Incorporation of uncrewed ground robots in ITS

5GAA Automotive Association
Technical Report

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Foreword

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The contents of the present document are subject to continuing work within the Working Groups (WG) and may change following formal WG approval. Should the WG modify the contents of the present document, it will be re-released by the WG with an identifying change of the consistent numbering that all WG meeting documents and files should follow (according to 5GAA Rules of Procedure):

x-nnzzzz

(1) This numbering system has six logical elements:
- (a) x: a single letter corresponding to the working group:
  where x =
  T (Use cases and Technical Requirements)
  A (System Architecture and Solution Development)
  P (Evaluation, Testbed and Pilots)
  S (Standards and Spectrum)
  B (Business Models and Go-To-Market Strategies)
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Introduction

An uncrewed ground robot (UGR), which travels along the ground without people (including a driver) on board, includes robots for delivery, road cleaning, road works (e.g., lane marking, pothole repairing), etc. Many activities are ongoing to test various kinds of UGR and start their commercialization. For example, delivery robots are a specific type of UGR that are becoming an everyday sight in some cities [1][2]. They have emerged as convenient and cost-effective tools for last-mile logistics, and regulations enabling delivery robots are being prepared in some countries; for example, an act defining the basic rules for personal delivery devices (PDD) came into effect in around 20 states in the U.S. [3][4]. Also, in Korea, a high-level plan for legislation has been established for 'outdoor delivery robots' driving in parks and on sidewalks [5]. In Japan, meanwhile, there are guidelines for demonstrating delivery robots on public roads provided by the Japanese government – National Police Agency (NPA) – so as to prepare basic policy based on the result of the demonstration and enhance social acceptance [6]. As another example of demonstrations for UGRs, 5G-based road cleaning and police robots were tested in China [7][8], and an AI-based pothole repair robot is under development in the UK [9][10]. Thus, it is clear that various kinds of UGRs will become another type of road user in the near future. Also, it is expected that UGRs are or will be connected via 4G/5G mobile network to a service controlling and scheduling the fleet operation. It is, however, not clear to what extent these robots are going to be controlled in real time or whether they will operate autonomously.

So far, UGRs have not been explicitly considered in current intelligent transport system (ITS) standards, because the focus has been on mobility for people on board and has thus not considered robots as a road user moving around on roadways as well as sidewalks. However, there are news reports and research findings describing accident and safety issues caused by UGRs [11][12][13] and in [14]; mobile robots (e.g., delivery robots) are much less visible than cars, and people are less acquainted with dangers associated with the robots (compared to the dangers caused by cars or other conventional road users). Therefore, UGRs can benefit from C-V2X-based interaction with other traffic users (e.g., car, cyclist, pedestrian, roadside unit (RSU), traffic light, uncrewed aerial/surface/underwater vehicle). Also, incorporating UGRs in ITS would add another dimension to the C-V2X technology evolution and enhance traffic safety and efficiency in the presence of this new type of road user.

1. Scope

The present 5GAA Technical Report provides the state of the art including demonstrations and market status, (regional/international) regulation, and safety-related aspect regarding UGRs as well as common analysis and system/component requirements for UGRs. Thereafter, this present document describes a gap analysis of the existing ITS use cases and identifies potential updates and/or additional use cases for the operation of UGRs in ITS. With this gap analysis, the present document also shows the methods of communication between UGRs and road users in view of existing gaps in ITS standards, and it identifies a way forward to incorporate UGRs in future standards.

2. References

- References are either specific (identified by date of publication, edition number, version number, etc.) or nonspecific.
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3. Definitions and abbreviations

3.1. Definitions

For the purposes of the present document, the following definitions apply:

Uncrewed ground robot: robot that travels on the ground without people (including a driver) on-board.

3.2. Abbreviations

ARRES	Autonomous Road REpair System
AV	Automated Vehicle
BSM	Basic Safety Message
CAGR	Compound Annual Growth Rate
CAM	Cooperative Awareness Message
CPM	Collective Perception Message
C-V2X	Cellular-V2X
ETSI	European Telecommunications Standards Institute
EU	European Union
FMVSS	Federal Motor Vehicle Safety Standards
GVWR	Gross Vehicle Weight Rating
HMI	Human Machine Interface
HTA	Highway Traffic Act
HV	Host Vehicle
IFR	International Federation of Robotics
ITS	Intelligent Transport Systems
LSV	Low Speed Vehicle
MEC	Mobile Edge Computing
METI	Japan's Ministry of Economics, Trade and Industry
MTO	Ministry of Transportation of Ontario
MUD	Micro-Utility Device
NACK	Negative Acknowledgement
NHTSA	National Highway Traffic Safety Administration
NPA	National Police Agency
PDD	Personal Delivery Devices
PennDOT	Pennsylvania Department of Transportation
PSM	Personal Safety Message
RSE	Roadside Equipment
RSU	Roadside Unit
RTA	Road Traffic Authorities
SAE	Society of Automotive Engineers
SDSM	Sensor Data Sharing Message
SLR	Service Level Requirements
StVO	Strassen Verkehrs-Ordnung (Road Traffic Regulations in English)

StVZO	Strassen Verkehrs-Zulassung-Ordnung (Road Traffic Licensing Regulations in English)
TC	Technical Committee
TIC	Transport Innovation Challenge
ToD	Tele-operated Driving
TTC	Time To Collision
UCD	Use Case Description
UGR	Uncrewed Ground Robot
US DOT	United States Department of Transportation
VAM	VRU Awareness Message
VRU	Vulnerable Road User

4. Landscape of UGRs

Uncrewed ground robots (UGR) are used in a wide range of applications across various industry verticals providing a range of services such as delivery, road cleaning, road survey services, and more. [15] This section conveys some of the representative UGRs, providing different kinds of services from various aspects, including market status, state of the art, international/regional regulations, and the impact of UGRs on safety and traffic efficiency.

4.1. Robot for delivery

4.1.1. Definition

UGRs which provide delivery services typically offer or bring a variety of goods to customers, including food, parcels/mail, and pharmaceuticals.

4.1.2. Market status

According to the report by Astute Analytica [15], which provides a detailed and comprehensive study of the field, the global delivery robot market was valued at US$100.8 million in 2021 and is projected to reach US$262.7 million by 2027, growing at a Compound Annual Growth Rate (CAGR) of 17.31% from 2022 to 2027, while the market size by volume is expected to grow from 19,331 units in 2021 to 56,633 units by 2027, at a CAGR of 19.6% during the same forecast. The delivery robot market in this report includes indoor and outdoor delivery robots.

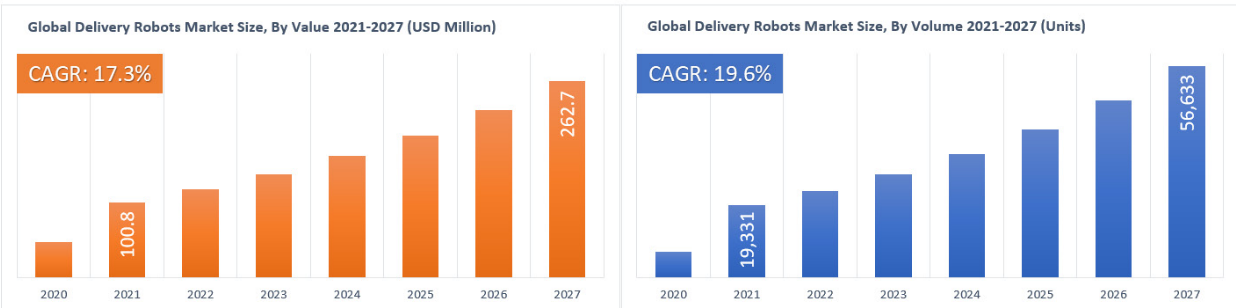


Figure 1 Global delivery robots market size [15]

As shown in *Figure 1*, it is clear that the global market size of delivery robots is steadily increasing until 2027, but not yet sufficient to have attracted regulatory interest. According to the report 'World Robotics 2021 – Service Robots' [16], which presents a market survey of service robots carried out by the International Federation of Robotics (IFR) in 2021, the lack of a legal framework for the deployment of delivery robots inhibits the robot market expansion.

Nevertheless, four key players are pushing ahead with UGR-based delivery services and commercialization.

1. Robot manufacturers

   As well as start-up robot manufacturers such as 'Nuro', 'Starship Technologies', 'Eliport' and 'Kiwi Campus', automotive OEMs (e.g., Volkswagen, Toyota, Hyundai) and automotive part-makers (e.g., Valeo, Continental) develop and manufacture UGRs. The participation and investment of these manufacturers in robot development is an important catalyst in determining the robot market size.

2. Service providers

   Service providers include e-commerce platforms (e.g., Amazon, Rakuten, Meituan), logistic companies, postal and parcel delivery companies (e.g., FedEx, DHL, UPS, PostNL), food delivery companies (e.g., Uber Eats, Delivery Hero, Domino), and public service providers. The market for UGR is growing as more and more providers and services start using UGRs.

3. Tele-communication operators

   Connectivity is an important element in the deployment of UGRs on roads. Advanced connectivity solutions providing lower latency, higher data-rates and more reliable connectivity performance can support more efficient and robust UGR-based services and operations.

4. Road/Facility management administrations

   In order to operate UGRs on public roads, permission must be obtained from road traffic authorities (RTA) such as transportation ministries, police agencies, and local authorities. Accordingly, there are activities and emerging policies to ease regulations related to the operation of UGRs on public roads in some countries. In other cases, to facilitate the operation of UGRs in private domains (e.g., shopping malls, hospitals, amusement parks, resorts/hotels, etc.), facility owners or managers are activating pilot programs to provide UGR-based delivery services on their territories.

It is noted that there are various activities to grow the robot market such as demos/trials based on collaborations between different key players/fields/industries. For example, collaboration between robot manufacturers and service providers (e.g., Starship Technology and Domino [17], Panasonic and Rakuten [18], and Valeo and Meituan [19]).

4.1.3. Demos/Trials

Starship Technologies

Starship Technologies is a dominant start-up company in the delivery robot industry and the company manufactures its own delivery robot called 'Starship Robot'. Since 2018, Starship Technologies has been commercializing its autonomous delivery service using the Starship Robot and is now operating a fleet of more than 1,700 robots daily in 20 countries and over 100 cities. The Starship Robots provide door-to-door delivery of parcels, groceries, and other food items. Customers can use the robot delivery service via a mobile application. Once ordered, the robots' entire journey and location can be monitored on the customer's smartphone. [20]

The Starship Robot, which rides on six small wheels, has a total width of 56.9 cm, length of 67.8 cm and height of 124.8 cm (incl. a raised flag). The Starship Robot weighs 23 kg and can carry a 10 kg payload at a maximum speed of 6 km/h. It not only drives autonomously but can also be driven by a human operator, depending on its situation. As shown in the Figure 2, the operating environment of the robot is outdoors – mingling with traffic and moving on sidewalks and crosswalks. [20]

Figure 2 Starship robot by Starship Technologies [21][22][23]

LG Electronics

Another typical application of UGR is the 'Door-to-Door Delivery Robot' by LG Electronics. It is four-wheel robot that drives at a maximum speed of 9 km/h. It can be operated in both indoor and outdoor environments via indirect and direct control tele-operated driving (ToD) – the robot sends video and visualized sensor information to a monitoring/control system using 4G/5G, as shown *Figure 3*.

The demonstration performed in July 2021 in Seoul showed LG Door-to-Door Delivery Robot performing delivery and security/patrol services in private areas; driving of delivery robots on public roads was not permitted at that time in Korea. 5G communication was used for sensor and camera information reporting and message delivery between the robot and the control center. [24]

In addition, LG Electronics is conducting an autonomous robot delivery service demonstration project with 'Woowa Brothers', which provides a delivery service platform. In 2022, it was demonstrated in an indoor environment at the Convention and Exhibition Center (COEX) in Korea. Outdoor trials were initiated on Teheran-Ro in the Gangnam district of Seoul from 2023. The goal of this demonstration project was to develop basic standards and privacy guidelines for robot operation using data collected. [25]

Figure 3 LG door-to-door delivery robot by LG Electronics [26]

4.2. Robots for other types of service

4.2.1 Definition

As well as the robot for delivery services described in Section 4.1. *Robot for delivery*, there are robots that provide various other services in a wide range of environments, e.g., robots for public services (i.e., management and improvement of people's lives and public functions such as roadworks, road cleanings, and patrol services), a charging robot for electric vehicles, and a robot supporting valet parking services in parking lots.

4.2.2. Demos/Trials

Public services

- Roadworks
  - Road survey and marking: TinyPreMarker Robot by TinyMobileRobots [26]

    TinyPreMarker Robot by TinyMobileRobots performs autonomous roadworks by calculating the positions of the lanes and carrying out a pre-marking of new or resurfaced roads. The operation of the TinyPreMarker can increase the productivity and accuracy of the road markings, compared to roadworks done by human workers, and also improve the safety of road workers while reducing traffic congestion caused by the roadworks.

    This tiny robot has three wheels and a high-precision positioning system with built-in GNSS receiver providing centimeter-level accuracy. The robot can work fully autonomously or with long-range remote control. The maximum marking speed of the robot is 7 km/h, and the weight of the robot is 18 kg.

    This UGR has already been commercialized and is being used in large-scale highway projects in many countries. In the UK's highways upgrade project, launched in 2015, the robot was used to pre-mark an 8 km stretch of road surface before permanent markings were painted on.
  - Road maintenance system: ARRES (Autonomous Road Repair System) by Robotiz3d [28]

ARRES is a pothole repair robot made by Robotiz3d, a spin-off company from the University of Liverpool. The van-sized robot uses artificial intelligence to detect and repair road defects autonomously, including potholes and road cracks on roads.

- Road cleaning service
  - Street sweeper: Trombia Free by Trombia Technologies [29]

    Road cleaning services can also be performed by UGR. Trombia Free developed by Trombia Technologies in Finland is an autonomous street sweeper and began the first pilot operation along bicycle lanes, roadways as well as street cleaning in Helsinki. In addition, there was another pilot for cleaning streets and parking lots within Helsinki international airport in 2021. The robot has a total width of 1.7 m, length of 3.82 m and height of 1.66 m, and it weighs 2,600 kg in empty state. The robot typically operates at 2-6 km/h for sweeping and dust removal operations autonomously or by a human operator using 4G mobile network. The positioning system of the robot is based on advanced LiDAR-GNSS sensor fusion, which enables the robot to navigate with 2 cm accuracy.

- Patrol service
  - Patrol in residential districts: Goalie by Mando [30]

    A patrol robot Goalie developed by Mando provides an outdoor autonomous patrol service, and it can quickly report emergencies and crimes using ultra-low latency video information sharing based on cloud with 5G and mobile edge computing technology. The maximum speed of the robot is 9 km/h, and an autonomous/tele-operated driving mode is available. The patrol robot was demonstrated patrolling at a park in Siheung City (2020-2022) and since 2022 started another patrol service in a residential area of Gwanak-gu in Korea. [31]

  - Patrol in industrial areas: Autonomous Monitoring Robot by LG Uplus and Unmanned Solution [32]

    Another demo of a patrol service is an autonomous monitoring robot for industrial areas. LG Uplus, one of the mobile carriers in Korea, is cooperating with a robot manufacturer Unmanned Solution to enhance performance of outdoor autonomous driving, by providing LG Uplus's technologies to integrate communication and image analysis into autonomous driving robots by Unmanned Solution. In 2020, the two companies demonstrated the patrol robot within a large plant in Korea. The robot, equipped with thermal imaging camera and harmful gas-detection sensors, patrolled the entire area around the clock. If the robot detected abnormal temperatures or sensed harmful gas, the robot immediately raised the alarm and sent real-time images to the integrated control center.

EV charging service: Mobile charging robot by Volkswagen [33]

Volkswagen is currently developing a prototype mobile charging robot which provides autonomous charging for electric vehicles in parking areas via an application or V2X communication. After receiving a charging request from an electric vehicle, the robot brings a mobile energy storage unit that can connect with and then charge the vehicle.

Valet parking service: Autonomous Valet Parking Robot by Stanley Robotics [34]

The autonomous valet parking robot developed by Stanley Robotics provides a transportation service for vehicles. The robot moves a stopped vehicle from the location where a driver exits/hands over to a designated or available parking spot. In order to transport a vehicle, the robot positions its forklift-like platform under the vehicle and picks it up. The robots have already been installed at Lyon-Saint Exupéry and London Gatwick airport and provide valet parking services.

4.3. International/Regional regulation

4.3.1. U.S.

In the United States, state legislatures are proactively passing explicit statutes regarding the operation of delivery robots. [35] To date, the laws regarding personal delivery devices (PDD), which are ground delivery devices for the transport of cargo or goods, have been enforced in around 20 U.S. states (Virginia, Idaho, Indiana, Arkansas, Washington, Oklahoma, Utah, Arizona, Maryland, Iowa, Texas, Louisiana, Wisconsin, Missouri, Florida, Ohio, North Carolina, Tennessee, Michigan and Pennsylvania).[36]

Currently, PDD operations are not regulated under motor vehicle laws, and each U.S. state's laws in this area are slightly different. For example, the acts for Virginia, Washington and Pennsylvania can be summarized as follows: PDDs are regarded as pedestrians as long as they yield or give right of way to pedestrians, people in wheelchairs and cyclists; then they may operate in pedestrian areas such as sidewalks, crosswalks. [37] PDD manufacturers should clearly identify information about the PDD including a unique identifying number. Also, the entity eligible to operate such services should have an insurance policy that includes general liability coverage of not less than US$100,000 per incident for damages arising from the operation of the PDD. [37][38][39] However, the maximum size, weight and speed allowed for PDDs are different in each state.

Virginia [37]

Virginia was the first state to regulate the operation of PDDs, since 2017. In Virginia, PDDs may operate on sidewalks and crosswalks at a speed that does not exceed 10 mph (ca. 16 km/h). If a sidewalk or crosswalk is not accessible or available, the PDD is permitted to operate on the side of roadway with a speed limit of 25 mph (ca. 40 km/h).

Washington [38]

In Washington, PDD is defined as an electrically powered device which transports goods on sidewalks and crosswalks at a maximum speed of 6 mph (ca. 10 km/h) and weighs less than 120 pounds (ca. 54 kg) excluding goods being carried in the device. If a sidewalk is not accessible or available, PDDs may operate in an area along the adjacent roadway with speed limit of 45 mph (ca. 72 km/h). The PDDs shall be equipped with a driving system that allows remote or autonomous operation, or both with the support and supervision of a remote PDD operator.

Washington law requires an eligible entity to report any incident that results in personal injury or property damage within 48 hours of the incident.

Pennsylvania [39]

In 2020, Pennsylvania enacted the operation of PDDs weighing up to 550 pounds (ca. 250 kg) without payload. PDDs are allowed to operate with a speed limit of 12 mph (ca. 19 km/h) on sidewalks. Basically, PDDs can operate with a speed limit of 25 mph (ca. 40 km/h) on all roadways, shoulders and berms of roadways, where posted at or under 25 mph. If authorized by the Pennsylvania Department of Transportation (PennDOT) or the applicable municipality, PDDs may operate on roadways or shoulders of roadways up to 35 mph (ca. 56 km/h).

A crash that resulted in human injury, death or damage to property should be reported by the eligible entity to PennDOT and the applicable municipality within 24 hours of it occurring.

There are also regulatory activities related to UGRs as a vehicle in the U.S. In 2021, the United States Department of Transportation (US DOT) released the 'Automated Vehicles Comprehensive Plan' [40] for automated driving systems. As one goal of this plan, US DOT sought to modernize regulations and remove unintended and unnecessary barriers to automated driving systems. Furthermore, the National Highway Traffic Safety Administration (NHTSA) sought comments/input on establishing regulatory requirements specific to classes of specialized motor vehicles equipped with automated driving systems such as passenger-less delivery vehicles equipped with automated driving systems. An example of which is the 'Grant of Temporary Exemption for a Low-Speed Vehicle with an Automated Driving System' [41]. In 2020, NHTSA granted a request from 'Nuro' [42] for the temporary exemption on a 'low-speed vehicle' (LSV) with certain requirements in the Federal Motor Vehicle Safety Standards (FMVSS). Nuro is an autonomous vehicle manufacturer and the first company to receive NHTSA approved exemption for an autonomous vehicle in U.S.[43] The terms and conditions of the exemption cover fewer FMVSS requirements than typical passenger cars (e.g., a vehicle without side-view mirrors, a narrower profile, and without a windshield comes under such a definition).

[Note] NHTSA defines an LSV as a four-wheeled motor vehicle whose speed over a distance of 1.6 km (1 mile) is over 32 km/h (20 mph) and not more than 40 km/h (25 mph) on a paved level surface, and whose gross vehicle weight rating or GVWR is less than 1,361 kg (3,000 pounds).

4.3.2. Korea

As per Road Traffic Law in Korea, an autonomous driving robot is a 'vehicle' and thus should not drive or be driven on or in pedestrian areas. In addition, a driver must get into the vehicle and directly control the steering and braking system on roadways. However, through some activities to promote and support the commercialization of autonomous vehicles and robots, the relevant government ministry in Korea set up an 'Autonomous Driving Vehicles Regulation Innovation Roadmap' [44] and 'Mobility Innovation Roadmap' [45].

First, the regulations related to UGRs operating in pedestrian areas have been relaxed gradually, through a regulatory sandbox for developments concerning autonomous driving robots. As can be seen in the three phases below, it was planned for autonomous driving robots operating on sidewalks and crosswalks to be allowed from 2023 in Korea: [46] [47]

- Phase 1:
  - Under the regulation from 2021, the driving of power units weighing less than 30 kg could take place in city parks with a maximum speed of 25 km/h. From 2022, the weight limit of autonomous driving robots in city parks was relaxed through the regulatory sandbox.
  - Prior to 2022, at least one field agent had to accompany an autonomous driving robot during a demonstration, for safety reasons. But from 2022, the field agent was declared as not mandatory for operating an autonomous driving robot. [48]
  - For privacy reasons, the regulations stated that the collection and use of personal information is strictly prohibited, in line with the 'Personal Information Protection Law'. [49] From 2023, this regulation for autonomous driving robots in certain condition has been relaxed thanks to the regulatory sandbox.
- Phase 2: From 2023, autonomous driving robots were expected to be allowed to drive with a speed of up to 6 km/h on sidewalks and crosswalks.
- Phase 3: Legislation on high-speed autonomous driving robots will be prepared by 2027, based on trials/evaluations of robots operating within a regulatory sandbox framework.

UGRs operating on roadways with vehicles are subject to the 'Autonomous Vehicle Law' [50]. According to this law, since 2022 tests of autonomous vehicles are allowed in a trial operation zone with the approval of the Minister of Land, Infrastructure and Transport. In the law, autonomous vehicles are classified into the following three types according to their shape, characteristics, and functions.

- Type A: Autonomous vehicle with a steering wheel and acceleration/brake pedals with only a test driver (or with a test driver and passenger) on-board.
- Type B: Autonomous vehicle without steering wheel and acceleration/brake pedals with a test driver only (or both a test driver and passenger) on-board.
- Type C: Autonomous vehicle with a structure in which a driver/passenger cannot be on-board; operating principally for cargo transportation or a special purpose (e.g., autonomous delivery truck).

UGRs operating on roadways correspond to Type C autonomous vehicles in terms of structure. The additional condition for Type C is that vehicles should be equipped with a real-time monitoring system overseen by a test operator from outside the vehicles, a control unit to stop and move it to a safe area in an emergency, and a forced operation mode (switching device), which can be activated from outside, must be installed on the left and right sides of the vehicle. The conditions for test operation regarding maximum speed and driving space do not differ between the three types. [51]

4.3.3. Japan

In Japan, the implications of realizing autonomous driving robots for the last-mile have been discussed to resolve social issues such as labor shortages and aging in the logistics industry. [52] This led to the Road Traffic Act being amended to cover remote-controlled, low-speed deliveries and services by small autonomous delivery robots. [53] This amendment was put into effect from April 2023 and includes specifications on: maximum vehicle size (120 cm (L) x 70 cm (W) x 120 cm (H)), maximum speed (e.g., 6 km/h), passage area (e.g., sidewalks, side bands and right side of road), traffic rules to follow during operation, and related administrative actions. In the passage area and traffic rules specified, these remote-controlled small vehicles follow traffic rules for pedestrians (e.g., traffic lights and road signs). When they travel with pedestrians in areas like sidewalks, they should yield or give the right of way to the pedestrians. To operate the remote-controlled small vehicle, prior notification including the name of the user, expected pathway, places to perform remote control, and specifications for the robot all need to be submitted to the public safety commission (e.g. local authorities) that has jurisdiction over the deployment. As per any administrative actions specified, a police officer or relevant authority may stop or move a remote-controlled small vehicle for safety reasons, as needed, and the public safety commission/authority may issue instructions (e.g., operation stop) when a user has violated laws or administrative regulations.

As per industry activities in Japan, the 'Robot Delivery Association' was founded in 2022 by eight companies including Honda Motor, Japan Post, Kawasaki Heavy Industries, Panasonic, Rakuten Group, TIER IV, TIS, and ZMP.[54] The association aims to establish a foundation and achieve/implement socially acceptable, convenient and safe robot delivery services by establishing voluntary safety standards and a certification system for autonomous delivery robots to operate on public roads. For its rule-making activities, the association plans to coordinate with the Japanese government and administrative agencies on matters related to robot delivery services. As a result of the amended regulation and industry activities, Japan's Ministry of Economics, Trade and Industry (METI) and the Robot Delivery Association jointly held a press event on 27 March 2023 to showcase delivery robots via the METI site [55]. Since 2023, several outdoor deployments of such delivery robots have been considered in Japan. Among the most recent deployment is the Uber Eats/Mitsubishi electric self-driving delivery robots deployed in two Tokyo Nihonbashi area stores: Tonkatsu Aoki and Benihana Annex. [56]

4.3.4. Canada

UGRs are termed micro-utility devices (MUDs) in Canada. MUDs mostly operate on sidewalks and bike lanes, which are the jurisdictions of the municipalities. The Provincial Highway Traffic Acts do not have a classification for MUDs, so they remain largely unregulated. At the time of writing, license and registration are not required for either automated or remotely controlled MUDs to operate in public spaces including sidewalks, bike lanes, and curve lanes. Trials and limited operations using MUDs for food delivery existed in Toronto and Vancouver, but many cities including Toronto and Ottawa, have banned them from operating on sidewalks and bike lanes. Toronto's Accessibility Advisory Committee also recommended banning MUDs from operating on sidewalks and bike lanes after receiving complaints from a disability rights advocacy group citing safety concerns for people with low mobility and vision, as well as seniors and children. The concerns included obstructions by stopped or stalled MUDs and inability to quickly detect MUDs'presence and maneuver around them. Toronto City Council acted upon the recommendations and issued on 15 December 2021 a ban on all MUDs, either automated or remotely controlled, from the sidewalks and bike lanes. [57] However, City Council also directed staff to issue a Transport Innovation Challenge (TIC) [58] in the first half of 2022 to better understand the capabilities of MUDs and their implications for accessibility, economic development, local businesses, and cybersecurity. The staff provided an update on the TIC to the Council on 5 May 2022 covering likely participants, applications, learning, and future research. [59]

On 1 January 2016, the Ministry of Transportation of Ontario (MTO) launched a 10-year pilot project under the Highway Traffic Act (HTA) to allow for the testing of automated vehicles (AVs) under certain conditions. MTO proposed amendments on 29 September 2021 to 'The AV pilot project', including the development of a pilot framework for the testing of MUDs. [60] The proposal would create a new 10-year pilot regulation for automated or remote-controlled MUDs under the pilot authority of section 228 of the HTA. Parameters under consideration for these MUDs include:

- Defining MUDs to broadly cover devices that will not be defined as a motor vehicle (in Ontario) are not meant for the transport of passengers, operate primarily off-roads in places such as sidewalks, and are task-oriented and operated primarily to provide services such as the delivery of goods;
- A 125 kg maximum weight and a 74 cm maximum width for all MUDs, except automated snow plows which have no proposed weight and dimension restrictions;
- A 10 km/h maximum speed on sidewalks and a 20 km/h maximum speed on shoulders of roads or bike lanes;
- A municipal opt-in and collision reporting regime, with authority to set by-laws and limit operations;
- Mandatory operator oversight, capable of creating a safe stop;
- Mandatory audible signals to alert those nearby;
- A requirement for reflectors and lights, with lights to be lit if operated between sunset and sunrise;
- A requirement for MUDs to be equipped with brakes;
- Prohibiting the carrying of controlled substances and dangerous goods that require a federal placard;
- General liability insurance, good working order, and secured loads requirements;
- A requirement to yield to pedestrians; and
- A requirement for an operator name, contact, and unique device number to be displayed on the exterior of the MUD.

4.3.5. Europe

In November 2023, the European Union updated its Directive (EU) 2023/2661 on the framework for the deployment of intelligent transport systems in the field of road transport and for interfaces with other modes of transport. [61] With this update, the Directive's scope was extended to cover emerging challenges, allowing ITS services to be made mandatory across the EU and aiming to reap the benefits of digitalization in the road sector. However, this legislative text does not address UGRs. The deployment of UGRs is therefore a topic that is dealt with individually by each of the 27 Member States.

As it is beyond the scope of this document to give an overview of each EU Member State, and to maintain consistency with the overview provided in Section 4.3.1 *U.S.*, a selection of three EU Member States has been made to give an impression of the legislative progress made regarding UGR deployment. These countries were chosen to represent different geographic areas, notably in northern Europe (Estonia), central Europe (Germany), and western Europe (Belgium).

Estonia

In the European Union, Estonia is the frontrunner when it comes to the deployment of UGRs on sidewalks alongside pedestrians. In June 2017, the Estonian Parliament voted unanimously for a country-wide regulation [62] of delivery robots by adding to the Traffic Act a new vehicle category called 'self-driving delivery robots' (See Chapter 7 on requirements and traffic rules for self-driving delivery robots in [62]). In this text, key aspects around the deployment of UGRs are specified. Among others, it is specified that the dimensions of a self-driving delivery robot moving on a road with or without cargo must be such that they do not endanger or obstruct other road users (§ 1511). The text also states that a self-driving delivery robot may be used on a sidewalk, footpath and the part of a cycle and pedestrian track designated for pedestrians, which is sufficiently wide for it to move, and thereby the robot must not exit the boundaries of said road or designated area (§ 1513). A third and last critical paragraph that may be specifically emphasized is § 1514, which specifies that a carriageway may be crossed by a self-driving delivery robot in designated pedestrian crossings. Estonia has thus developed a legislative text to frame the deployment of UGRs in the public space.

Germany

In the second Member State example, the German Bundesrat (Upper House) has set the legal framework for future automated and connected driving with the Autonomous Vehicle Approval and Operation Ordinance, in May 2022 [63]. The ordinance implements the 'Act Amending the Road Traffic Act and the Compulsory Insurance Act – Act on Autonomous Diving', from July 2021 [64]. Germany therefore has a comprehensive legal framework for the use of automated cars, trucks, and busses. However, when it comes to scenarios involving robots driving on roads, the ordinance's impact on the Road Traffic Regulations (StVO) remains to be clarified because the StVO is based on the presence of a vehicle driver. More specifically, it needs to be clarified to what extent StVO exemption permits are still necessary, e.g., for delivery robots to drive on sidewalks. In the German capital, for example, the Berlin Senate has granted exemptions under the Road Traffic Licensing Regulations (StVZO) and the StVO for a period of six months. [65] In this particular case, the delivery robot is accompanied by a ‘safety person’. Another employee follows the robot’s movements remotely and can also intervene by remote control. The maximum permitted speed for driving on sidewalks is 6 km/h.

Belgium

The third and final EU example, Belgium, has seen an increase in trials of UGRs in public streets throughout 2023. The approach taken is that the Federal Public Service Mobility and Transport examines applications from organizers of (semi)autonomous UGR trials and, where appropriate, authorizes testing on public roads by issuing special permits. These permits are handled in collaboration with the regions responsible for infrastructure and the approval of prototype vehicles, since the regions play an active role in drafting the code of good practice for experimentation in Belgium [66]. Although legislative debate on a national level has not yet taken place to the same extent as for the other EU examples, regional governments such as the Parliament of Wallonia have asked what plans there are to adapt legislation for UGRs especially in light of the intention of major supermarkets to trial them. The response from the regional minister back in 2023 was that it is necessary to support the development of new modes of transport, so they fit into the mobility system on the public highway in a correct and safe way. Further legislative work in this area is therefore to be expected.

4.4. Impact of UGRs on road safety and traffic efficiency

The introduction of UGRs into the existing transportation system may cause various issues for other conventional road users such as pedestrians and vehicles, both in terms of road safety and traffic efficiency.

There have been several cases of crashes occurring between UGRs and conventional road users like vehicles and pedestrians. One accident in the U.K. [67] took place when a vehicle was backing out of a garage and a UGR was moving along the road shoulder. Due to the crash, the UGR received damage and stopped operating. Another accident in Estonia took place between a vehicle and a UGR on the crosswalk; the vehicle was turning right and a UGR was crossing at the time. [68] Both accidents occurred because the drivers in the vehicle did not notice the small UGRs.

Concerns about the safety and reduced traffic efficiency caused by UGRs were also raised. For example, in the U.S., a UGR paused suddenly on a narrow ramp at a crosswalk with a wide curb. The UGR blocked a pedestrian trying to cross the crosswalk in a wheelchair. [12] The pedestrian was reported to have been distressed/embarrassed, not knowing what to do in this situation, because she had no way to communicate with the UGR. Another issue regarding traffic efficiency was raised in Estonia, where a UGR attempted to cross a crosswalk without a traffic light, but faced difficulties. [13] Even though drivers in a vehicle tried to yield and wait for a short time to give the UGR a chance to cross, it could not understand the drivers’ intentions. As there was no movement of the UGR, the vehicles passed by after a short wait. These cases imply that it would be difficult for other road users to predict or adapt to the behavior and maneuvers of UGRs in some situations. Likewise, it seems UGRs struggle to understand the behavior and intention of other road users. Therefore, it is expected that the above-mentioned issues can be mitigated or reduced if UGRs can communicate with other road users (e.g. vehicles, RSUs, VRUs) based on C-V2X.

5. Common analysis and system/ component requirements for UGRs

5.1. Classification of UGRs

As shown in demos/trials in the previous Section 4. *Landscape of UGRs*, there are various types of UGRs. In this section, we categorize them into different groups based on the driving space and operating environment. The driving domain of UGRs (i.e., roadways and sidewalks) means they must coexist with other road users (e.g., pedestrians and vehicles). For example, when UGRs operate on sidewalks, they should share the space with pedestrians without collisions, while UGRs operating on roadways have to share the space with vehicles. UGRs can operate in public and private areas depending on the service provided or the user scenario. This operational division – public and private areas – determines whether and how UGRs are treated under the law. Some countries have regulations defining the types of driving space that UGRs can drive on, but these provisions are generally applied only when the UGRs operate in public areas. Also, UGRs can be classified based on their operating environment (e.g., outdoor or indoor) which influences network connection and positioning accuracy requirements. With these considerations, the driving space and the operating environments could be divided into four types, as shown in *Figure 4.*

- Type 1: Indoor environment on sidewalks and crosswalks, e.g., underground passageway and convention center
- Type 2: Pedestrian areas in outdoor environments, e.g., public sidewalks/ crosswalks and parks
- Type 3: Outdoor settings such as public roads and outdoor parking lots
- Type 4: Indoor areas where vehicle may drive, e.g., underground roads and warehouses

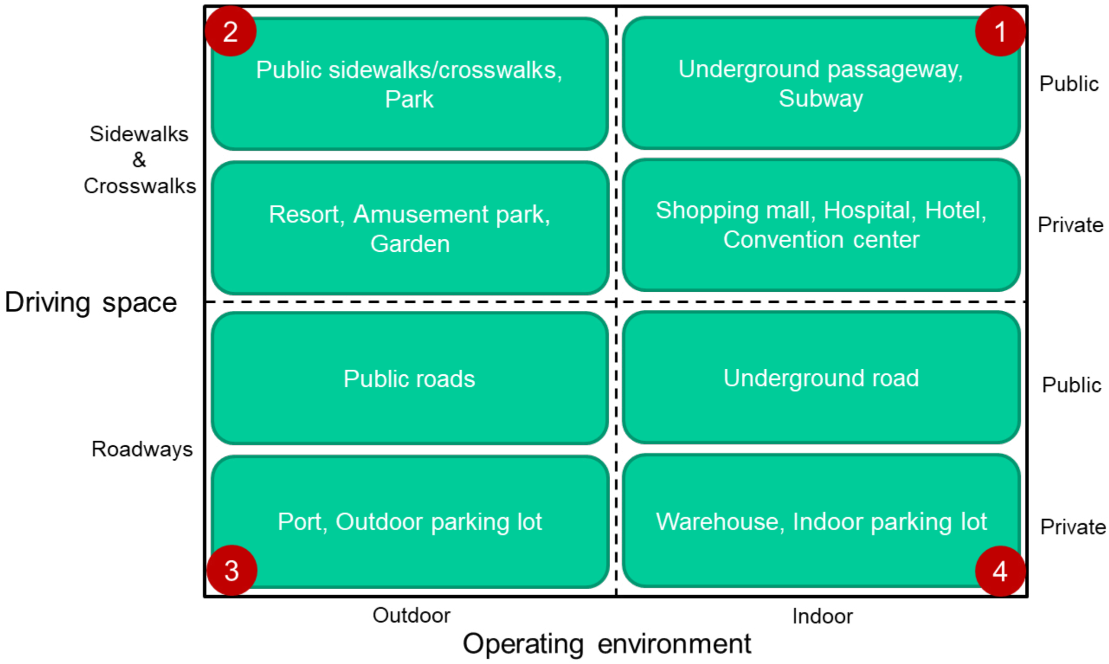


Figure 4 Types of UGRs

This classification, based on driving space and operating environment, shows the diversity of UGRs that exists or will exist around us. UGRs operating in Type 3 and 4 are similar to automated vehicles and much research for automated vehicles is ongoing or already completed. In this study, we only focus on the UGRs operating in Type 1 and 2 from the following analytical perspectives: 6. *Use cases and requirements*, and 7. *Communication between UGR and road users using ITS standards*, since the UGRs operating in Type 1 and 2 have new characteristics compared to conventional ITS actors (e.g., vehicles, pedestrians, bicycles).

5.2. Connectivity links used for UGRs

Various demos/trials performed by different companies are introduced in the previous section, and it is observed that 4G/5G mobile network communication is already used for the efficient operation of UGRs. In this subsection, it is described how mobile network communication technology helps UGRs operate effectively.

In current UGR implementations, the mobile network communication is used to implement the following functionalities:

1. Monitoring and management of UGRs

   The operation and health of UGRs are generally monitored by the control center, and mobile network communication is used to exchange information about their status; i.e., diagnostics of the UGRs and control center. For example, for the monitoring of driving status, data obtained by sensors deployed in UGRs can be sent to the control center. The sensor data shared by the UGRs can also be used to support direct/indirect control of the UGRs. In this case, information for control/guidance required for the ToD is sent from the control center to the UGRs via mobile network communication. Using mobile network communication, a UGR can also report back or check in with the control center when it needs a maintenance check, update, etc.

2. Processing/computing of data obtained by UGRs using mobile edge computing (MEC)/server

   One of technical trends being discussed in relation to UGRs is the so-called 'brainless robot' [69], which means that the processing/computing of data acquired by robots is performed on the MEC/server, and there is minimal physical computing/processing on or within UGR itself. For example, when a brainless robot uploads images obtained from its sensors, the server performs image analysis – requiring high-performance computing resources – and shares the result with the robot. As another example, a server can process data received from robots related to 3D mapping, visual localization and path planning, and send the processed data to robots. [70] With this approach, UGRs benefit from, for example, reduced battery consumption, smaller hardware/battery size (weight and volume), and lower overall cost.

3. Management of services performed by UGRs

   As explained in Sections 4.1.3 and 4.2.2, various services are carried out using UGRs. In general, information required to perform the services is exchanged between UGRs and a control center (or server/cloud of the service provider) using mobile network communication. For example, providers of food delivery services using UGRs have their own platforms/apps to connect stores, customers and UGRs based on mobile network communication. More specifically, a customer can place an order for food using the app of service provider, and then information about the order is sent to a UGR and restaurant via the service provider's platform. Additionally, until the delivery service is completed, the UGR can report the status of the service (e.g., service started, in process, completed) to the service provider's platform so the restaurant and customer can track the status of the delivery.

5.3. System requirements for UGRs

Based on the classification and connectivity links, system requirements can be identified for UGR. Since the connectivity of UGR plays a large role in the operation and service of UGRs and depends on the driving and operating environment, system requirements for UGRs are introduced via two categories:

Requirements relevant to telecommunication

- Localization
  - UGR should be equipped with a positioning system and be able to know its geographical position.
    - E.g., UGRs operating on roadways (i.e., Type 3 and 4) should be able to drive within a designated lane and navigate around objects blocking the way. When UGRs operate in pedestrian areas (i.e., Type 1 and 2),

the positioning requirements need to be more exacting compared to those for operating on roadways, because they are needed to navigate through small gaps and often between several objects. [73] Furthermore, the positioning system must be equipped differently depending on the indoor and outdoor operating environments.

- Cellular communication (e.g., 4G/5G) and direct communication support
  - UGRs should be capable of exchanging information with the control center.
  - UGRs should be capable of transmitting and/or receiving information from/to road users (e.g., RSUs, vehicles, pedestrians) via PC5 and/or Uu interface.
- Security
  - UGRs should exchange information through a secured session with a control center.

Requirements not relevant to telecommunication

- Dimensions
  - The width of UGR should be narrower than the width of road.
    - E.g., Width of UGRs operating in a pedestrian area (i.e., Type 1 and 2) < Width of sidewalk defined by law.
    - E.g., Width of UGRs operating on roadways (i.e., Type 3 and 4) < Width of roadway defined by law.

[Note] The requirement about dimensions depends on the classification (i.e., driving space and operating environment). According to Korean regulations [71], the width of a sidewalk should be more than 1.5 m and the width of the roadway should be more 3 m.

- Identification
  - UGRs should have a label with the name, contact information and a unique identification number. [39]
- Hardware
  - Ambient detection ability
    - UGRs should be equipped with sensor facing towards the moving direction (e.g., camera, Lidar, Radar).
  - Braking ability
    - UGRs should be equipped with a braking system that brings the UGR to a complete stop.
  - Driving ability
    - UGRs should be capable of driving on an uneven surface and ramp.
  - Human-machine-interface (HMI)
    - UGRs should be equipped with an HMI to provide information in different ways (e.g., visual/audio/haptic-based information sharing)

- Operation
  - UGRs should have a driving system that allows remote or autonomous operation, or both.
  - When the connectivity requirement for UGRs cannot be fulfilled during service, they should be able to attempt to resolve the connectivity issue and/or decide whether to continue the service without the connectivity according to the situation.
    - E.g., Continue to provide service without connectivity.
    - E.g., Move to an area where the quality of connectivity improves.
    - E.g., Move to a safe area and terminate operation.
  - UGRs should be able to calculate the time to collision (TTC) or reaction, in order to avoid obstructing pedestrians and/or collisions with other road users (e.g., vehicle, another UGR).
  - UGRs should obey the traffic rules in public areas.
    - E.g., When UGRs operate in public areas shared with pedestrians (i.e., sidewalks/crosswalks), they should follow traffic rules for pedestrians. [36]
  - UGR operations should be terminated in abnormal situations based on the UGR's own decision or external input (e.g., from a control center or pushing emergency stop button on the UGR).

6. Use cases and requirements

In ITS, many use cases have been developed in various organizations and involving different actors such as vehicles, infrastructure and pedestrians. UGRs are also beginning to appear on our roads and in pedestrian areas and look set to increase in the future. This introduces new challenges and will usher in changes to the existing ecosystem and ITS use cases. This section shows the impacts of UGRs on ITS use cases when operating on roads: 6.1 *Adaptation of UGR on the existing ITS use cases and requirements* and 6.2 *New UGR-specific use case and requirements*.

[Note] As mentioned in Section 5.1 *Classification of UGRs*, the analysis of use cases and requirements for UGRs is focused on the UGRs operating in pedestrian areas (i.e., UGRs belonging to Type 1 and 2 in *Figure 4*).

6.1. Adaptation of UGR on the existing ITS use cases and requirements

In this subsection, we address specific ITS use cases (Interactive UGR crossing, ToD support and Vehicle health monitoring) among the many developed in 5GAA [72][73][74] in order to analyze issues arising when UGRs are incorporated into the ITS. This gap analysis shows how the existing user stories and requirements of the selected use cases could change for the purpose of harmonizing UGRs within ITS.

6.1.1. Interactive UGR crossing

The first use case analyzed is 'Interactive VRU crossing' [73], helping to protect vulnerable road users (VRU) from vehicles when crossing. In this context, UGRs operating in pedestrian areas classified Type 1 and 2 (Section 5.1 *Classification of UGRs*) may also cover crossing intersections or crosswalks. When applying UGRs in this use case description (UCD), their behavior often differs significantly from VRUs. To describe this difference, a separate UCD of 'Interactive UGR crossing' is elaborated from the existing UCD for 'Interactive VRU crossing'[73]. For example, a scenario when a UGR crosses an intersection without traffic lights (User Story #1) and another scenario when there are traffic lights which change or stay green on request (User Story #2).

The first user story describes UGRs crossing a marked crosswalk without traffic lights. A UGR expresses its intention to enter a crosswalk without traffic lights. Vehicles approaching the area in which the UGR intends to cross receive the message and send an acknowledgment and acceptance/refusal message. If the vehicles accept, they subsequently adapt their behavior to allow the UGR to cross safely. Upon receiving these positive acknowledgments from the vehicles, the UGR may cross the street. The detailed UCD and its service level requirements (SLR) are shown in *Table 5* and *Table 6* in A.1 *Interactive UGR crossing*.

The second user story presents a scenario where a UGR crosses a marked crosswalk with traffic lights operated on request (similar to a pedestrian activating a green light by pushing the button). In this scenario, a UGR expresses its intent to cross a crosswalk that is signaled by a request to vehicles and/or RSEs (i.e., infrastructure which controls the traffic lights). Approaching vehicles and/or RSEs receive the message and send an acknowledgment and acceptance/refusal message. The traffic lights can be changed by RSEs to allow for the UGR crossing. If the vehicles accept the request, they subsequently adapt their behavior to allow the UGR to cross safely. Its UCD and SLR are detailed in *Table 7* and *Table 8* in A.1 *Interactive UGR crossing*.

6.1.2. Tele-operated driving support

As mentioned in Section 5.2, UGRs operate using various methods and ToD is one of them. The use case 'Tele-operated driving support' described in [73] is thus far only for autonomous vehicles. When UGRs operate in ITS, this use case is explicitly related to UGR because there is no pilot/driver controlling the machine on-board. When a UGR performs a service (e.g., road cleaning, food delivery), it faces some difficult and challenging situations that it cannot solve by itself. ToD support can help the UGR to resolve the situation. This means ToD of UGRs in specific environments is considered in the updated UCD in pedestrian areas, as shown *Figure 5*.

The first user story of this use case is when an autonomous vehicle/UGR (e.g., passenger cars or even a vehicle/UGR that performs dedicated tasks in very complex environments, such as snow ploughing, cleaning, loading, and unloading) detects a highly uncertain situation and cannot make the appropriate decision for a safe and efficient maneuver. In this case, the autonomous vehicle/UGR can ask for the support of a remote driver to resolve the situation and then switch back to normal autonomous driving mode without the remote driving support. The first user story ('Remote steering') of the updated UCD for UGR and its SRL are described in *Table 9* and *Table 10* in A.2 *Tele-operated driving support*.

The second user story covers uncertain situations when a host vehicle (i.e., autonomous vehicle and UGR) has detected problems using its sensors and subsequently cannot adequately/safely perform autonomous driving tasks. In this case, a remote driver does not operate the UGR directly, but rather helps to provide instructions or guidance to it. The detailed UCD and SLR are shown in *Table 11* and *Table 12* in *A.2 Tele-operated driving support*.

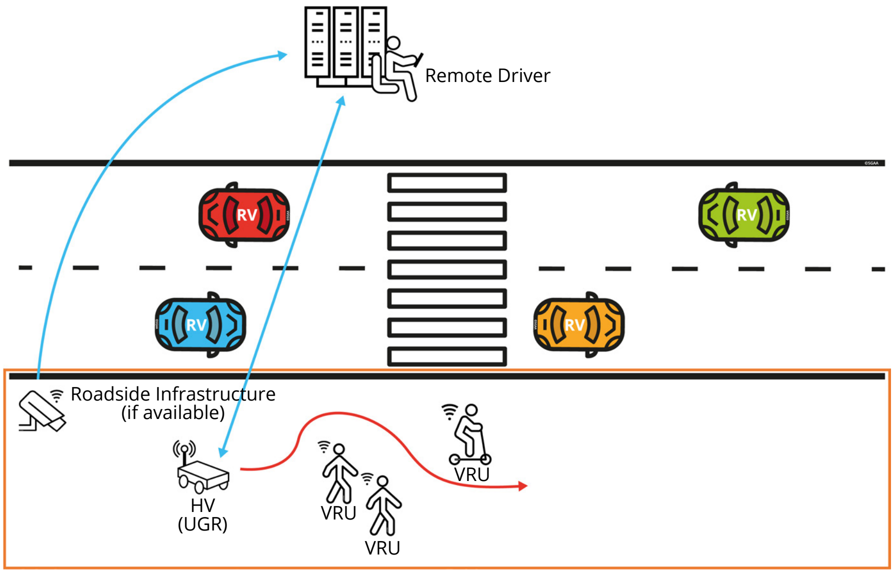


Figure 5 ToD support use case for UGR in pedestrian area

6.1.3. Vehicle health monitoring

As with automated vehicle, UGRs require monitoring and maintenance during operation. UGRs equipped with a monitoring and maintenance system are permitted by law to operate on public roads in some countries, as specified in 4.3 *International/ Regional regulation*. The use case 'Vehicle health monitoring' in [72] – which describes how owners, fleet operators and service providers monitor the health of a vehicle during its operation and should be immediately alerted when maintenance is required – can be applied to UGRs during its operation. To incorporate UGR into this use case, it is added as an actor and the UGR-specific user story is included, as shown in *Table 13* and *Table 14* in A.3 *Vehicle health monitoring*. It covers when a UGR is travelling on a permitted road (e.g., sidewalk, crosswalk) and faces some technical and/or maintenance issues, such as a defective sensor which means it cannot properly recognize the driving environment. The UGR operator needs to be informed of the situation. The SLR for the UGR-specific user story is defined in *Table 15* in A.3 *Vehicle health monitoring*.

6.2. New UGR-specific use case and requirements

The operation of UGRs in pedestrian areas (e.g., sidewalks, crosswalks) is permitted by law in some countries providing they follow set rules, as specified in 4.3 *International/ Regional regulation*. One such constraint is that the UGRs must yield or give right-of-way to VRUs including pedestrians and bicyclists in the pedestrian area. For a specific example, a regulation (2020 Act 106) for personal delivery devices [39] was introduced on 30 January 2021 in Pennsylvania, U.S. with the following condition:

"PDDs must yield the right-of-way to all pedestrians and pedal cyclists in a pedestrian area."

According to this rule, UGRs should not interrupt or obstruct the movement of VRUs and we can consider a new UGR-specific use case and requirements. As in User Story #1, a UGR receives information, such as location or route, from the VRUs and determines whether it is interfering with the passage of pedestrians or other types of VRUs. If it is determined that the UGR is likely to obstruct the VRU's path, the UGR should change its route or wait until it no longer blocks the VRU's path. The obstruction of VRU traffic is likely to be a more common scenario than the detection of collision risk, for example, when a narrow street/area is crowded with a large number of UGRs or when a UGR moves too slowly/fast compared to the VRUs. This user story is described in *Table 1* as User Story #1.

Table 1 UCD of User Story #1 Yielding right-of-way to VRUs: individual operation

Use Case Name	Yielding right-of-way to VRUs.
User Story #1	**Yielding right-of-way to VRUs: individual operation.** According to regulations covering UGRs in certain countries, they must yield the right-of-way to all pedestrians and cyclists in pedestrian areas including sidewalks and crosswalks. When a UGR drives in the pedestrian area and it is expected the UGR could interrupt/obstruct a VRU's path, the UGR changes its route/operation to avoid the obstruction individually (even though there is no/low risk of imminent collisions between the UGR and VRU).
Category	VRU safety, traffic efficiency.
Road Environment	Urban.
Short Description	UGR receives information about other road users including VRUs such as pedestrians and cyclists from RSE (and other road users and UGRs), and it tries to adjust its speed, heading, and route to avoid obstructing a VRU's path on crosswalks/sidewalks.
Actors	UGR, roadside infrastructure and VRUs.
Vehicle Roles	Not applicable.
Road/Roadside Infrastructure Roles	▶ Roadside equipment (RSE) collects information about VRUs (e.g., pedestrians, cyclist) on crosswalks/sidewalks by using sensors deployed on the RSE or by receiving messages (e.g., VAM, PSM, BSM, CPM, SDSM) from road users. ▶ RSE sends the collected information to the UGR.
Other Actors' Roles	▶ (Optional) VRUs send information notifying RSE (and other road users, UGRs) of their presence/status.
Goal	Improve safety for VRUs and improve pedestrian traffic efficiency, when VRUs and UGRs share the pedestrian areas.
Needs	The operation of UGRs must comply with regulations.
Constraints/ Presumptions	UGRs need to be able to collect information about VRUs in the vicinity and perform adjustments to their maneuvers based on the information.
Geographic Scope	Pedestrian areas including sidewalks and crosswalks.

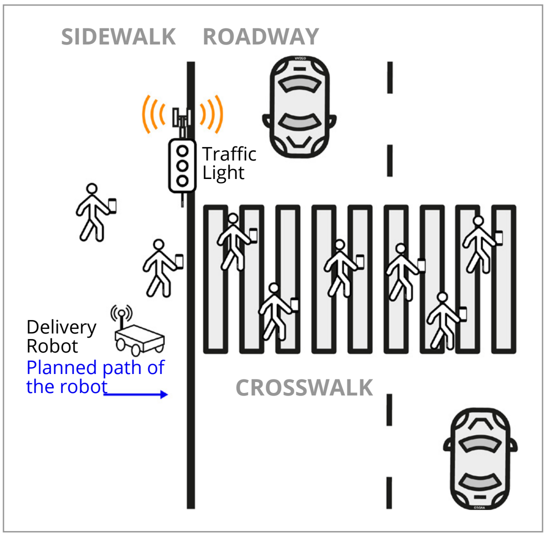
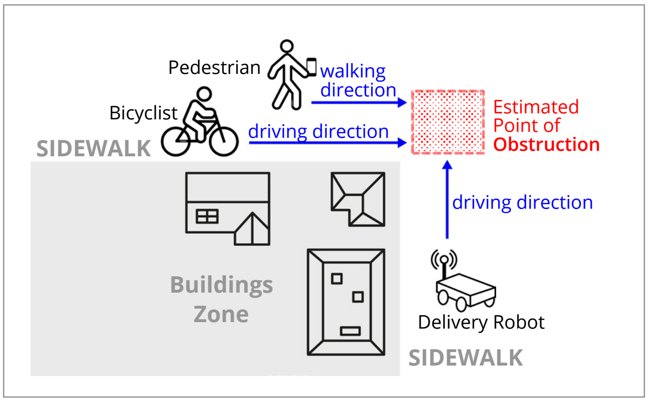
Illustrations	  For individual UGR
Pre-Conditions HV	UGR in pedestrian areas should be allowed by the regulation. Velocity of UGRs in pedestrian area should be limited by the regulation. (e.g., 20 km/h = 5.6 m/s).
Main Event Flow	▶ A UGR is operating in a pedestrian area, e.g., sidewalk/crosswalk. ▶ The UGR receives information about VRUs and the area (e.g., location density/distribution of VRUs, the number of VRUs, width/length of the sidewalk/crosswalk) from either RSE/VRUs, or service provider. ▶ The UGR uses the information and can judge whether it will interrupt VRU's path. ▶ If it is expected that the UGR will obstruct VRUs' path in the pedestrian area, the UGR changes its route/operation to avoid obstruction. – E.g., by making a detour around the area crowded by VRUs. – E.g., by pausing its operation (or stopping entering the sidewalk) and waiting until the VRUs on the sidewalk pass by.
Post-Conditions	None.
Information Requirements	▶ Accurate positioning. ▶ location/density/distribution/number of VRUs in the pedestrian area. ▶ Local map data (to understand width/length of pedestrian areas).

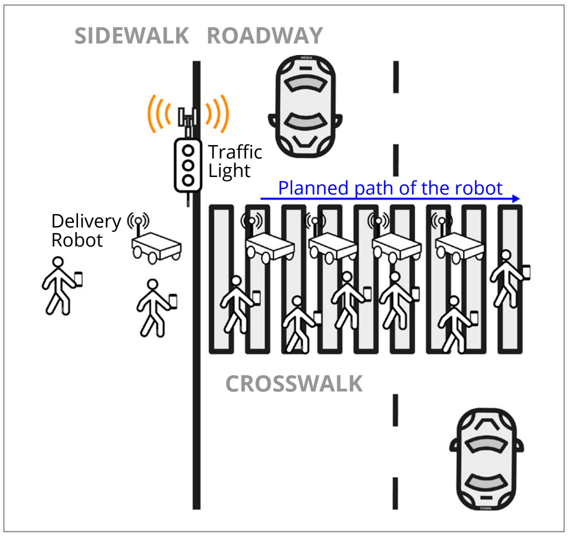
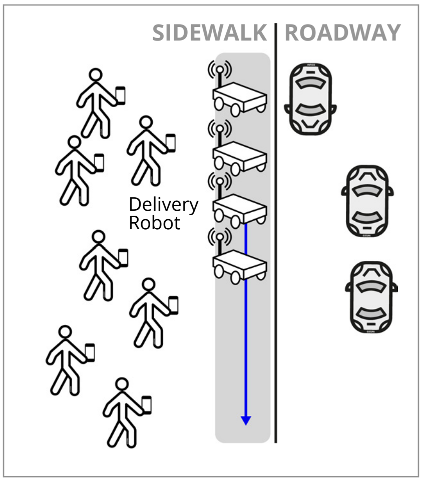
Table 2 SLR of User Story #1 Yielding right-of-way to VRUs: individual operation

User Story #1 Yielding right-of-way to VRUs: individual operation			
Service Level Requirement	**SLR Unit**	**SLR Value**	**Explanations/Reasoning/Background**
Range	**[m]**	300	Message does not need an extreme range, as it only needs to reach nearby UGRs that should yield the right-of-way to VRUs.
Information Requested/Generated	**Quality of information/ Information needs**	~ 3 Mbytes per message 300 bytes x 10,000 (VRU density)	VRUs and/or RSE need to provide kinematics and position information (e.g., using PSM/ VAM/CPM/SDSM) to inform UGRs of the VRUs' presence/status.
Service Level Latency	**[ms]**	200	Exchange of messages must happen quickly, but the latency should be defined considering the reaction time of UGRs. The reaction time includes time required for data processing at the UGR (e.g., decoding/ analysis of messages received from other road users, judge whether the UGR will interrupt VRU traffic).
Service Level Reliability	**%**	99.9	The reliability should be sufficient to guarantee QoS. 99.9%. Sensors deployed on UGRs can help to avoid the obstruction.
Velocity of UGRs	**[m/s]**	5.6	20 km/h=5.6 m/sec
Vehicle Density	**[vehicle/km^2]**	-	-
VRU density	**[VRU/km^2]**	Concerned VRUs: ~300 total Present VRUs per km^2: ~10,000	Figures given only for urban areas, since we consider this as the more critical case with regards to vehicle number/density. Concerned VRUs are those near streets, not counting workers in offices or the like. However, for total network load, etc., all VRUs in the given area have to be considered.
Positioning	**[m]**	1	Very exact positioning might not be needed.
Interoperability/ Regulatory/ Standardization Required	**[yes/no]**	Yes/Yes/Yes	Interoperability due to different UGR manufacturers, in communication between UGR-RSE, and UGR-VRU. Regulation is needed to determine whether to allow driving of UGRs in pedestrians areas. A standardized protocol might be needed.

We may consider the operation of UGRs in more complex situations. If there are many UGRs in the pedestrian area and each UGR determines its route individually, UGRs will occupy a large portion of the pedestrian area, which increases the probability that the UGRs may obstruct/interrupt pedestrian traffic. As a second user story, if UGRs heading along similar paths can travel in rows similarly to platooning/clustering, the area needed for UGRs' using the sidewalk can be reduced and optimized. With this method, UGRs can run on the sidewalks/crosswalks more efficiently without disturbing pedestrians. The detailed UCD and SLRs of the User Story #2 are specified in *Table 3* and *Table 4*.

Table 3 UCD of User Story #2 Yielding right-of-way to VRUs: group operation

User Story #2	**Yielding right-of-way to VRUs: group operation.** According to regulations for UGRs in certain countries, they must yield the right-of-way to all pedestrians and cyclists in pedestrian areas including sidewalks and crosswalks. When multiple UGRs drive in the pedestrian area and it is expected the UGRs could interrupt VRU's paths, the UGRs change their route/operation to avoid the obstruction by driving in similar paths similarly to platooning/clustering (even though there is no/low risk of imminent collisions between the UGR and VRUs).
Category	VRU safety, traffic efficiency.
Road Environment	Urban.
Short Description	UGR receives information about VRUs and UGRs from the RSE, fleet operator/service provider (and other road users and UGRs). Then, the UGR tries to adjust its speed, heading, and route in cooperation with other UGRs to minimize the area they occupy on the sidewalk/crosswalk. The information provided includes position/speed/heading/acceleration of the UGR(s) running in the vicinity of the ego-UGR. For example, UGRs drive in a single line and occupy a minimal area by tailing other UGRs on roads to avoid an interrupting VRU paths.
Actors	UGRs, roadside infrastructure and VRUs.
Vehicle Roles	Not applicable.
Road/Roadside Infrastructure Roles	▶ Roadside equipment (RSE) collects information about VRUs (e.g., pedestrians, cyclist) and UGRs on crosswalks/sidewalks by using sensors deployed on the RSE or by receiving messages (e.g., VAM, PSM, BSM, CPM, SDSM) from road users or fleet operators/service providers. ▶ RSE sends the collected information to the UGRs. ▶ RSE may provide UGRs maneuver instruction.
Other Actors' Roles	(Optional) VRUs send information notifying RSE (and other road users) of their presence/status. (Optional) UGR fleet operators/service providers send information notifying RSE of UGRs presence/status.
Goal	Improve safety for VRUs and improve pedestrian traffic efficiency, when VRUs and UGRs share the pedestrian areas.
Needs	Not applicable.
Constraints/ Presumptions	UGRs need to be able to collect information about VRUs in the vicinity and perform adjustments to their maneuvers based on the information from infrastructure, fleet operator or service provider.
Geographic Scope	Pedestrian area including sidewalks and crosswalks.

Illustrations	  For multiple UGRs.
Pre-Conditions HV	UGR in pedestrian areas should be allowed by the regulation. Velocity of UGRs in pedestrian area should be limited by the regulation. (e.g., 20 km/h = 5.6 m/s)
Pre-Conditions RVs	Not applicable.
Main Event Flow	▸ A UGR is operating in a pedestrian area, e.g., sidewalk/crosswalk. ▸ The UGR receives information about VRUs, other UGRs and the area (e.g., location density/distribution of VRUs, the number of VRUs, width/length of the sidewalk/crosswalk) from either RSE/VRUs, or UGR fleet operators/ service providers. ▸ The UGR uses the information and can judge whether it will interrupt VRU traffic. ▸ If it is expected that the UGR will disturb VRU traffic in the pedestrian area and other UGR exists in the vicinity, the UGR changes its route/ operation to avoid obstruction. – E.g., by following other UGR driving in front of the ego-UGR by keeping short distance. – E.g., by following the instruction provided by infrastructure, fleet operator or service provider.
Post-Conditions	None.

Information Requirements	▸ Accurate positioning. ▸ Location/density/distribution/number of VRUs in the pedestrian area. ▸ Local map data (to understand width/length of pedestrian areas). ▸ UGR maneuver instruction (e.g., planned path, speed, acceleration, heading, etc.).

Table 4 SLR of User Story #2 Yielding right-of-way to VRUs: group operation

User Story #2 Yielding right-of-way to VRUs: group operation			
Service Level Requirement	**SLR Unit**	**SLR Value**	**Explanations/Reasoning/Background**
Range	**[m]**	10,000	Assuming V2N: Communication range within the coverage of a macro cell.
Information Requested/Generated	**Quality of information/ Information needs**	Up to 1,000 bytes per message (up to 400 Kbps) (Commands from remote driver)	The value is referred from ToD support, User Story #2 (Remote driving instructions).
Service Level Latency	**[ms]**	200	With only the instructions to be transmitted from service provider to the UGR, latency requirements are more relaxed. The value is referred from ToD support, user story #2 (Remote driving instructions).
Service Level Reliability	**%**	99.999	The transmission of commands from the service provider requires a high level of reliability because this affects the safe and efficient operation of the UGR.
Velocity of UGR	**[m/s]**	5.6	Velocity of UGRs in pedestrian area is limited by the regulation. (e.g., 20 km/h = 5.6 m/s).
Vehicle Density	**[vehicle/km^2]**	Concerned VRUs: ~300 total Present VRUs per km^2: ~10,000 Vehicles: 1,500	Figures given only for urban areas, since we consider this as the more critical case with regards to vehicle number/density. Concerned VRUs are those near streets, not counting workers in offices or the like. However, for total network load, etc., all VRUs in the given area have to be considered.
Positioning	**[m]**	1	Very exact positioning might not be needed.
Interoperability/ Regulatory/ Standardisation Required	**[yes/no]**	Yes/Yes/Yes	Interoperability due to different UGR manufacturers, in communication between UGR-RSE and UGR-VRUs. Regulation is needed to determine whether to allow driving of UGRs in pedestrians areas. A standardized protocol might be needed.

This section covered use case gap analyses to incorporate UGR into ITS. UGRs operating in pedestrian areas with pedestrian-like behavior is considered with the 'Interactive UGR crossing' use case based on 'Interactive VRU crossing'. As such, UGRs have several characteristics similar to automated vehicles as reflected in the 'Tele-operated driving support' description for different operating environments. From a maintenance perspective, we analyzed the 'Vehicle health monitoring' use case that combines UGR in ITS considering different driving environments for UGR. As a new

UGR-specific illustration, the 'Yield right-of-way to VRUs' use case is introduced based on regulations enforced in some countries. Through this use case gap analysis, we may adopt UGRs as a new type of actor in ITS, and need to see this new type of mobility from a mobility extension perspective.

7. Communication between UGR and road users using ITS standards

To enable the use cases covered in Section 6, UGRs may need to communicate with existing ITS road users such as vehicles and VRUs. This section describes communication scenarios between UGRs and road users in the ITS and any gaps in existing ITS standards and relevant cases.

7.1. Communication scenarios between UGRs and road users

Connected road users exchange information about their presence and state using awareness messages (e.g., CAM/BSM, VAM/PSM) as a basic ITS application. Additionally, connected road users with environmental sensing capabilities can detect objects including road users and provide that information to other road users using messages for collective perception service and sensor sharing service (e.g., CPM/SDSM), as an advanced ITS application. This exchange of awareness messages and messages for collective perception service and sensor sharing service can improve traffic safety by preventing collisions on roads. When sharing public roads with existing road users, UGRs must perceive their environment including road users using their own sensors and then drive without incidents or collisions. If UGRs can communicate with road users as well as infrastructure and collect information about road users, they can better perceive the presence and state of connected and/or detected road users; this communication can enhance UGRs' trajectory/path planning and collision avoidance performance on roads.

The new UGR-specific use case 'Yielding right-of-way to pedestrians' described in Section 6.2 is a typical example illustrating communication between UGRs and road users/infrastructure/RSU. According to this use case, UGRs must try to adjust their path/trajectory to yield or give right-of-way to pedestrians. Having received information about road users, UGRs can thus drive more effectively without collisions than they can when only using their own sensors. In this case, reception of awareness messages and messages for collective perception service and sensor sharing service plays a huge role in perceiving the environment, but the transmission of awareness messages from UGRs is not essential for yielding the right-of-way. Therefore, for UGRs to better perceive road users, they require at least the capability of receiving and utilizing the awareness messages from road users as well as messages for collective perception service and sensor sharing service.

In most cases, simply receiving environmental data, including information from road users, may be sufficient for UGRs to avoid collisions and give right-of-way to pedestrians. However, there are several cases where it is hard for UGRs to avoid collisions with road users, such as vehicles and bicycles approaching rapidly and failing to see or perceive a UGR. As illustrated in Section 4.4, where an accident occurs between the vehicle turning right and a UGR passing over a crosswalk at an intersection. [68] In this case, the driver is not aware of the UGR crossing despite the fact that the UGR had been affixed with an elevated/visible flag, similar to those on children's bicycles. Another case is when a UGR occupies a large portion/part of the road (e.g., road cleaning robot on a narrow sidewalk) or performs a special task (e.g., roadworks), making it harder for the robot to yield to pedestrians. In these cases, the transmission of awareness/perception messages about UGRs can help road users become aware of them on roads and prevent collisions. Furthermore, User Story #2 (Yielding right-of-way to pedestrians: group operation), describing a new UGR-specific UC in Section 6.2, introduces a situation with multiple UGRs operating in unison by exchanging awareness messages, similar to platooning/clustering. This group operation reduces obstructions to existing road users and enhances traffic efficiency.

So far, several communication scenarios have been introduced to harmonize UGRs with existing road users in ITS. However, the bidirectional awareness message exchange of UGRs using ITS band (5.9 GHz) would be challenging, when operating in channel congested areas. To address this concern, a possible solution to signal to road users the presence of UGRs operating on roads with minimal ITS bandwidth usage is for the UGRs to send awareness messages (e.g., CAM/BSM, VAM/PSM) under certain conditions.

To determine the specific conditions, collective perception service and sensor sharing service in ITS and the aforementioned situations in which awareness messages sent by UGRs provide benefits can be taken into account. Infrastructure/RSUs and vehicles can send to road users messages for collective perception service and sensor sharing service (e.g., CPM, SDSM), if they have sensing and communication capabilities. When a UGR operating on the road is detected as an object, a message containing information about the detected UGR is provided to road users. If there is no message sender who detects the UGR on the road, it may be helpful for it to send awareness message. Additionally, the UGR may send its awareness messages only if a potential collision risk is detected or when TTC is below a threshold. Another transmission condition can be considered when a UGR is crossing a road or intersection or when it is unable to yield or give right-of-way to pedestrians.

In terms of ITS band usage, transmitting awareness messages for UGRs only under specific conditions may be better than transmitting awareness messages under all conditions defined in the relevant standards. Although this possible solution uses minimal ITS bandwidth, further research is needed on the impact of this solution on ITS band usage.

As another possible solution for ITS bandwidth saving, it would be helpful for UGRs or UGR operators to use mobile networks to send awareness information to V2N end users (V2N apps of road users) or infrastructure/RSUs (see *Figure 6*). When a UGR sends its awareness messages or a V2N UGR operator sends the status of a UGR being managed to a V2N service provider, the received information can then be forwarded to end users (i.e., road users connected to the V2N service provider). In another scenario, a UGR or UGR operator provides information to the connected infrastructure/RSU alias and infrastructure owner operator (IOO) application server through an information-sharing entity. The infrastructure/RSUs then aggregate the received information about the UGR and broadcast a message for collective perception service and sensor sharing service (e.g., CPM, SDSM) to road users.

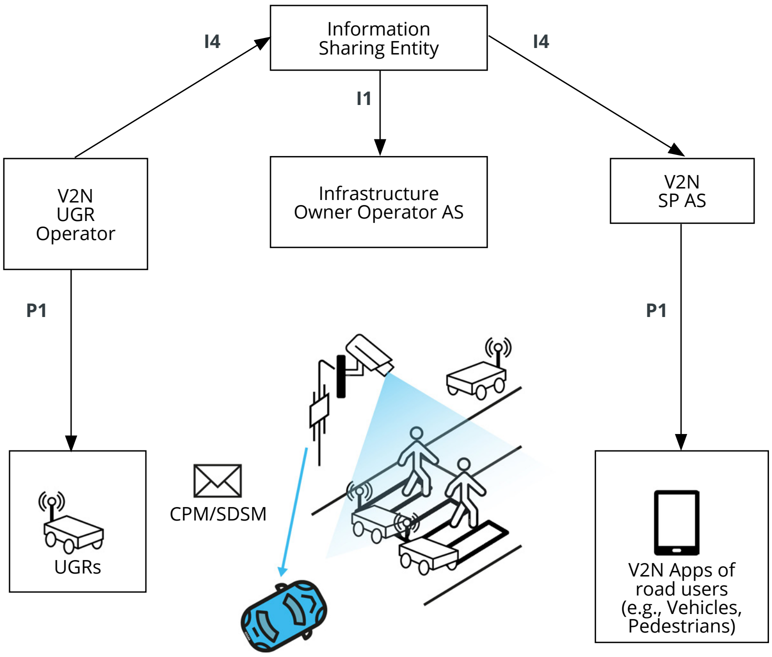


Figure 6 Network architecture for possible solution #2

The findings and potential solutions introduced above are summarized as follows:

- [Finding #1] A UGR requires the capability to receive and utilize the awareness messages (e.g., CAM, BSM, VAM, PSM) from road users as well as messages for collective perception service and sensor sharing service (e.g., CPM, SDSM) to better perceive road users.
- [Finding #2] Transmission of awareness messages from a UGR may provide benefits to existing road users in some situations.
  - [Possible solution #1] A UGR may send its awareness messages (e.g., CAM, BSM, VAM, PSM) under the following conditions.
    - [Condition #1] only if there is no RSU nearby sending a message for collective perception service and sensor sharing service informing the UGR's presence,
    - [Condition #2] only if a potential collision risk is detected or when TTC is below a threshold,
    - [Condition #3] during crossing,
    - [Condition #4] only if the UGR cannot yield to pedestrians.
  - [Possible solution #2] For ITS bandwidth saving, it would be helpful for UGRs or UGR operators to use mobile network to send awareness information to V2N end user or infrastructure/RSUs.
    - E.g., A UGR sends its awareness messages or a V2N UGR operator sends the status of a UGR being managed to a V2N service provider. The V2N service provider can disseminate the received information to end users (i.e., road users connected to the V2N service provider).

– E.g., A UGR or UGR operator provides information about the UGR to the connected infrastructure/RSUs. The infrastructure/RSUs then aggregate the received information about UGRs and broadcast messages for collective perception service and sensor sharing service (e.g., CPM, SDSM) to road users.

7.2. Gaps on existing ITS standards

To communicate between UGRs and road users, there could be two approaches:

- Communication using newly defined messages for UGR, and
- Communication by using V2X messages defined in ITS standards.

Regarding the first approach, once new messages for UGRs are standardized to communicate with road users, the new messages can represent the state and behavior of UGRs in detail, and receivers (i.e., road users) can understand the information about UGRs contained in the messages. However, a barrier to standardizing new messages for UGRs is that it takes a lot of time and effort. Also, road users will need the ability to interpret the new messages for UGRs.

Alternatively, UGRs could use messages already existing in the ITS standards to enable harmonized communication with ITS road users. In order to utilize the existing ITS standards, it is necessary to identify whether they can fully encompass the characteristics of UGRs and determine whether standard changes are necessary to deliver accurate information about UGRs. Therefore, this subsection shows the gaps, when UGRs communicate with road users using existing messages defined in ITS standards. Particularly, according to the introduced use cases and communication scenarios, this subsection focuses on messages for collective perception service and sensor sharing service to include UGRs and UGR awareness messages for the gap analysis.

Before starting the gap analysis, it is necessary to clarify which standards are to be considered. Even though there are many ITS-related standards, this present document will focus on the European ITS standards (i.e., ETSI TC ITS) and U.S. V2X standards defined (i.e., SAE V2X Committees) to be considered for the gap analysis.

7.2.1. Gap analysis on messages for collective perception service and sensor sharing service to include UGRs

Figure 7 offers a typical example or illustration of messages for collective perception service and sensor sharing service containing detected UGRs using existing V2X messages. A RSU detects a UGR operating within sensor coverage as an object and sends a message for collective perception service and sensor sharing service to vehicles and pedestrians, as shown in the figure. To use standardize the approach, Collective Perception Message (CPM) defined by ETSI TC ITS [75] and Sensor Data Sharing Message (SDSM) defined by SAE [76] can be considered. Generally, the message for collective perception service and sensor sharing service contains a set of detected objects and obstacles, along with their status information (e.g., detection time, position) and optional attributes (e.g., object type, kinematic state).

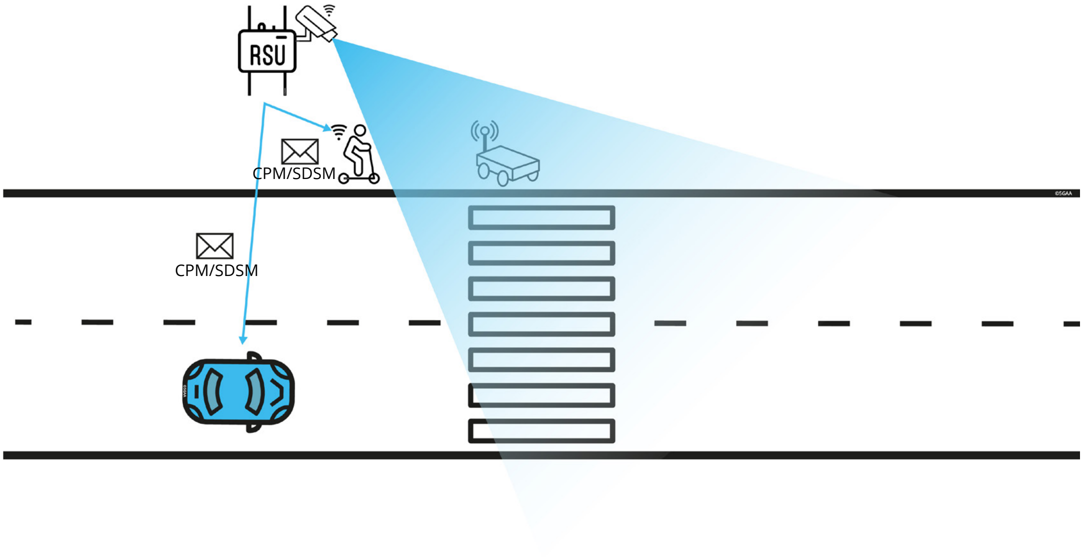


Figure 7 Broadcasting messages for collective perception service and Sensor sharing service including information of detected UGR

One issue or gap in this regard is the lack of suitable object type and class for UGRs and attribute information data-field for UGRs in analyzed ITS standards for ETSI TS 103 324 Collective Perception Service [75] and SAE J3224 V2X Sensor-Sharing for Cooperative and Automated Driving [76]. Even though a message for collective perception service and sensor sharing service (i.e., CPM or SDSM) including a detected UGR can be delivered with the data-field of object type and class configured as 'unknown', or with the data-field of object type and class and the attribute information data-field omitted (see note), it cannot provide accurate information about the detected UGR to the receiver. To remedy this and ensure the benefits of this approach are extended to receivers, it is recommended to **add a new object type and class for UGRs** (e.g., UGR, mobile robot, PDD) as well as **attribute an information data-field for UGRs** (e.g., UGR data, detected robot data) in existing ITS standards.

[Note] Because the data-field 'object type' defined in SAE J3224 is a mandatory field, it cannot be omitted.

7.2.2. Gap analysis on awareness messages for UGRs

As mentioned in the previous subsection, UGRs may send awareness messages under specific conditions. For example, a UGR intending to enter a zebra crossing may send awareness messages during the crossing maneuver, as shown in *Figure 8*. In this case, UGRs can use awareness messages for vehicles (e.g., Cooperative Awareness Message defined in [77], Basic Safety Message defined in [78]) as well as awareness messages for VRUs (e.g., VRU Awareness Message defined in [79], Personal Safety Message defined in [80]). Generally, these awareness messages of a road user contain its position, dynamics, and attributes.

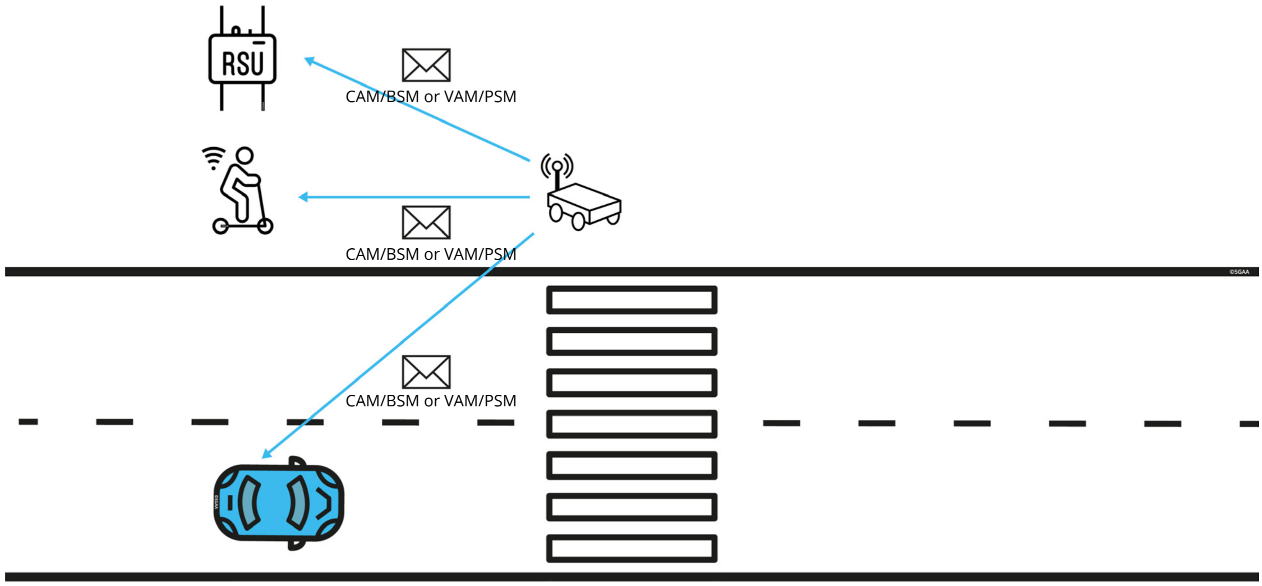


Figure 8 Dissemination of awareness messages from UGR

The first gap in this scenario is the lack of a suitable sender type and class for UGRs, similar to the gap in messages for collective perception service and sensor sharing service. Since the data-field of transmitter 'type' and 'class' is mandatory in this case, UGRs must send the message (e.g., CAM, BSM, VAM, PSM) with the data-field configured as 'unknown' when sending awareness messages. In order to contain precise UGR type and class information in the awareness messages, it is recommended to add a new type and class for UGRs (e.g., UGR, mobile robot, PDD) in existing ITS standards.

Another gap is the scope and definition of transmitters in the mentioned standards. Awareness messages related ITS standards (e.g., BSM, VAM, PSM) say that particular ITS road users may send awareness messages. For example, the awareness messages for VRUs (e.g., VAM, PSM) are naturally defined to be sent by the vulnerable road user. But according to the definition of VRUs in the standards [79][80], UGRs cannot be considered a VRU. This is because UGRs are defined in Section 3.1 as a type of mobility which moves over the ground without people (including a driver) on-board. When a UGR sends awareness messages using BSM, there is a similar gap in SAE J3161/1 [78]. This standard specifies system requirements for an on-board vehicle-to-vehicle safety communications system for light vehicles and public safety vehicles which are class 2, 3, 4 and 5, as defined in the FHWA Vehicle Classification [81]. According to the FHWA Vehicle Classification, there is no appropriate vehicle class for UGRs. Regarding the transmission of awareness messages using CAM, the common understanding on the scope of the standard is for transmission to take place from a vehicle and RSU, even though the standard for CAM defines that all road users may send them. Therefore, in order to transmit CAM, BSM, VAM, PSM from UGRs, it is recommended to **extend the scope of ITS standards** [77][78][79][80].

The recommendations on how to use the existing ITS standards to provide accurate information about UGRs introduced above are summarized as follows:

- [Recommendation #1] It is recommended to define a new (road user, object) 'type' or 'class' for UGRs (e.g., UGR, mobile robot, PDD) in the ITS standards (e.g., CAM, BSM, VAM, PSM, CPM, SDSM).

- [Recommendation #2] It is recommended to extend the scope of ITS standards (e.g., CAM, BSM, VAM, PSM) such that a UGR can transmit its awareness messages.

[Note] It is up to the SDO on which message (e.g., CAM vs VAM) is more appropriate for UGRs.

The gaps on the awareness message and message for collective perception service and sensor sharing service in relevant ITS standards have now been introduced in this document. As further study on gap analysis to incorporate UGRs in ITS, the automated vehicle marshalling system (e.g., ETSI TS 103 882, SAE J3292) and maneuver sharing and coordinating service (e.g., ETSI TS 103 561, SAE J3186) should be analyzed.

[Note] ETSI TS 103 882 is not yet published and standardization for SAE J3292 and ETSI TS 103 561 is in progress.

Annex <A>: <Use case descriptions and service level requirements>

A.1 Interactive UGR crossing

Table 5 UCD of User Story #1 Interactive UGR crossing without traffic lights

Use Case Name	Interactive UGR crossing.
User Story #1	**Interactive UGR Crossing without traffic lights.** A UGR expresses intent to cross a crosswalk without traffic lights. Vehicles approaching the area in which the UGR intends to cross receive the message and send an acknowledgment and acceptance/refusal message. If the vehicles accept, they subsequently adapt their behavior to allow the UGR to cross safely. Upon receiving these positive acknowledgments from the vehicles, the UGR may cross the street. Upon reaching the other side of the street, the UGR may send another message to the vehicles confirming that they have finished crossing.
Category	Traffic efficiency.
Road Environment	Urban, marked crosswalk without traffic light.
Short Description	▶ A UGR is preparing to cross the crosswalk. ▶ After signaling this intent, nearby vehicles acknowledge to reassure the UGR that the request from UGR is accepted by the vehicles. ▶ If accepted, the UGR starts crossing. ▶ As the UGR is crossing, the UGR tells vehicles when it has cleared the zone in front of them so that they may continue driving. The UGR double checks with vehicles just before moving in front of them that they are clear to move forward.
Actors	Vehicle(s), UGR(s).
Vehicle Roles	Remote vehicle.
Road/Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	Not applicable.
Goal	Improved traffic safety and efficiency at crosswalks and awareness for vehicles.
Needs	Not applicable.
Constraints/ Presumptions	A UGR is preparing to cross the crosswalk, but there is no traffic light.
Geographic Scope	Crosswalk without traffic light.
Illustrations	Not applicable.
Pre-Conditions HV	UGR in pedestrian areas should be allowed by the regulation. Velocity of UGRs in pedestrian area should be limited by the regulation. (e.g., 20 km/h = 5.6 m/s)
Pre-Conditions RVs	Not applicable.

Main Event Flow	▶ UGR approaches marked crosswalk without traffic lights. ▶ UGR expresses intent to cross. ▶ Approaching vehicles receive the message and perform target classification. ▶ If a vehicle determines that it can accommodate the request, it acknowledges the UGR and notifies nearby vehicles that it is participating in the request. ▶ When the UGR receives sufficient evidence that it is safe to cross (may vary with number of lanes and vehicles present), crossing is initiated. ▶ While the UGR is crossing, it may send information (e.g. PSMs, VAMs, BSMs, CAMs) notifying stopped vehicles of its progress. ▶ Upon reaching the other side of the crosswalk, the UGR may send another message to the vehicles confirming that they have safely crossed. When vehicles are safe to proceed after the UGR crosses, they begin moving again.
Alternative Event Flow	After a vehicle has sent a positive acknowledgment, but, if they begin their maneuver early again (due to an unavoidable exception such as accommodating an emergency vehicle for example), a NACK should be sent to the UGR, cancelling the indication they previously received and warning the UGR. The UGR initiates the communication with other vehicle after crossing of the vehicle that sent the NACK.
Post-Conditions	The UGR may send a session-closing message to vehicles notifying them of successful crossing.
Information Requirements	▶ Accurate positioning. ▶ UGR ID. ▶ Local map data (to get information about the location of crosswalks and to determine how many vehicles need to stop, i.e. how many lanes are there).

Table 6 SLR of User Story #1 Interactive UGR crossing without traffic lights

User Story #1 (Interactive UGR crossing without traffic lights)			
Service Level Requirement	**SLR Unit**	**SLR Value**	**Explanations/Reasoning/Background**
Range	[m]	300	Message does not need an extreme range, as it only needs to reach nearby vehicles that could stop for UGRs at a crosswalk.
Information Requested/Generated	Quality of information/ Information needs	64 Kbps	UGR can send a ‘heartbeat’ message (including location data e.g. PSM, VAM) after a small ‘request’ message; the vehicle only needs to send acknowledgment.
Service Level Latency	[ms]	200	Slow messaging does not result in safety result in this use case, and maneuver will only be initiated upon agreement.
Service Level Reliability	%	99.9	Again, since a maneuver will only be initiated upon agreement, dropped messages will not result in safety risk and severe traffic efficiency degradation.
Velocity of vehicles	[m/s]	13.9	Upper end of the speed that a vehicle will be driving at on a road where UGR crossing would take place (50 km/h).

Vehicle Density	[vehicle/km^2]	1,500	This Use Case is expected to mostly happen in less densely populated areas, since visibility at intersections is mostly good, speeds are limited around 50 km/h.
Positioning	[m]	0.2 (3σ)	If a UGR is standing next to a roadway, it only takes a slight position error to place them in the middle of the street on a map, or directly in the trajectory of a vehicle. Alternatively, if the UGR is crossing, a small error could falsely indicate to a nearby vehicle that the pedestrian is on the sidewalk.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes/No/Yes	Interoperability due to different OEMs and robot manufacturers. A standardized protocol is needed.

Table 7 UCD of User Story #2 of Interactive UGR crossing with request-driven traffic light

User Story #2	**Interactive UGR crossing with request-driven traffic light** A UGR expresses intent to cross a crosswalk where there is a traffic light operated by a request. The traffic light will be changed to green light to cross only when someone requests. Approaching vehicles and/or RSE receive the message and send an acknowledgment and acceptance/refusal message. The traffic light can be changed by RSEs to allow for the crossing UGR. If the vehicles accept the request, they subsequently adapt their behavior to allow the UGR to cross safely. Upon reaching the other side of the street, the UGR may send another message to the RSE and/or vehicles confirming that they have finished crossing.
Category	Traffic efficiency.
Road Environment	Urban, marked crosswalk with traffic light operated by request.
Short Description	▶ A UGR is preparing to cross the crosswalk. ▶ After signaling this intent, nearby vehicles acknowledge to reassure the UGR that the request from UGR is accepted by the vehicles or RSE. ▶ If accepted, the UGR starts crossing. ▶ As the UGR is crossing, the UGR tells vehicles and/or RSE when it has cleared the zone in front of them so that they may continue driving. The UGR double checks with vehicles just before moving in front of them that they are clear to move forward.
Actors	Vehicle(s), UGR(s), RSE(s).
Vehicle Roles	Remote vehicle.
Road/Roadside Infrastructure Roles	RSE receives messages from UGRs (e.g., request for crossing) and vehicles (e.g., response to request from UGR) and controls the traffic light based on the requests from UGRs and responses from vehicles.
Other Actors' Roles	Not applicable.
Goal	Improved traffic safety and efficiency at crosswalks and awareness for vehicles.
Needs	Not applicable.
Constraints/ Presumptions	A UGR is preparing to cross a crosswalk where there is a request-driven traffic light.
Geographic Scope	Crosswalk with traffic light.
Illustrations	Not applicable.

Pre-Conditions HV	UGRs in pedestrian areas should be allowed by the regulation. Velocity of UGRs in pedestrian area should be limited by the regulation. (e.g., 20 km/h = 5.6 m/s)
Pre-Conditions RVs	Not applicable.
Main Event Flow	▶ UGR approaches a crosswalk. ▶ UGR expresses intent to cross and asks traffic lights to turn to green for the crossing. ▶ RSE (and approaching vehicles) receives the message which includes UGRs' intent to cross. ▶ The RSE determines that it can accommodate the request. – (Optional) The RSE acknowledges the UGR and notifies UGR (and nearby vehicles) that it will accept/reject the UGR request or plan for changing traffic signal phase. ▶ When the traffic light turns green, the UGR starts crossing. ▶ While the UGR is crossing, it may send information (e.g. PSMs, VAMs) notifying stopped vehicles (and RSE) of its progress. ▶ Upon reaching the other side of the crosswalk, the UGR may send another message to the RSE (and vehicle) confirming that they have safely crossed. ▶ (Optional) After receiving the message, RSE may change the traffic light to red. When vehicles are safe to proceed after the UGR crosses, they begin moving again.
Alternative Event Flow	▶ UGR approaches a crosswalk. ▶ UGR expresses intent to cross at the current existing green light phase. ▶ Approaching vehicles and RSE receive the message which includes UGR intent to cross. ▶ A vehicle determines that it can accommodate the request (since it is still stopped at the traffic light), it acknowledges the UGR/RSE and notifies nearby vehicles that it is participating in the request. ▶ When the UGR (and RSE) receives sufficient evidence that it is safe to cross (may vary with number of lanes and vehicles present), – (Optional) The RSE extends green light phase for the crosswalk. – UGR starts crossing. ▶ While the UGR is crossing, it may send information (e.g. PSMs, VAMs) notifying stopped vehicles (and RSE) of its progress. ▶ Upon reaching the other side of the crosswalk, the UGR may send another message to the vehicles (and RSE) confirming that they have safely crossed. When vehicles are safe to proceed after the UGR crosses, they begin moving again.
Post-Conditions	The UGR may send a session-closing message to RSE (and/or vehicles) notifying them of successful crossing.
Information Requirements	▶ Accurate positioning. ▶ UGR ID. ▶ Local map data (to get information about the location of crosswalks).

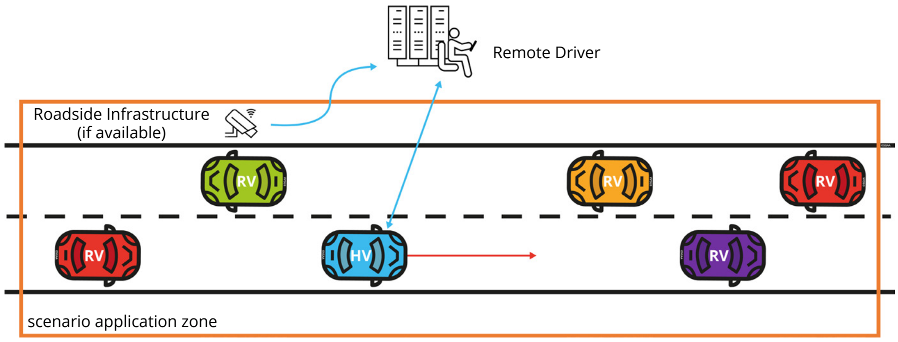
Table 8 SLR of User Story #2 Interactive UGR crossing with request-driven traffic light

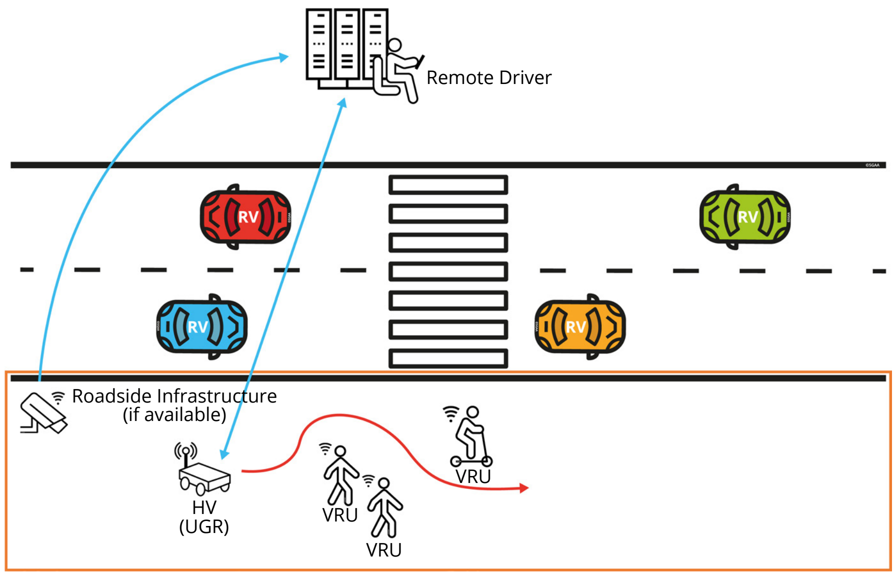
User Story #2 (Interactive UGR crossing with request-driven traffic light)			
Service Level Requirement	**SLR Unit**	**SLR Value**	**Explanations/Reasoning/Background**
Range	[m]	300	Message does not need an extreme range, as it only needs to reach nearby vehicles that could stop for UGRs at a crosswalk.
Information Requested/Generated	Quality of information/ Information needs	64 Kbps	UGR can send a 'heartbeat' message (including location data e.g. PSM, VAM) after a small 'request' message; the vehicle only needs to send acknowledgment.
Service Level Latency	[ms]	200	Slow messaging does not result in safety result in this use case, and the maneuver will only be initiated upon agreement.
Service Level Reliability	%	99.9	Again, since a maneuver will only be initiated upon agreement, dropped messages will not result in safety risk and severe traffic efficiency degradation.
Velocity	[m/s]	13.9	Upper end of the speed that a vehicle will be driving at on a road where UGR crossing would take place (50 km/h).
Vehicle Density	[vehicle/km^2]	1,500	This Use Case is expected to mostly happen in less densely populated areas, since visibility at intersections is mostly good, speeds are limited around 50 km/h.
Positioning	[m]	0.2 (3σ)	If a UGR is standing next to a roadway, it only takes a slight position error to place them in the middle of the street on a map, or directly in the trajectory of a vehicle. Alternatively, if the UGR is crossing, a small error could falsely indicate to a nearby vehicle that the pedestrian is on the sidewalk.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes/No/Yes	Interoperability due to different OEMs and robot manufacturers. A standardized protocol is needed.

A.2 Tele-operated driving support

Table 9 UCD of User Story #1 Tele-operated driving support: Remote steering

Use Case Name	Tele-operated driving support.
User Story #1	**Tele-operated driving support: Remote steering.** An autonomous vehicle/UGR (e.g. passenger cars, or even a vehicle/UGR that performs dedicated tasks in very complex environments, e.g. snow ploughing, cleaning, loading and unloading) may detect a highly uncertain situation and cannot make the appropriate decision for a safe and efficient maneuver. In this case, the autonomous vehicle/UGR can ask for the support of a remote driver in order to resolve the difficult situation and then switch back to the normal autonomous driving mode without the remote driving support.
Category	Autonomous driving.
Road Environment	Urban, rural, highway, intersection.
Short Description	When the autonomous vehicle/UGR detects the need for remote support, it starts sharing video and/or sensor data (e.g. from RADAR and LIDAR sensors in either raw or pre-processed form) and/or 'situation interpretation' data to communicate what is going on in the environment to the remote driver. Based on the perceived situation, the remote driver can provide the appropriate trajectory and maneuver instructions to help the autonomous vehicle/UGR resolve the highly uncertain situation.
Actors	Host vehicle/UGR, remote driver, remote vehicle/VRU, road and roadside infrastructure.
Vehicle Roles	Host vehicle (HV) represents the remotely driven vehicle/UGR. Remote vehicle (RV) represents other neighboring vehicles/VRUs.
Road/Roadside Infrastructure	▶ Roads are defined by their lane designations and geometry. ▶ Traffic signs provide laws, guidelines and timely information. ▶ (Optional) video feed from traffic cameras.
Other Actors' Roles	Remote driver (human or machine) undertakes to drive the HV remotely for a short period of time to overcome a dangerous or complex situation en route.
Goal	Enable the remote driver to support the HV remotely.
Needs	The HV needs to receive and apply the driving instructions sent by the remote driver.
Constraints/ Presumptions	The HV provides the infrastructure and data to enable remote driving functionality.
Geographic Scope	Everywhere.

<table>
<tr>
<td>Illustrations</td>
<td>


For autonomous vehicle


For UGR
</td>
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<tr>
<td>Pre-Conditions</td>
<td>

The HV has detected a situation which is too uncertain to select a safe and efficient maneuver.
The HV has asked and established an authenticated and secure communication channel with the remote driver.
UGR in pedestrian areas is allowed by the regulation.
Velocity of UGRs in pedestrian area is limited by the regulation. (e.g., 20 km/h = 5.6 m/s)

</td>
</tr>
</table>

Main Event Flow	If the remote driver is a machine, then: ▶ The HV provides to the remote driver information about the type of the HV, its destination and also information that will enable the remote driver to build the model of surroundings. This information may include road conditions derived, for example, by the HVs' sensors and cameras, status information of neighboring RVs (e.g. location, speed, dynamics, etc.), and traffic conditions. ▶ If available, secondary information from roadside infrastructure is accessed to obtain a more holistic view of the situation. ▶ The remote driver analyses the situation and selects the appropriate trajectory and/or maneuver instructions that will help the HV to resolve the corresponding situation where uncertainty is high. ▶ The remote driver sends to the HV trajectory and/or maneuver instructions and executes them, according to HV's on-board security checks. ▶ Feedback is provided to the remote driver in parallel with the execution of the maneuver.
Alternative Event Flow	If the remote driver is a human, then: ▶ The HV provides high-quality video streams (e.g. to identify road conditions, neighboring RVs) and its status information (e.g. speed, location, destination). ▶ If available, secondary information from roadside infrastructure is accessed to obtain a more holistic view of the situation. ▶ The remote driver analyses the situation and selects the appropriate trajectory and/or the maneuver instructions that will help the HV to resolve the corresponding situation where the uncertainty is high. ▶ The remote driver sends to the HV trajectory and/or maneuver instructions and executes them, according to HV's on-board security checks. ▶ Feedback (video, other sensors, HV status) is provided to the remote driver in parallel with the execution of the maneuver.
Post-Conditions	▶ The HV has left from the point where the support was needed. The tele-operated driving support session is de-activated and the HV switches back to its normal autonomous driving mode to continue performing its planned task or the trip to its destination.
Information Requirements	▶ Video streams. ▶ Equipped sensor data (RADAR, LIDAR, etc.). ▶ Road conditions. ▶ RVs' status (e.g. location, dynamics, etc.). ▶ Traffic signs. ▶ Traffic information. ▶ Lane designations and geometry. ▶ HV's status (location, speed, etc.). ▶ HV's trajectory. ▶ HV's maneuver instructions (steering wheel, acceleration and brake pedal inputs).

Table 10 SLR of User Story #1 Tele-operated driving support: Remote steering

User Story #1 Tele-operated driving support: Remote steering			
Service Level Requirement	**SLR Unit**	**SLR Value**	**Explanations/Reasoning/Background**
Range	[m]	10,000	Assuming V2N: Communication range within the coverage of a macro cell.
Information Requested/Generated	Quality of information/ Information needs	From HV to Remote driver: 32 Mbps (video streaming) Or From HV to remote driver: Optional: 36 Mbps (if video streaming and object information is sent) From remote driver to HV: Up to 1,000 bytes per message (up to 400 Kbps) (Commands from remote driver)	From HV to remote driver: ~8 Mbps are needed for a progressive high-definition video/camera (h.264 compression). Four cameras are needed (one for each side): 4 * 8 = 32 Mbps. From HV to remote driver (optional): Sensor data (interpreted objects) are also provided from the HV to the remote driver. Assuming 1 kB/object/100 ms and 50 objects, the result is 4 Mbps. From remote driver to HV: The size of command messages, e.g. a) turn steering wheel, direction, angle, etc., b) apply the brake, brake pressure, etc. including appropriate security headers. The command messages will be sent every 20 ms (maximum 50 messages per second).
Service Level Latency	[ms]	From HV to Remote driver: 100 From Remote driver to HV: 20 From Remote driver to HV(UGR): 50	From remote driver to HV: Depends on the reaction time needed, which is directly related to the maximum driving speed allowed. For instance, at a speed of 50 km/h, the HV will move 0.27 m within 20 ms. In case of UGR, the service level latency requirement can be relaxed, because the operation speed is lower than vehicle. For instance, at a speed of 20 km/h, the UGR (HV) will move 0.27 m within 50 ms.
Service Level Reliability	%	From HV to Remote driver: 99 From Remote driver to HV: 99.999 (Very high)	From remote driver to HV: The transmission of commands or paths from the remote driver requires a very high level of reliability because this affects the safe and efficient operation of the HV. In addition, the video streams and/or sensor information should be sent with high reliability to make sure that the remote driver has the correct (current) view of the surroundings.
Velocity	[m/s]	2.78	<10 km/h is considered the maximum speed for remote steering under highly uncertain conditions.
Vehicle Density	[vehicle/km^2]	10	Vehicle/UGR density reflects the number of HVs. Many more remote vehicles and VRUs could be present.
Positioning	[m]	0.1 (3σ)	Positioning accuracy is needed to navigate around objects blocking parts of the driving lane and to navigate through small gaps between two or more objects.

Interoperability/ Regulatory/ Standardization Required	[yes/no]	No/Yes/No	Typically, these ToD solutions are proprietary implementations. Regulation is needed because authorities may need to specify maximum speed, minimum accuracy, data formats, etc.

Table 11 UCD of User Story #2 Tele-operated driving support: Remote driving instructions

User Story	**Tele-operated driving support: Remote driving instructions** There are also situations where uncertainty is high due to detection problems in one of the sensors (e.g. unresolved objects). For instance, a road construction area has just been set up or changed and with that road direction and lane markings have changed or are confusing. Such situations might need the decision of a human (tele-operator) to be resolved. The difficult situation is resolved by a remote driver who advises the HV how to proceed with the autonomous driving task. The remote driver will provide instructions to the HV, which will then execute them in its autonomous driving mode. The remote driver does not take over control of steering and acceleration. However, it is possible for the remote driver to control the brakes.
Other Actors' Roles	Remote driver (human or machine) undertakes to send driving commands or instructions remotely (e.g. 'ignore lane marking', 'pass car blocking the road on the right/left') to the HV for a short period of time to overcome a dangerous or complex situation en route.

Table 12 SLR of User Story #2 Tele-operated driving support: Remote driving instructions

User Story #2 Tele-operated driving support: Remote driving instructions			
Service Level Requirement	**SLR Unit**	**SLR Value**	**Explanations/Reasoning/Background**
Range	[m]	10,000	Assuming V2N: Communication range within the coverage of a macro cell.
Information Requested/Generated	Quality of information/ Information needs	From HV to remote driver: 32 Mbps (video streaming) Or From HV to remote driver: Optional: 36 Mbps (if video streaming and object information is sent) From remote driver to HV: Up to 1,000 bytes per message (up to 400 Kbps) (Commands from remote driver) or From remote driver to HV: Up to 25 Kbps (Path from remote driver)	From HV to remote driver: ~8 Mbps are needed for a progressive high-definition video/ camera. Four cameras are needed (one for each side): 4 * 8=32 Mbps From HV to remote driver (optional): Sensor data (interpreted objects) are also provided from the HV to the remote driver. Assuming 1 kB/object/100 ms and 50 objects, the result is 4 Mbps. From remote driver to HV: The size of command messages, e.g. a) turn steering wheel, direction, angle, etc., b) apply the brake, brake pressure, etc. including appropriate security headers. The command messages will be sent every 20 ms (maximum 50 messages per second). From remote driver to HV: The data of provided paths are several Kbps (e.g. 100 points and 32 bytes for each point).

Service Level Latency	[ms]	From HV to remote driver: 100 From remote driver to HV: 200	From remote driver to HV: With only the instructions to be transmitted from remote driver to the HV, latency requirements are more relaxed.
Service Level Reliability	%	From HV to remote driver: 99 From remote driver to HV: 99.999 (Very high)	From remote driver to HV: The transmission of commands or paths from the remote driver requires a very high level of reliability because this affects the safe and efficient operation of the HV. In addition, the video streams and/or sensor information should be sent with high reliability to make sure that the remote driver has the correct (current) view of the surroundings.
Velocity	[m/s]	2.78	<10 km/h is considered the maximum speed for remote steering under highly uncertain conditions.
Vehicle Density	[vehicle/km^2]	10	Vehicle/UGR density reflects the number of HVs. Many more RVs could be present.
Positioning	[m]	0.1 (3σ)	Positioning accuracy is needed to navigate around objects blocking parts of the driving lane and to navigate through small gaps between two or more objects.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	No / Yes / No	Typically, those ToD solutions are proprietary implementations. Regulation is needed because authorities may need to specify maximum speed, minimum accuracy, data formats, etc.

A.3 Vehicle health monitoring

Table 13 UCD of Vehicle health monitoring

Use Case Name	Vehicle Health Monitoring.
User Story	Owners, fleet operators and authorized vehicle/UGR service providers monitor the health of HV and are alerted when maintenance or service is required.
Category	Vehicle Operations Management.
Road Environment	Intersection, Urban, Rural, Highway, Other.
Short Description	▸ Owners, operators and vehicle/UGR service providers request a report of the HVs current health including: – On-board diagnostic trouble codes. – Predicted maintenance (fluids, brakes, tires, battery, etc.). ▸ Owners, operators and vehicle/UGR service providers are alerted to new vehicle health issues requiring service and the HV's location when detecting: – On-board diagnostic trouble codes. – Required maintenance (fluids, brakes, tires, battery, etc.).

Actors	▶ Host vehicle (HV). ▶ Vehicle/UGR owner. ▶ Fleet operator. ▶ Vehicle/UGR service provider.
Vehicle Roles	HV represents the vehicle/UGR that needs maintenance or service.
Roadside Infrastructure Roles	Not applicable.
Application Server Roles	Not applicable.
Other Actors' Roles	Not applicable.
Goal	▶ Provide owners, operators and vehicle/UGR service providers of HV health report on request. ▶ Alert owners, operators and vehicle/UGR service providers of HV health issues requiring maintenance or service.
Needs	▶ Owners, operators and vehicle/UGR service providers need to know the health of the vehicle including: – Required and estimated maintenance. – Detected problems that require service and the location of HV.
Constraints/ Presumptions	Not applicable.
Geographic Scope	Global.
Illustrations	Not applicable.
Pre-Conditions	UGR in pedestrian areas is allowed by the regulation. Velocity of UGRs in pedestrian area is limited by the regulation. (e.g., 20 km/h = 5.6 m/s).
Main Event Flow	▶ Vehicle/UGR owner, operator or vehicle/UGR service provider requests a health report. ▶ HV provides on-board diagnostic trouble codes. ▶ Required maintenance is determined based on component use and wear. ▶ A health report is provided to the requester.
Alternate Event Flow	▶ HV detects a problem using on-board diagnostics. ▶ The vehicle/UGR owner, operator or vehicle/UGR service provider is notified of the detected on-board diagnostic trouble code.
Alternate Event Flow	▶ HV detects a problem that requires service. ▶ The vehicle/UGR owner, operator or vehicle/UGR service provider is notified of the driver reported problem.
Alternate Event Flow	▶ A HV component requires maintenance based on determined use and wear. ▶ The vehicle/UGR owner, operator or vehicle/UGR service provider is notified of the required maintenance.
Post-Conditions	▶ The vehicle/UGR owners, operators and vehicle/UGR service providers are aware of the health of the HV including: – Required and estimated maintenance. – Detected problems that require service and location of HV.
Service Level Key Performance Indicators	Location accuracy.

Information Requirements	▶ HV health report: – On-board diagnostic trouble codes. – Predicted maintenance (fluids, brakes, tires, battery, etc.). – Required maintenance (fluids, brakes, tires, battery, etc.). ▶ HV location.

Table 14 User Stories of vehicle health monitoring

User Story	Detailed description and specifics.
User Story #1	In case of vehicle, a HV is traveling on a highway and is losing air pressure in one or more of its tires. A road or fleet operator needs to be made aware of the situation.
User Story #2	In case of UGR, a UGR is traveling on a permitted road (e.g., sidewalk, crosswalk) and is facing some technical and/or maintenance issues. For instance, a sensor of UGR is defective and UGR cannot recognize properly the driving environment. The UGR operator needs to be informed of the situation.

Table 15 SLR of User Story #2 of vehicle health monitoring

User Story #2 of vehicle health monitoring			
SLR Title	**SLR Unit**	**SLR Value**	**Explanations/Reasoning/Background**
Range	**[m]**	N/A	There is no concrete upper limit to the desired range. The UGR needs to convey the message to the UGR operator cloud which in most cases is physically far away from the UGR.
Information Requested/ Generated	**Quality of information/ Information needs**	<1 KB	The information must be timely and accurate. Since the information is safety related, it must be accurate.
Service Level Latency	**[ms]**	<30,000	Latency is not a critical factor.
Service Level Reliability	%	99.99	It is critical that the information be sent and received successfully.
Velocity	**[m/s]**	5.6	Health monitoring related events and messages should be able to be sent successfully at permitted driving speeds for UGRs (example 20 km/h).
Vehicle Density	**[vehicle/km^2]**	4,000 or max.	UGR that is on the verge of becoming stranded due to a degrading condition should be able to successfully send the information in a traffic congested environment.
Positioning Accuracy	**[m]**	1.5 m ^3 s (99.8%)	Since this information may be used to dispatch assistance, the location of the UGR must be known within a sidewalk width and within the UGR's length. Here, 1.5 m is the typical accuracy required to locate a UGR within a width of sidewalk.
Interoperability/ Regulatory/ Standardization Required	**[yes/no]**	Yes	Information should be standardized to enable road operators to identify UGRs that are at risk of becoming stranded and dispatch an appropriate level of assistance.

5GAA is a multi-industry association to develop, test and promote communications solutions, initiate their standardisation and accelerate their commercial availability and global market penetration to address societal need. For more information such as a complete mission statement and a list of members please see https://5gaa.org

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