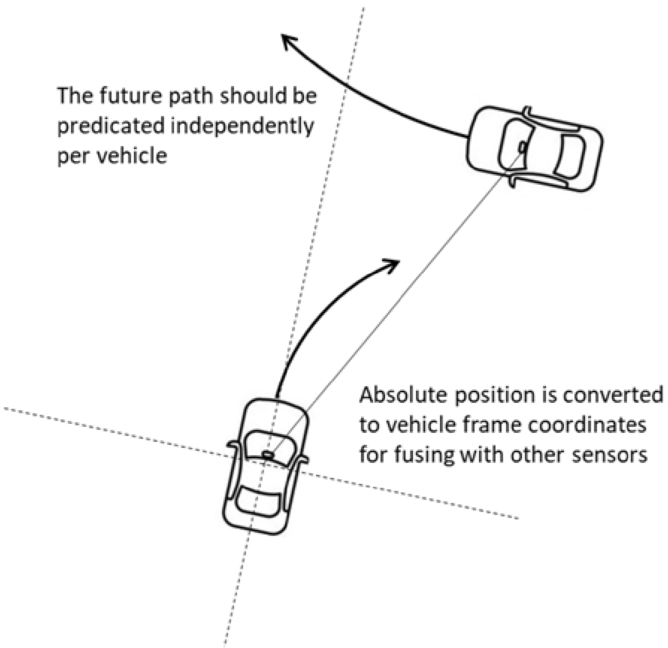
Aligning V2X with ADAS data

Data from all sensors must be synchronized to a uniform sampling time and adjusted to the same positioning coordinates.

Positioning coordinates alignment:
All sensors, other than V2X, position the targets relative to the vehicle frame. V2X provides the absolute positioning of both self and target vehicles. To simplify V2X usage in ADAS, specifically in the sensor fusion phase, V2X data should be represented in vehicle frame coordinates.

Sensor fusion weights data confidence of each sensor. V2X confidence of speed and acceleration is higher than other sensors, but the location confidence is lower. A fused object position is taken mostly from other sensors and speed and acceleration are taken mostly from the V2X sensor.

Path prediction should be performed in absolute coordinates. First, the driven road by self and target vehicles can be different so the future route should be calculated independently per vehicle. Second, V2X provides rich data that isn't available in other sensors, like accurate acceleration, yaw rate, and steering wheel angle . The movement equation in vehicle frame coordinates doesn't reflect the specific kinematic parameters of both vehicles, thus reducing prediction accuracy.

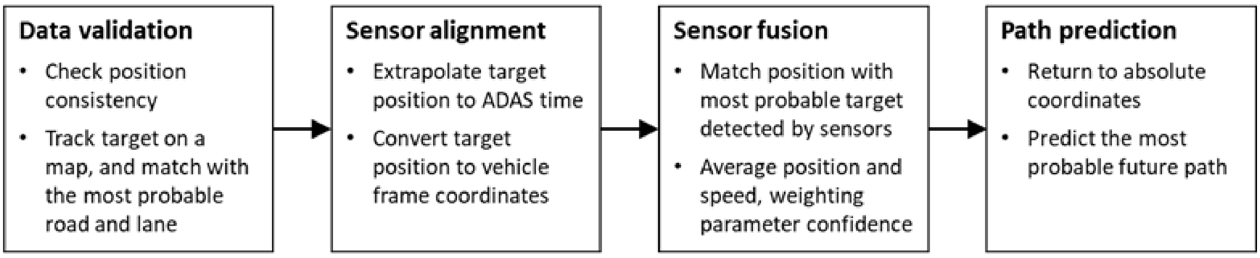


Timing alignment: Sensors differ by their perception latency and sampling rate. The actual data generation time is included in the message, allowing extrapolation to any time desired by ADAS.

The average time between V2X transmissions is 100mSec with some intentional fluctuation. In DSRC, the transmission time includes a random jitter. In C-V2X, the transmission slightly shifts once every few seconds when a new transmission slot is selected. The gap between transmissions may grow above 100mSec when the wireless channel is congested, and the vehicle kinematics haven't changed.

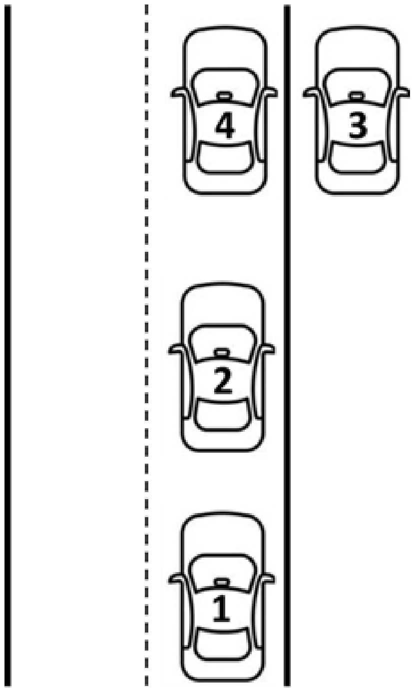
Flow chart

The following chart summarizes all the actions mentioned above. It is performed for each target vehicle or other road user. As mentioned above, a subset of the most safety relevant V2X targets can be selected to limit the required processing.



Examples

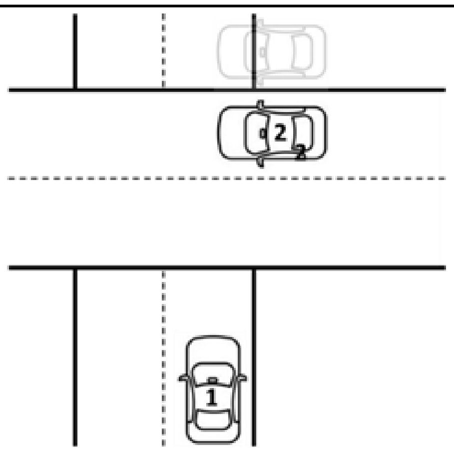
V2X operation in the same indicative scenarios is explained using several cases:



Stopped vehicle

Self-vehicle is vehicle #1. Obstructed target vehicles #3 and #4 have stopped.

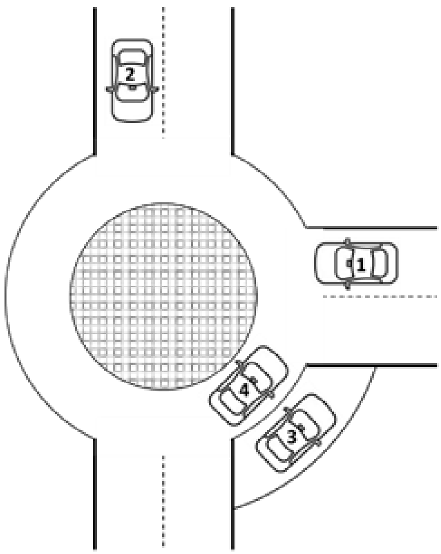
- **[no corroborated positioning] Vehicle #3 + 4:** V2X is ignored (no action).
- **[lane-level positioning] Vehicle #3:** Depending on the OEM's preference, a warning is issued, for example when left-turn signal is on. The warning is canceled after passing vehicle #3.
- **[road-level positioning] Vehicle #3:** Depending on the OEM's preference, a warning is issued. The warning can be canceled after vehicle #3 is detected by self-vehicle sensors. The vehicle is assumed to be parking if the path history doesn't exist.
- **[lane-level positioning] Vehicle #4:** The self-vehicle initially applies moderate braking. Shortly thereafter, when vehicle #2 braking is detected by the other sensors, the braking intensity increases.
- **[road-level positioning] Vehicle #4:** The driver receives a warning because there is a higher likelihood of drivers in adjacent lanes changing lanes, and the possibility of an event in the driven lane. Once vehicle #2's braking is detected by the sensors, the braking force increases.



Overpass (bridge)

Self-vehicle is vehicle #1. Target vehicle #2 is crossing the bridge.

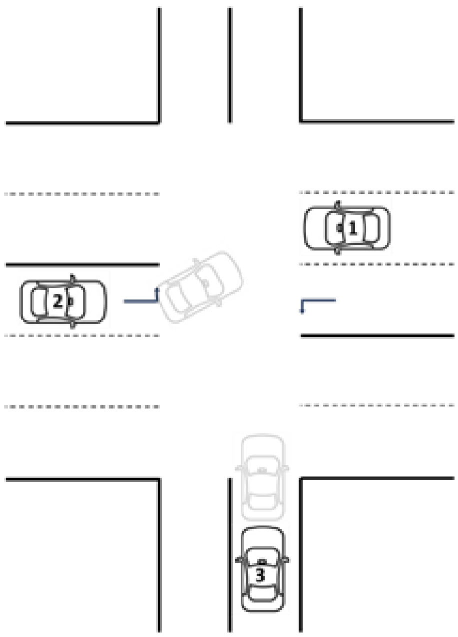
- **[lane-level or road-level positioning]:** No risk (no action).
- **[no corroborated positioning]:** V2X is ignored.



Roundabout

Self-vehicle #1 and target vehicles #2 and #3 enter the roundabout, while vehicle #4 bypasses it.

- **[lane-level or road-level positioning] Vehicle #2:** No risk if vehicle #2 is not slower than self-vehicle.
- **[lane-level positioning] Vehicle #3:** No risk.
- **[road-level positioning] Vehicle #3:** Warning and "pre-braking" until observed by sensors. Then the warning is cancelled.
- **[lane-level positioning] Vehicle #4:** Moderate braking.
- **[road-level positioning] Vehicle #4:** Warning and "pre-braking" until observed by sensors. Then automatically braking is activated.



Intersection

Self-vehicle is vehicle #1. Vehicle #2 turns left. Vehicle #3 runs a red light.

- **[lane-level positioning] Vehicle #2:** Based on risk, regardless of heading, the vehicles are braking moderately.
- **[road-level positioning] Vehicle #2:** If vehicle's #2 left-turn light is on, a warning is issued in both vehicles #1 and #2, even if the wheel points forward. Without the left-turn light, the future route can't be predicted, and no warning is issued. Once vehicle #2 steering turns left, both vehicles moderately brake.
- **[lane-level or road-level positioning] Vehicle #3:** Moderate braking when vehicle #3 is driving fast. If vehicle #3 is static in self-vehicle path, then sensors are expected to detect it, and warning is issued till that detection, and then hard braking begins.

Summary

V2X data is undeniably different than data provided by other sensors, but this is its strength. With some additional functions, explained in this document, ADAS can brake reliably based on V2X.

On top of the obvious ability to protect from obstructed road users, V2X enhances the precision of path prediction. This enhanced precision can also be used to predict the vehicle's future route, especially in situations involving a dedicated exit lane.

V2X data integrity is assured with V2X ASIL. Positioning accuracy can be validated with two means, confirming movement consistency, and matching with map data. With map matching, the future paths of self-vehicle and target vehicle can be predicted to determine a future risk in all road scenarios.