

White Paper on Bicycle Safety Use Cases



CAR 2 CAR
COMMUNICATION CONSORTIUM

About the C2C-CC

Enhancing road safety and traffic efficiency by means of Cooperative Intelligent Transport Systems and Services (C-ITS) is the dedicated goal of the CAR 2 CAR Communication Consortium (C2C-CC). The industrial driven, non-commercial association was founded in 2002 by vehicle manufacturers affiliated with the idea of cooperative road traffic based on Vehicle-to-Vehicle Communications (V2V) and supported by Vehicle-to-Infrastructure Communications (V2I). The Consortium members represent worldwide major vehicle manufactures, equipment suppliers and research organisations.

Over the years, the C2C-CC has evolved to be one of the key players in preparing the initial deployment of C-ITS in Europe and the subsequent innovation phases. C2C members focus on wireless V2V communication applications based on Direct Communication and concentrate all efforts on creating standards to ensure the interoperability of cooperative systems, spanning all vehicle classes across borders and brands. As a key contributor, the C2C-CC and its members work in close cooperation with the European and international standardisation organisations.

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Table of contents

- About the C2C-CC.....1
- Disclaimer2
- Intellectual Property Rights – Essential patents2
- Document information.....3
- Changes since last release4
- Table of contents5
- List of tables6
- List of Figure.....6
- 1 Introduction7
- 2 Definitions8
- 3 Use Cases9
 - 3.1 Intersection Movement Assist involving bikes (IMA-B) 9
 - 3.2 Intersection Movement Assist with Standstill Vehicle (IMA-S) 12
 - 3.3 Right-turn Warning for bike (RTW-B) 14
 - 3.4 Left-turn Warning for bike (LTW-B)..... 17
 - 3.5 Slow Moving Vehicle Ahead..... 19
 - 3.6 Bike Accident Warning..... 22
- 4 Use case mapping table for releases 24
- 5 References..... 26
- 6 Appendix A – Accident analysis and use case prioritization 27
 - 6.1 Accident Research 27
 - 6.1.1 Input data.....27
 - 6.1.2 Analysis and results27
 - 6.1 Prioritization of scenarios 31

List of tables

Table 1: Document information 3

Table 2: Changes since last release..... 4

Table 3. Example alert level time thresholds..... 25

Table 4. Alert levels mapped to the use cases 25

List of Figure

Figure 1. Alert levels..... 24

Figure 2: Ranking of probability of bike-to-car accident scenarios, according to [2]. The codes are taken from Unfalltypenkatalog [3]..... 27

Figure 3: Frequency distribution of the most common car-cyclist crash scenarios and sketch of the most relevant scenarios UTYP 341 and 342 [4] 28

Figure 4: Accident type clustering and probability distributions from CATS project [5] 29

Figure 5: Distribution of seriously injured over the 9 main accident scenarios that are distinguished for 6 EU countries [5] 29

Figure 6: Distribution of fatally injured over the 9 main accident scenarios that are distinguished for 6 EU countries [5] 30

1 Introduction

Vulnerable road users (VRUs) are particularly exposed to injuries in road accidents. Bicyclists are frequently sharing the same road with cars, trucks and buses leading to a high number of conflict zones where the probability of a possible collision is increased. Even if there is a dedicated infrastructure for bicycles, conflict points still frequently occur. In many cases, the perception zone of the drivers and riders are limited, e.g., due to obstacles, leading to dangerous situations. C-ITS technology provides means to address those scenarios, since it does not require direct line of sight.

It is very encouraging that cycling activities are currently increasing. Unfortunately, the same is true for the accident numbers involving cyclists. Therefore, equipping bicycles with C-ITS technology is an obvious step to address these accidents.

In this white paper, we are presenting a set of use cases addressing bicycle safety challenges. As a preparatory measure for this work item, we've analysed accident statistics (presented in the Annex) and selected the most relevant scenarios. Real-life situations may even be the combination of those scenarios. For example, in an urban environment a car may overtake a bicycle with a speed not expected by a cyclist coming from a perpendicular road. This is a mix of the Intersection Movement Assist and the Slow-Moving Vehicle Ahead.

This whitepaper's goal is to raise the attention and inspire bike and automotive OEMs, Tier1s and cities, fleet and delivery services to invest in deploying C-ITS technology addressing the listed, or possibly even newer use cases. This whitepaper also serves as a contextual background to the bicycle-related requirements in the Car2Car Basic System Profile.

2 Definitions

Other (informational)

Car2Car Basic System Profile v.1.6.8 [1], defines the following terms that we use extensively in the document:

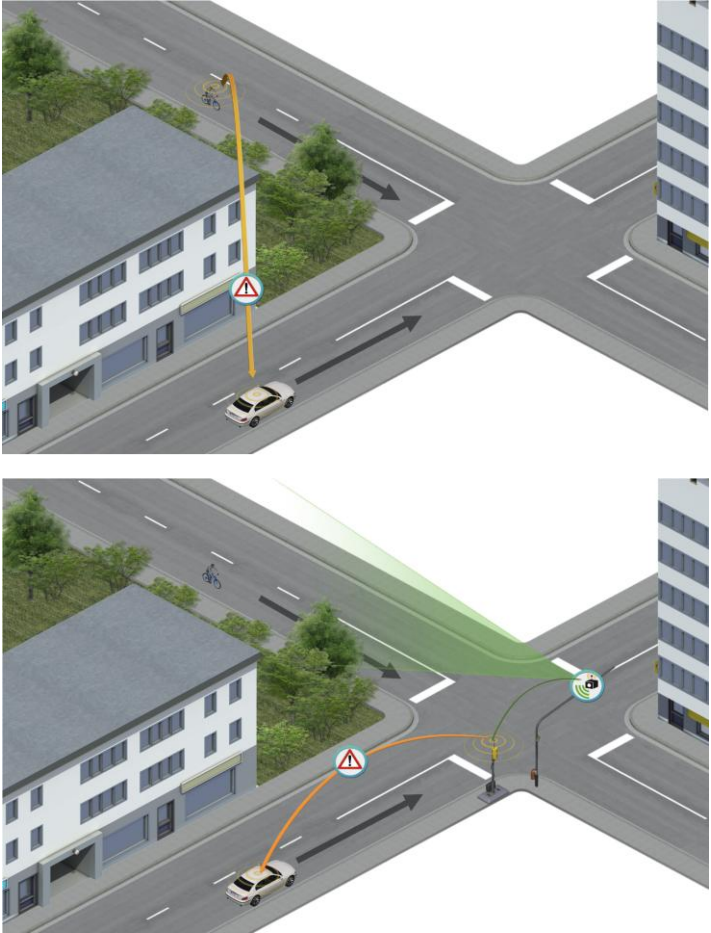
Cycle: a vehicle which has at least two wheels and is propelled at least partially by the muscular energy of the persons on that vehicle, by means of pedals or hand cranks.

3 Use Cases

3.1 Intersection Movement Assist involving bikes (IMA-B)

Intersection Movement Assist involving bikes (IMA-B)

UC_BIKE_00001

<p>Summary</p>	 <p>The Intersection Movement Assist for bike (IMA-B) V2V/I2V use case involves a bike (ego vehicle), a car (remote vehicle) and potentially a smart RSU- communicating to enhance safety at intersections. It provides notifications to the bike rider/car driver about potential collisions approaching the intersection, helping to prevent accidents.</p>
<p>Motivation</p>	<p>The motivation for the IMA-B use case is to improve safety for bike riders at intersections by providing real-time notifications about approaching vehicles. This helps to reduce the risk of accidents and enhances the overall safety of vulnerable road users.</p>

	<p>The expected benefit of the IMA-B use case includes improved safety and additionally, it contributes to the efficient flow of traffic by minimizing delays caused by accidents or congestion.</p>
<p>Roles</p>	<ol style="list-style-type: none"> 1. Bike rider: The user operating the bike, receiving notifications and alerts from its V2X OBU system, in case the bike is equipped with it. 2. Car driver: The operator of the car approaching the intersection, whose vehicle interacts with the bike via V2X communication. 3. Smart RSU equipped with sensors such as a camera, detecting road users like vehicles and bicycles, sharing their location with nearby V2X OBU systems. <p>Note- when an RSU is involved, not all participants must have an OBU V2X system to be involved. As long as one of the participants is able to receive V2X messages it can be aware of the other through Collective Perception Messages from the RSU</p>
<p>Description (incl. possibly scenarios and desired outcome)</p>	<p>The bike and the car cross each other's paths perpendicularly, typically at an intersection, cycle path crossing or in other straight path crossing scenarios.</p> <p>The aim is to avoid a side-front/front-side accident by issuing a notification to the driver of the host vehicle in case of an impending collision with a remote vehicle driving in a perpendicular direction to the ego vehicle.</p> <p>The vehicles can approach each other from the left OR right.</p> <p>The system is expected to detect approaching vehicles at an intersection and provide notifications to both the bike rider and car driver to prevent collisions. Users are intended to heed these alerts and adjust their speed or direction accordingly to ensure safe passage through the intersection.</p>
<p>Data source</p>	<p>The data sources for the Intersection Movement Assist (IMA) use case include the On-Board Unit (OBU) installed in both the bike and the car, vehicle ITS sub-systems, GNSS (Global Navigation Satellite System), and user input. These sources provide real-time information about the positions, speeds, and directions of the vehicles involved, etc., allowing the system to assess potential collision risks at the intersection.</p>

Data sink, user	Cyclist, car driver
C-ITS Messages	CAM, CAMv2, CPM
Penetration rate	<p>The V2V variant of this use case can work between one C-ITS enabled car and bike.</p> <p>However, it must be emphasized the importance of achieving a critical mass. The effectiveness of the Intersection Movement Assist (IMA) system relies on a sufficient number of vehicles equipped with C-ITS technology to ensure reliable communication and coordination at intersections. Therefore, the goal is to reach a penetration rate where a substantial portion of cars and bikes on the road are equipped with C-ITS capabilities, enabling the system to deliver its intended safety and efficiency benefits effectively.</p> <p>Alternatively, when the use case is realized with a smart RSU it may require reduced penetration rate to be effective since only one of the participants must be equipped with a C-ITS station.</p>
Expected Benefit	<p>The expected benefit of the IMA use case includes improved safety and efficiency. By providing real-time notifications to drivers about potential collisions at intersections, the system enhances road safety and reduces the risk of accidents. Additionally, it contributes to the efficient flow of traffic by minimizing delays caused by accidents or congestion.</p> <p>The added value of the IMA use case lies in its ability to prevent accidents and enhance traffic flow at intersections. Actors, including drivers of both bikes and cars, benefit from increased safety and reduced risk of collisions. Furthermore, road authorities benefit from improved traffic management and reduced accident-related costs. Overall, the IMA use case adds significant value by making intersections safer and more efficient for all road users.</p>

Intersection Movement Assist

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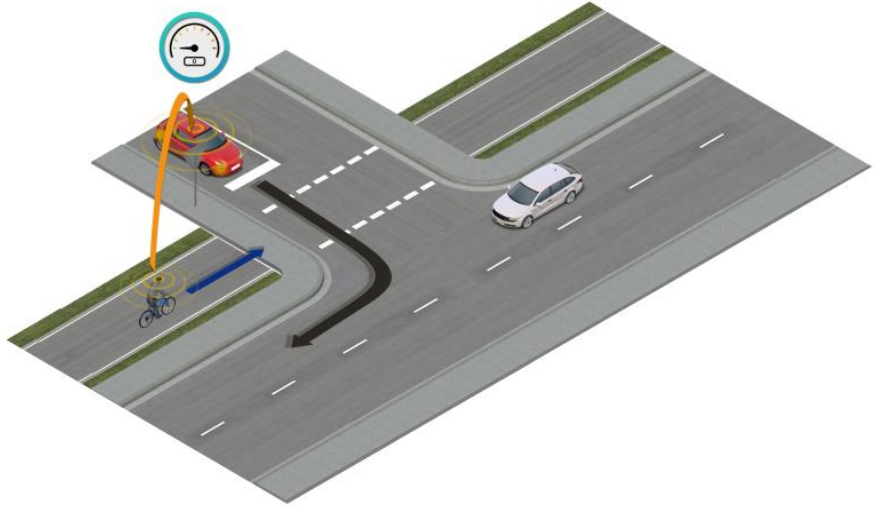
Summary	Intersection Movement Assist (IMA) is originally a V2V use case in which the ego vehicle is a car, while the remote
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	<p>vehicle is another vehicle. In case of situations where bike is involved, the remote vehicle is a bike.</p> <p>The same characteristics can be applied for this use case as in the IMA-B regarding the motivation, roles, and possible scenarios.</p> <p>The goal for the car drivers is to be able to detect the presence of an upcoming cyclist and to make possible avoiding collisions with the vulnerable road users. In this context, the use case increases awareness for the car driver primarily.</p>
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3.2 Intersection Movement Assist with Standstill Vehicle (IMA-S)

Intersection Movement Assist with Standstill Vehicle (IMA-S)

UC_BIKE_00003

<p>Summary</p>	 <p>Assuming a car is completely stopped at an intersection waiting for the possibility of departure in the closest position to the intersection (without a preceding vehicle), and a bike is approaching, the vehicle notifies the driver. If the vehicle did not start to move, then only subtly, but as soon as the car starts moving, the application should immediately deliver a notification alerting the driver about the approaching bike.</p> <p>The rationale is that if the car starts moving and the bike is near, the driver probably didn't notice it.</p> <p>Host vehicle is the car, and the remote is the bike.</p>
<p>Motivation</p>	<p>The motivation for this V2X bike to vehicle use case is to enhance safety at intersections by notifying car drivers of approaching bikes</p>

	<p>when they start moving from a stop. This notification helps prevent accidents by increasing driver awareness of nearby bikes, especially when they may not have been noticed otherwise. This use case aims to reduce the risk of collisions between cars and bikes at intersections, improving road safety for all road users.</p>
Roles	<ul style="list-style-type: none"> • Bike rider: The user operating the bike may also receive alerts from its V2X OBU system. • Car driver: The operator of the car approaching the intersection, whose vehicle interacts with the bike via V2X communication. The driver receives notifications about the passing bike. <p>Since the use case is V2V-based, there is no additional (infrastructure, service provider) entity involved.</p>
Description (incl. possibly scenarios and desired outcome)	<ul style="list-style-type: none"> • Scenario 1: A bike is approaching an intersection where a car is stopped. The car is about to enter the intersection from the front position, without the need for waiting for a preceding vehicle's departure. As soon as the car starts moving, the bike's proximity triggers a notification to the car driver, alerting them to the approaching bike. • Scenario 2: A car is waiting to make a right turn at an intersection in the front position, and a bike is approaching from behind. When the car begins to turn, the bike's presence triggers a notification to the car driver, prompting them to wait for the bike to pass safely. • Scenario 3: A car is turning left at an intersection, and a bike is approaching from the opposite direction. As the car initiates the left turn, the bike's proximity prompts a notification to the car driver, reminding them to yield to oncoming traffic, including the bike

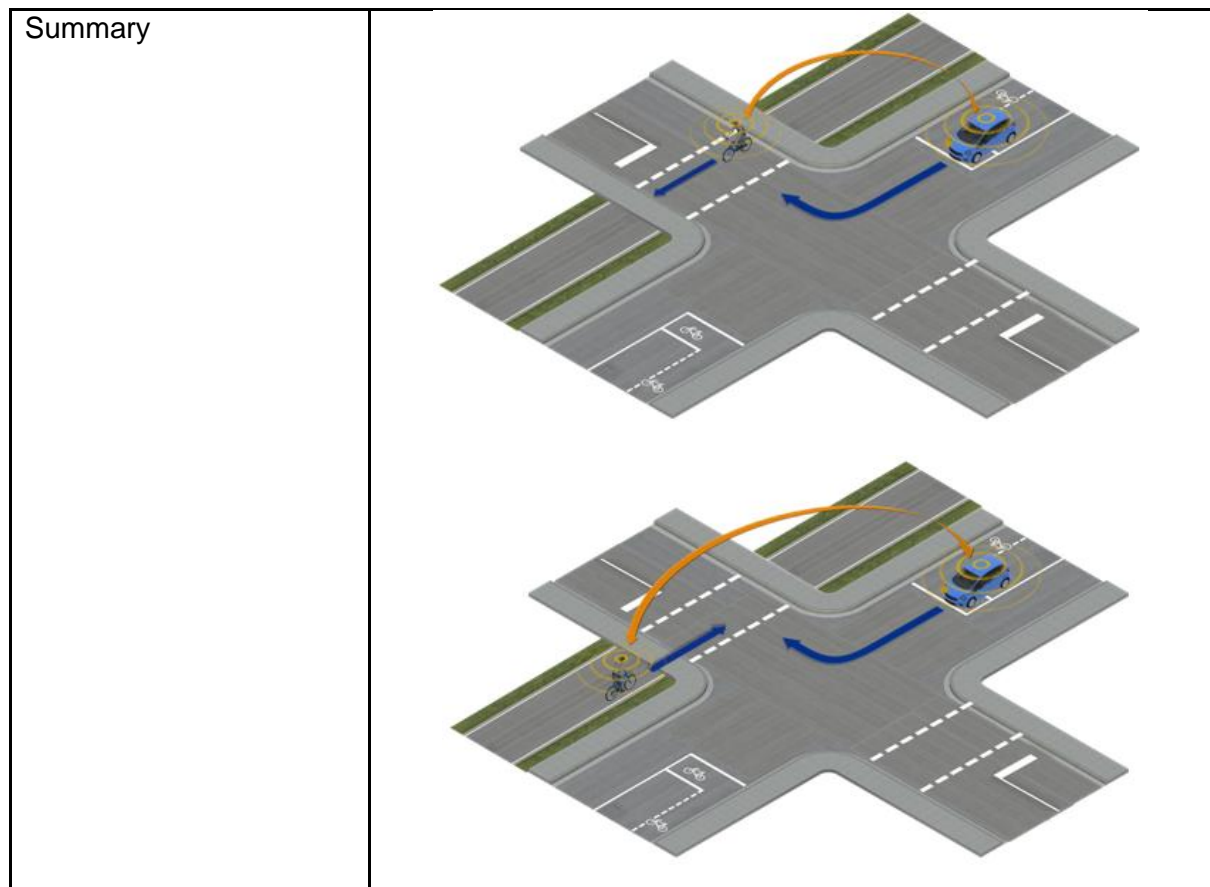
Data source	<p>The data sources for the IMA Standstill use case include the On-Board Unit (OBU) installed in both the bike and the car, vehicle ITS sub-systems, GNSS (Global Navigation Satellite System), and user input such as brake pedal / gas pedal position. These sources provide real-time information about the positions, speeds, and directions of the vehicles involved, etc., allowing the system to assess potential collision risks at the intersection.</p>
Data sink, user	<p>Cyclist, car driver</p>
C-ITS Messages	<p>CAM, CAMv2</p>
Penetration rate	<p>The required number of cars using C-ITS or equipped with the necessary infrastructure to run the use case depends on the</p>

	<p>desired effectiveness and coverage of the system. A higher penetration rate of cars equipped with C-ITS would lead to better outcomes in terms of safety, efficiency, and traffic management. However, even with a lower penetration rate, the use case can still provide significant benefits.</p>
<p>Expected Benefit</p>	<p>The expected benefits and added values of the IMA Standstill V2X use case include:</p> <ul style="list-style-type: none"> • Safety Improvement • Reduced Accidents • Cyclist Protection • Enhanced Awareness

3.3 Right-turn Warning for bike (RTW-B)

Right-turn Warning for bike (RTW-B)

UC_BIKE_00004



	<p>In the Right-turn Warning for bike (RTW-B) V2X use case, the bike (ego vehicle) sends an alert / a notification to the cyclist when it detects that the car (remote vehicle) intends to turn right while the bike is traveling straight and parallel to the car. This alert helps prevent potential collisions by notifying the car driver of the presence of the bike in its path.</p>
<p>Motivation</p>	<p>The motivation for the Right-turn Warning V2X use case is to enhance safety for cyclists and prevent collisions with vehicles making right turns.</p> <p>The expected benefits include reducing the risk of accidents at intersections, increasing awareness among drivers about nearby cyclists, and ultimately improving road safety for all road users.</p>
<p>Roles</p>	<ul style="list-style-type: none"> • Bike rider: The user operating the bike, receiving alerts from its V2X OBU system. • Car driver: The operator of the car approaching the intersection, whose vehicle interacts with the bike via V2X communication. <p>I2V version is also imaginable. For that case, the RSU equipped with a sensor would also be included.</p>
<p>Description (incl. possibly scenarios and desired outcome)</p>	<p>The bike and the car cross each other's paths while the bike going straight and the car turning right.</p> <p>The aim is to support right turn manoeuvre in an intersection, and to increase safety and manoeuvring confidence by providing potential collision notifications in right turning situations.</p> <p>The bike can approach from the opposite or in the same direction parallel with the car, while the car turns right in each situation.</p> <p>From the use case perspective, the host is the bike and the remote vehicle is the car.</p> <p>The desired outcome in each scenario is to prevent a collision between the car and the bike by providing timely notifications to the driver about the presence of the cyclist. This helps ensure safer interactions between vehicles and cyclists at intersections and other areas where right turns are made.</p>

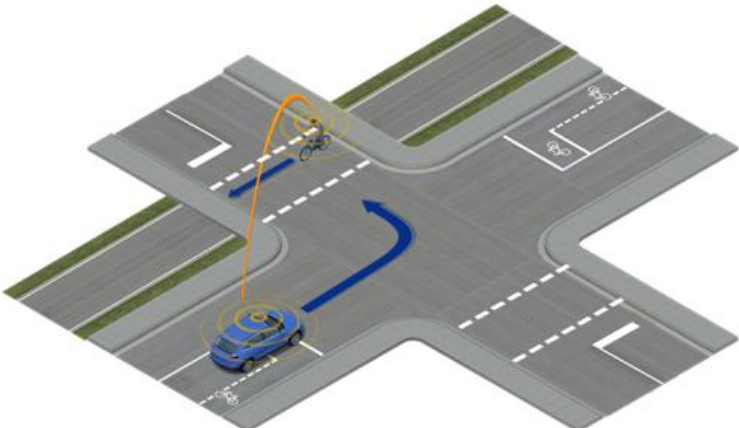
Data source	The data sources for the Right-turn Warning use case include the On-Board Unit (OBU) installed in both the bike and the car, vehicle ITS sub-systems, GNSS (Global Navigation Satellite System), and user input. These sources provide real-time information about the positions, speeds, and directions of the vehicles involved, etc., allowing the system to assess potential collision risks at the intersection.
Data sink, user	Cyclist, car driver
C-ITS Messages	CAM, CAMv2
Penetration rate	<p>The use case itself can work between one C-ITS enabled car and bike.</p> <p>However, it must be emphasized the importance of achieving a critical mass. The effectiveness of the use case relies on a sufficient number of vehicles equipped with C-ITS technology to ensure reliable communication and coordination at intersections. Therefore, the goal is to reach a penetration rate where a substantial portion of cars and bikes on the road are equipped with C-ITS capabilities, enabling the system to deliver its intended safety and efficiency benefits effectively.</p>
Expected Benefit	<p>The expected benefits and added values of the Right-turn Warning V2X use case include:</p> <ul style="list-style-type: none"> • Safety Improvement: By alerting drivers to the presence of cyclists, the use case reduces the risk of right-turn collisions between cars and bikes, enhancing overall road safety. • Reduced Accidents: By providing timely notifications to drivers, the use case helps prevent accidents and injuries involving cyclists, contributing to a decrease in road traffic incidents. • Cyclist Protection: The use case prioritizes the safety of cyclists by ensuring that drivers are aware of their presence, thereby reducing the likelihood of accidents caused by right-turning vehicles. • Enhanced Awareness: Drivers become more aware of their surroundings, particularly the presence of cyclists, leading to improved attentiveness and better decision-making at intersections and other areas prone to right-turn conflicts.

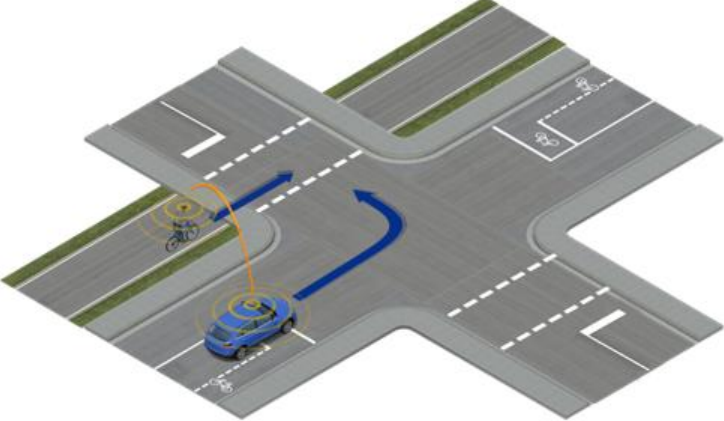
<p>Summary</p>	<p>Right-turn Warning (RTW) is originally a V2V use case in which the ego vehicle is a car, while the host vehicle is another vehicle. In case of situations where bike is involved, the remote vehicle is a bike.</p> <p>The same characteristics can be applied for this use case as in the RTW-B regarding the motivation, roles, and possible scenarios.</p> <p>The motivation, roles, and possible scenarios for this use case remain the same as in RTW-B.</p> <p>The goal for car drivers is to detect the presence of an approaching cyclist and to avoid collisions with vulnerable road users. This use case primarily increases awareness for car drivers.</p>
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3.4 Left-turn Warning for bike (LTW-B)

Left-turn Warning for bike (LTW-B)

UC_BIKE_00006

<p>Summary</p>	
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	 <p>In the Left-turn Warning for bike (LTW-B) V2X use case, the bike (ego vehicle) sends an alert / a notification to the cyclist when it detects that the car (remote vehicle) intends to turn left while the bike is traveling straight and parallel to the car. This alert helps prevent potential collisions by notifying the car driver of the presence of the bike in its path.</p> <p>All the characteristics listed for the RTW-B use case also apply to the LTW-B use case.</p>
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Left-turn Warning

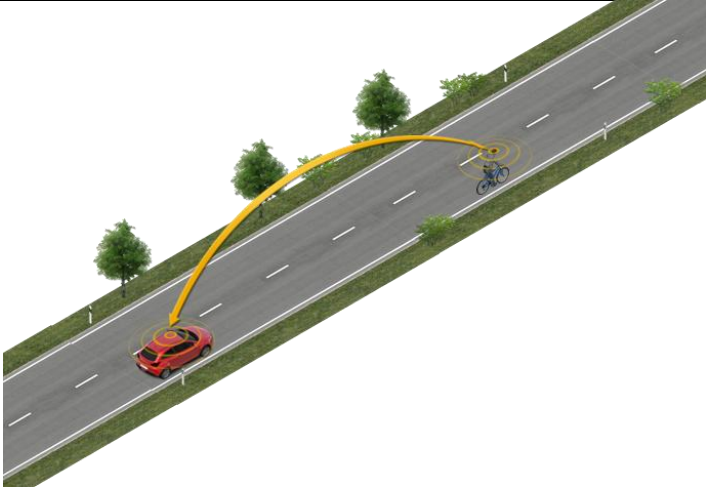
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<p>Summary</p>	<p>The same characteristics can be applied for the LTW use case as in the RTW regarding the motivation, roles, and possible scenarios. The only difference is the intended path of the car.</p> <p>The ego vehicle is the car while the remote is the bike.</p> <p>The motivation, roles, and possible scenarios for this use case remain the same as in RTW.</p>
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3.5 Slow Moving Vehicle Ahead

Slow Moving Vehicle Ahead (SMVA)

UC_BIKE_00008

<p>Summary</p>	 <p>Car is approaching a slow moving bike, or a group of bikes, called peloton, traveling in the same lane and direction. The car driver gets notification about the possible front-end collision.</p> <p>The notification helps avoiding accidents by increasing the driver's awareness of slow-moving vehicle ahead. There might be more vehicles between the slow vehicle and the car.</p> <p>The host vehicle is the car, and the remote is the bike.</p>
<p>Motivation</p>	<ul style="list-style-type: none"> • Increased Safety: The notification helps to avoid accidents by alerting the car driver about the possibility of a front-end collision with the slow-moving bike, or a peloton, thereby increasing safety for both the driver and the bike rider. • Collision Prevention: By providing timely information about the presence of a slow-moving vehicle or vehicles ahead, the notification enables the car driver to take necessary precautions to prevent a collision. • Enhanced Awareness: The notification enhances the driver's awareness of the road environment, especially the presence of vulnerable road users such as bikes, thereby reducing the risk of accidents. • Improved Traffic Flow: By alerting the car driver about the slow-moving bike(s), the use case contributes to smoother traffic flow by preventing sudden stops or collisions, especially in congested areas.

	<p>The motivation behind this use case is to leverage V2X communication to enhance road safety and prevent accidents involving bikes and cars. By providing real-time notifications to car drivers, the system aims to reduce the likelihood of collisions and create a safer road environment for all users.</p>
<p>Roles</p>	<ul style="list-style-type: none"> • Bike rider: The user operating the bike, whose vehicle interacts with the bike via V2X communication. • Car driver: The operator of the car approaching the cyclist,. receiving alerts from its V2X OBU system <p>Since the use case is V2V-based, there is no additional (infrastructure, service provider) entity involved.</p>
<p>Description (incl. possibly scenarios and desired outcome)</p>	<p>Step 1</p> <ul style="list-style-type: none"> • For Scenario 1: Car Approaching Slow-moving bike: The car is approaching a slow-moving bike traveling in the same lane and direction. The V2X system detects the proximity and relative speed between the car and the bike, sending a notification to the car's onboard system. • For Scenario 2: Car Navigating Through Traffic: The car is navigating through traffic, and there are multiple vehicles between the car and the slow-moving bike. The V2X system identifies the bike's position and velocity relative to the car, alerting the driver about the presence of the bike. <p>Step 2: Driver Receives Notification: Upon receiving the notification, the car driver becomes aware of the slow-moving bike ahead. The driver can then adjust their speed or change lanes to avoid a potential collision.</p> <p>Step 3: Driver Takes Preventive Action: The driver takes preventive action, such as slowing down, maintaining a safe distance, or signaling to alert other vehicles, to avoid a front-end collision with the bike.</p> <p>The desired outcome is to prevent accidents by increasing the car driver's awareness of the slow-moving bike ahead. By providing timely notifications and enabling proactive measures, the V2X system helps ensure the safety of both the car driver and the bike rider, reducing the risk of collisions and promoting smoother traffic flow.</p> <p>All of the mentioned scenarios are applicable for pelotons, or groups of cyclists as well.</p>

Data source	The data sources for the Slow Moving Vehicle Ahead use case include the On-Board Unit (OBU) installed in both the bike and the car, vehicle ITS sub-systems, GNSS (Global Navigation Satellite System), and user input. These sources provide real-time information about the positions, speeds, and directions of the vehicles involved, etc., allowing the system to assess potential collision risks at the intersection.
Data sink, user	Cyclist, car driver
C-ITS Messages	CAM, CAMv2
Penetration rate	The required number of cars using C-ITS or equipped with the necessary infrastructure to run the use case depends on the desired effectiveness and coverage of the system. A higher penetration rate of cars equipped with C-ITS would lead to better outcomes in terms of safety, efficiency, and traffic management. However, even with a lower penetration rate, the use case can still provide significant benefits.
Expected Benefit	The expected benefits and added values of the Right-turn Warning V2X use case include: <ul style="list-style-type: none"> • Safety Improvement • Reduced Accidents • Cyclist Protection • Enhanced Awareness

Backward Collision Warning for bike (BCW-B)

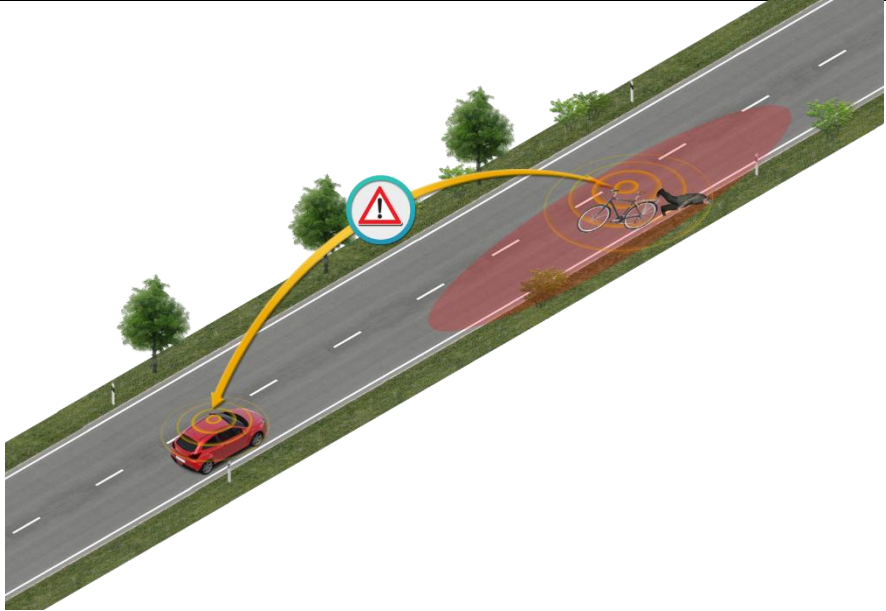
UC_BIKE_00009

Summary	<p>In a situation where a car is approaching a cyclist traveling in the same lane and direction closely with high speed from behind, the cyclist gets notification about the upcoming vehicle.</p> <p>The notification helps avoiding accidents by increasing the cyclist's awareness of nearby vehicles.</p> <p>The host vehicle is the bike, and the remote vehicle is the car.</p> <p>The same characteristics can be applied for the BCW-B use case as in the SMVA regarding the motivation, roles, and possible scenarios.</p>
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3.6 Bike Accident Warning

Bike Accident Warning (BAW)

UC_BIKE_00010

<p>Summary</p>	 <p>In this use case, a cyclist falls off their bike on the road, creating a potential hazard for approaching vehicles. The goal is to inform the driver of an approaching car about the cyclist's accident to prevent a secondary collision. The bike's On-Board Unit (OBU) sends a DENM to the car's OBU, detailing the accident type and location (lane segment) on the road.</p>
<p>Motivation</p>	<p>The primary motivation is to enhance road safety by preventing secondary accidents that could occur when a car approaches a fallen cyclist. Immediate notification to the driver allows them to take evasive action, potentially saving lives and reducing injuries.</p>
<p>Roles</p>	<ul style="list-style-type: none"> • bike rider: The vulnerable road user who has fallen off their bike and is at risk of further injury from approaching vehicles. • Car driver: The person operating the vehicle approaching the fallen cyclist. They need timely information to avoid hitting the cyclist. <p>Since the use case is V2V-based, there is no additional (infrastructure, service provider) entity involved.</p>
<p>Description (incl. possibly scenarios)</p>	<ul style="list-style-type: none"> • A cyclist falls off their bike on a busy road segment. The bike's OBU immediately sends a DENM to nearby vehicles, including an approaching car. The car's OBU receives the message and alerts the driver, who slows down and safely

and desired outcome)	<p>navigates around the fallen cyclist. The message is relevant for vehicles coming from both directions.</p> <ul style="list-style-type: none"> • Cyclist Falls on a Curvy Road: On a winding road, a cyclist falls and is not visible to drivers approaching the curve. The bike's OBU sends a DENM as soon as the fall is detected. The approaching car receives the alert in time to reduce speed and avoid hitting the cyclist when they come into view. • Nighttime Accident: A cyclist falls off their bike at night on a poorly lit road. The bike's OBU sends out a DENM to alert any approaching vehicles. The car's OBU receives the alert, and the driver is notified about the hazard ahead, allowing them to take necessary precautions.
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Data source	The data sources for the Bike Accident Warning use case include the On-Board Unit (OBU) installed in both the bike and the car, vehicle ITS sub-systems, GNSS (Global Navigation Satellite System), and user input. These sources provide real-time information about the positions, speeds, and directions of the vehicles involved, etc., allowing the system to assess potential collision risks at the intersection.
Data sink, user	Cyclist, car driver
C-ITS Messages	CAM, DENM
Penetration rate	Effective implementation requires a significant number of vehicles equipped with OBUs capable of receiving V2X messages. High penetration rates ensure timely and widespread alerting of potential hazards
Expected Benefit	Significantly enhances the safety of cyclists by preventing secondary collisions.

4 Use case mapping table for releases

In the following table we are summarizing the achievable level of notification level assuming compliance with a certain BSP release.

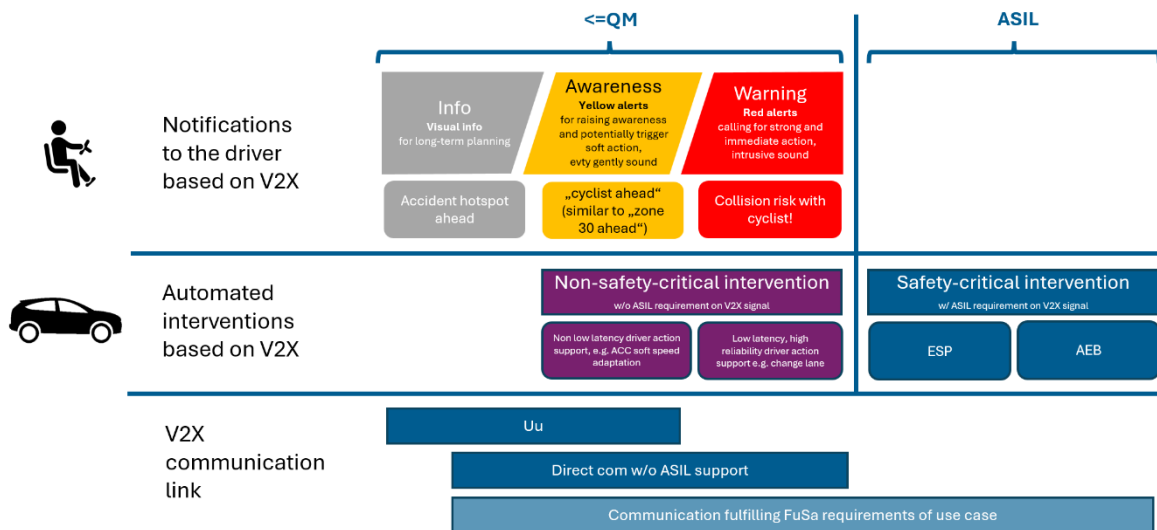


Figure 1. Alert levels

The implementation of the alert levels is generally OEM-specific. However, in this paper we propose three distinct levels of alerts to indicate the expected capabilities of the listed applications.

The level Info represents the lowest level of indication towards the bike rider or the vehicle driver. In case of Info, the visualization of the danger is continuously present, but lacks aggressive representation. A temporal audio alert may be issued.

The Awareness level has a higher severity, but it may not carry lane-level information. For this type of alert, the high probability for direct contact does not need to be proven. It may trigger continuous visualization, supported by audio signals. The triggering should happen in a way so that the driver has sufficient amount of time to assess the situation and react accordingly. The following table summarizes the alert levels.

Warning is the highest alert level. It triggers a continuous, aggressive audio-visual signal for the driver/rider. A situation with Warning level indicates an imminent danger.

Table 3. Example alert level time thresholds

Alert level	Example time to intersection point ¹
Info	> 10-30sec
Awareness	> 3-15sec
Warning	<= 5sec

The target severity level also depends on the chosen use case. Some use cases are even more powerful with lower alert level, whereas some only make sense with a higher alert level.

The table below summarizes the achievable alert levels assuming compliance with the respective BSP release. For BSP1, the existing profile [1] includes the assumptions.

Table 4. Alert levels mapped to the use cases

Use case	Alert level assuming BSP1 compliance	Prognosed possible alert level assuming at least lane level accuracy
Intersection Movement Assist for bikes (IMA-B)	Awareness	Warning
Intersection Movement Assist with Standstill Vehicle (IMA-S)	Awareness	Warning
Right-turn Warning for bikes (RTW-B)	Awareness	Warning
Left-turn Warning for bikes (LTW-B)	Awareness	Warning
Slow Moving Vehicle Ahead	Awareness	Warning
Bike Accident Warning	Awareness	Warning

¹ The exact values may vary based on the speed of the vehicle and the scenario.

5 References

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- [2] Traffic safety of e-bikes and technical solutions to increase cycling safety, *Oliver Maier*, International Cycling Safety Conference 2020
- [3] Unfalltypen-Katalog Leitfaden zur Bestimmung des Unfalltyps, *Unfallforschung der Versicherer*, Available: <https://www.udv.de/resource/blob/80022/89b4d80028aacf8cab649d3a3c6157a0/unfalltypenkatalog-data.pdf>
- [4] The "Typical" Car-Cyclist Collision Under the Microscope: A GIDAS-based Analysis of the Prevalent Crash Scenario, *27th International Technical Conference on the Enhanced Safety of Vehicles, ESV 2023*, Available: <https://index.miramart.com/27esv/PDFfiles/27ESV-000270.pdf>
- [5] CATS Deliverable 1.2: CATS car-to-cyclist accident scenarios. *TNO*, Available: <https://publications.tno.nl/publication/34622250/cNYv1h/TNO-2014-R11594.pdf>

6 Appendix A – Accident analysis and use case prioritization

6.1 Accident Research

6.1.1 Input data

Bicycle-to-car accidents have been analyzed based on two main inputs:

- GIDAS (German In-Depth Accident Study) is a unique database as the input data is provided by experts on crash reconstruction who join the police at the crash site and record the crash in great detail.
- Further databases are considered by the CATS study.

6.1.2 Analysis and results

6.1.2.1 Results of GIDAS database analysis

In [2], the occurrence probability of bike-to-car accident scenarios was analysed. Figure 2 shows the results. According to this analysis, the most relevant scenarios are intersection scenarios, especially cyclist coming from left or right and right-turn scenarios.

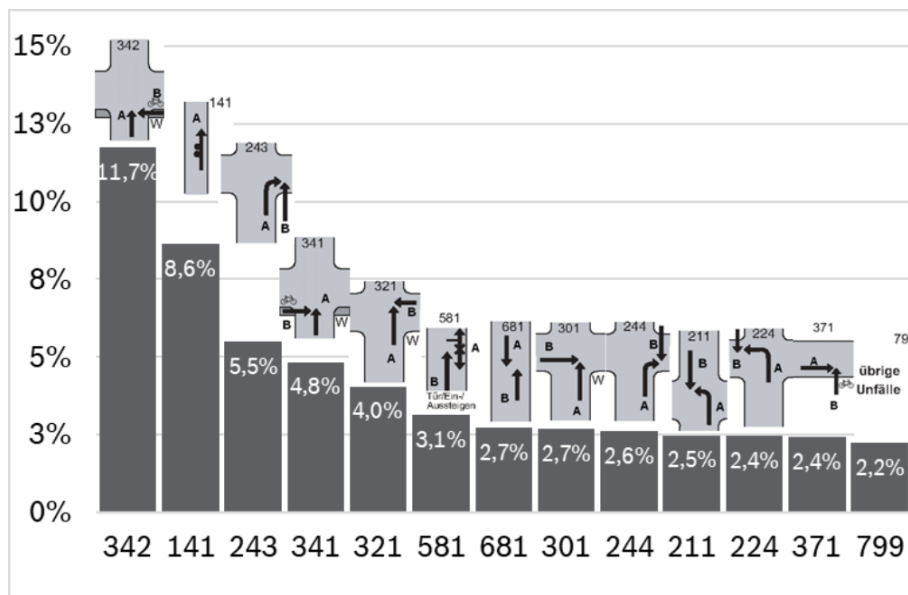


Figure 2: Ranking of probability of bike-to-car accident scenarios, according to [2]. The codes are taken from Unfalltypenkatalog [3]

An even more detailed analysis on recent accident statistics from GIDAS (2020-2021) has been done in [4].

Table 2.
Frequency distribution of the five most common car-cyclist crash scenarios

Rank	Rank KSI	Scenario	included UTYPEs	Count	Count KSI
1 st	1 st	before junction / car has to yield / cyclist from the right (on cycleway)	342	1776	275
2 nd	4 th	before junction / car has to yield / cyclist from the left (on cycleway)	341	682	127
3 rd	10 th	junction / turning right / cyclist in same direction on cycleway	242, 244, 275, 284, 285	560	61
4 th	7 th	junction / car has to yield / cyclist from left (on road)	301-303, 311, 312, 352	474	91
5 th	2 nd	junction / car has right of way / cyclist from the left (on road)	241, 243, 275, 284, 285	416	142

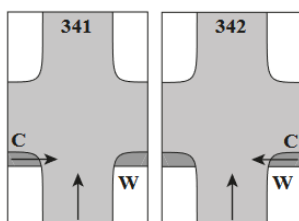


Figure 3: Frequency distribution of the most common car-cyclist crash scenarios and sketch of the most relevant scenarios UTYP 341 and 342 [4]

Not only the ranking of the most dominant accident scenarios (in general and with focus on KSI) is provided (see Figure 3, but also a lot of detailed analysis on the context of the accidents (traffic conditions, way of right conditions, lighting conditions and much more).

It turns out that especially the topmost scenarios, 342 and 341, usually happen in rather low traffic densities, rather T-Crossings or property exits (and not 4-way-intersections), mostly with the car’s intention to turn right (and e.g. not expect cyclists from right-hand side).

It also reveals the role of visual obstructions (~20% for #341, ~35% for #342), blocking the view at a time where the collision could have been prevented; in these situations, a warning to both (the cyclist and the car driver) seems to be meaningful.

In addition, even in line-of-sight #342 situations, the car driver does not see the cyclist because, turning right, his attention is to the traffic coming from the left-hand side. In many #341 situations, the car driver looks into the direction of the oncoming cyclist, but still does not perceive him. These situations again seem to justify appropriate hints or notifications to the car driver.

6.1.2.2 Results of CATS analysis

Even though based on older data, the Bike-2-Car accidents analysed in the CATS project still reveal lots of interesting information on Bike-2-Car crashes [5].

It includes several databases (besides GIDAS). The scenarios were clustered in a slightly different way, and the focus was on Severe Injuries (SI) and Killed (K), see Figure 4.

Interestingly, the lateral accidents show huge differences in the different regions of Europe (very rare in e.g., the Netherlands, but very prominent in southern countries of EU). Even in Germany, the role of the lateral accidents seems to be more dominant than in the GIDAS data above. Therefore (and also because lateral accidents are dominant in the US statistics), lateral accidents should also be addressed with priority.

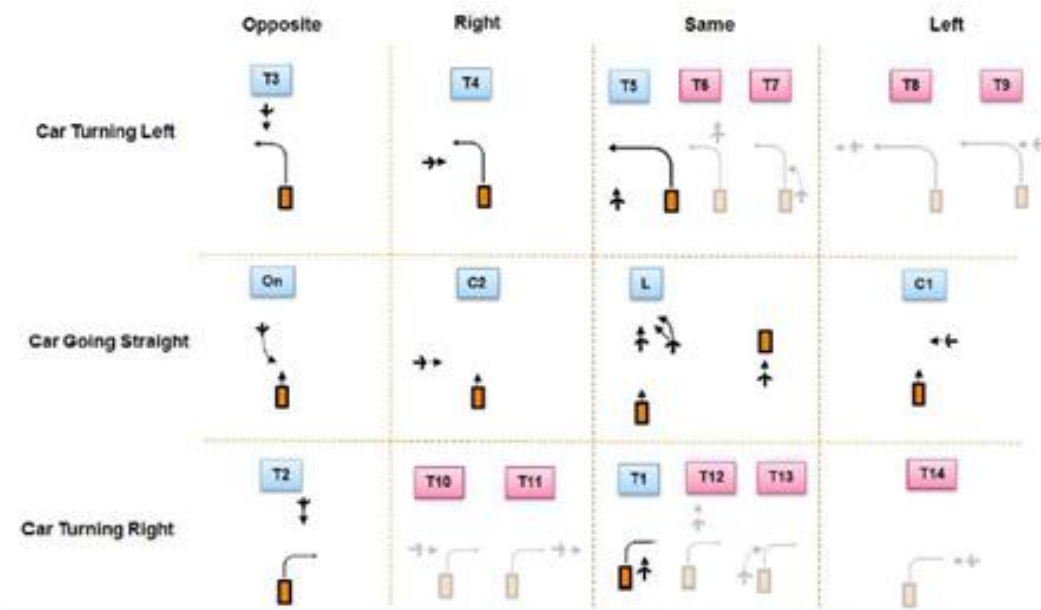


Figure 4: Accident type clustering and probability distributions from CATS project [5]

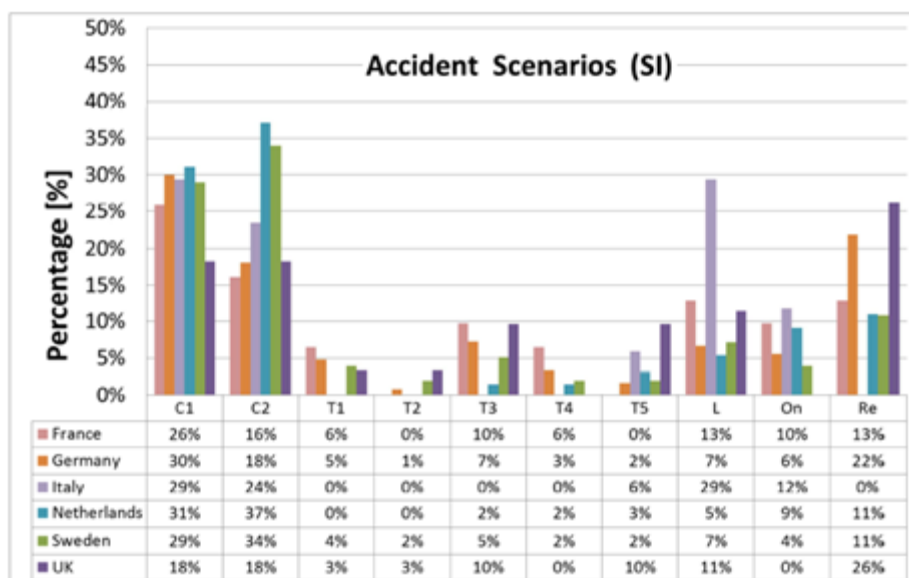


Figure 5: Distribution of seriously injured over the 9 main accident scenarios that are distinguished for 6 EU countries [5]

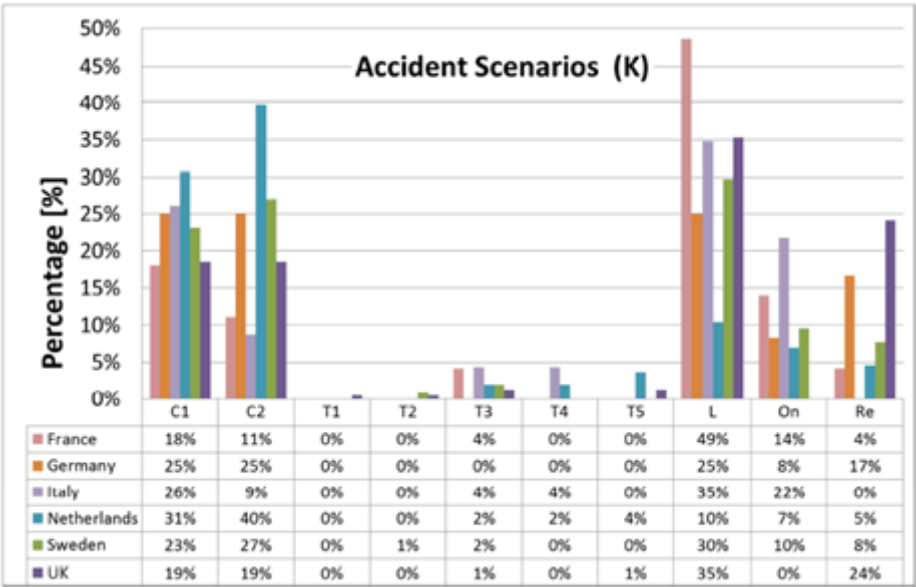


Figure 6: Distribution of fatally injured over the 9 main accident scenarios that are distinguished for 6 EU countries [5]

6.1 Prioritization of scenarios

Based on the rankings of the previously introduced statistics, and the corresponding impacts, it seems to be appropriate to focus on:

- Crossing Scenarios (esp. #341, #342 situations, see Figure 2)
 - For bikes and cars especially in obstructed scenarios
 - Additionally, especially for cars in these situations:
 - "fail to look" at cyclists coming from the right (#342)
 - "look but fail to see" cyclists from the left (#341)
 - Relates to:
 - E-Bike nearby,
 - Intersection Movement Assist
- Right-turn warning (cyclist and car in same direction)
 - for cars
 - for cyclists (at least in case of obstructions, otherwise cyclist sees the car and car's intention (blinker))
- Lateral scenario (car and bike in same direction, car approaching from behind, especially on rural roads)
 - especially to cars (Slow moving vehicle ahead)
 - potentially also to bikes (in order to make them ride more to the right-hand side of the street)