TECHNICAL REPORT

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Intelligent transport systems — Mobility integration — Mobility integration needs for vulnerable users and light modes of transport

Systèmes de transport intelligents — Intégration de la mobilité — Besoins d'intégration de la mobilité pour les usagers vulnérables et les modes de transport légers

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Contents

Page

Foreword

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This document was prepared by Technical Committee ISO/TC 204, *Intelligent transport systems*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In previous years, the development of intelligent transport system (ITS) standards has been focused on road vehicles and supporting traffic and transport systems. Although provisions in respect of accessibility and accommodation of all travellers, including people with disabilities and older adults, have been taken into consideration, related requirements for ITS have not been accommodated, primarily because of the lack of possibilities for communicating electronically with these travellers.

The more recent focus on Mobility as a Service (MaaS), cooperative, connected and automated mobility (CCAM), and multimodal end-to-end journey planning and management, incorporate travel means such as active modes (e.g. bicycles) and micromobility vehicles (MMV) such as powered bicycles, powered scooters, Segways, powered boards, etc. Often, they also involve device sharing. End-to-end multimodal journeys often also include part of the journey on foot.

ITS service provision has, to date, tended to agglomerate standards for “road users”, “drivers” and “vehicles” and is largely focused on car drivers and the systems that control or assist them. Some attention has also been focused on public service and commercial vehicles. But another group of light vehicle mode users are powered two-wheeled vehicle (P2WV) riders. With a few exceptions, there has been little appreciation of the different characteristics and behaviour of motorcycles, mopeds, trikes and quads and the requirements that they have that differ from those for other categories.

These categories of conveyances and travellers, at the least, have needs to be communicated in terms of ITS service provision. Conversely, many ITS services often need to communicate with, or be aware of the presence of, these actors. Yet, in previous years, there have generally not been any means for communicating with them individually.

However, during the last few years, smartphones and other nomadic devices have not only become available, but are already indispensable for multimodal journeys and assist in ITS service provision. Smartphone technology is also often used in devices assisting. The advent of low-cost communications and cooperative technologies can also assist in the provision of services.

Intelligent transport systems — Mobility integration — Mobility integration needs for vulnerable users and light modes of transport

1 Scope

This document provides a review of mobility integration standardization efforts supporting all travellers using active and light transport modes and identifies gaps where additional standardization is potentially required. The gap analysis is focused on cooperative intelligent transportation systems (C-ITS) for all users, including people with disabilities, as they plan, manage and carry out their “complete trip”, including all connections and transfers, from end-to-end.

The term “light mode conveyances" covers C-ITS for light power and active modes such as micromobililty vehicles (e.g. e-scooters), power or power-assisted vehicles (e.g. e-bikes, power wheelchairs), and full powered vehicles (e.g. motorcycles, mopeds).

This document identifies areas where standardization is potentially required to resolve problems and challenges, or to create opportunities, particularly with respect to enhancing safety and the provision of end-to-end multimodal journeys and support.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.2 Abbreviated terms

AI	artificial intelligence
BSM	basic safety message
CCAM	cooperative, connected and automated mobility
CV	connected vehicles
DSRC	dedicated short-range communication
HMI	human machine interface
HSM	hardware security module

IMN	in mobility network
ITS	intelligent transport system
ITS-S	intelligent transport system station
MaaS	mobility as a service
MIB	management information base
ML	machine learning
MM	micromobility
MMCS	micromobility cloud server
MMCN	micromobility communication network
MMG	micromobility gateway
MMV	micromobility vehicle
MU	mobile unit
ND	nomadic device
PCN	public communication network
P2P	pedestrian to pedestrian
P2WV	powered two-wheel vehicle
P-ITS-S	personal intelligent transport system station
RoW	right of way
SMIB	security management information base
UTMS	universal traffic management systems
V2V	vehicle to vehicle
V2I	vehicle to infrastructure
V2P	vehicle to pedestrian
V2x	vehicle to everything
VAM	vulnerable road vehicle awareness message
V-ITS-S	vehicle intelligent transport system station
VRU	vulnerable road user
VRV	vulnerable road vehicle

4 Vulnerable road users (VRUs)

4.1 VRUs in standardization

This clause describes the current provisions and differences among regions and standardization organizations when defining VRUs, the eco-system in which VRUs exist, the devices used for detection, control and communication, information exchanged with other actors, and the haptic sensory approaches used for notification.

4.2 VRUs in the context of C-ITS

4.2.1 Overview

C-ITS and connected vehicle (CV) programmes typically characterize communications between vehicles (V2V), between vehicles and infrastructure (V2I) and between vehicles and pedestrians (V2P). “Pedestrians” in this context typically refers to VRUs including people walking, passengers embarking and disembarking buses and trains, animals, people in work zones, people riding bicycles and people riding low-powered mobility devices such as e-scooters, powered wheelchairs and power assisted bikes.

4.2.2 C-ITS safety processes

Standards for VRUs are derived from the needs associated with their travel safety requirements. Typical C-ITS activities follow a process flow as shown in Figure 1. The flow begins when a vehicle, pedestrian or infrastructure detects the presence of a threat (1. Detection). Once detected, the system identifies the type of threat (2. Identification). In some cases, the path taken by the “threat” can be assumed by way of path restrictions (3. Compliance with right of way). Examples of right of way restrictions include a railroad grade crossing with gates drawn, a bicycle blocking a walkway, or pedestrians crossing against a traffic signal. For any actor to take evasive action or be notified of the threat, the threat’s expected manoeuvre needs to be determined (4. Expected manoeuvre). Finally, the appropriate action can be taken to inform or alert the actor of the threat (5. Communicate). These processes apply to V2V, V2I and V2P processes, albeit via different ITS-S devices and applications.

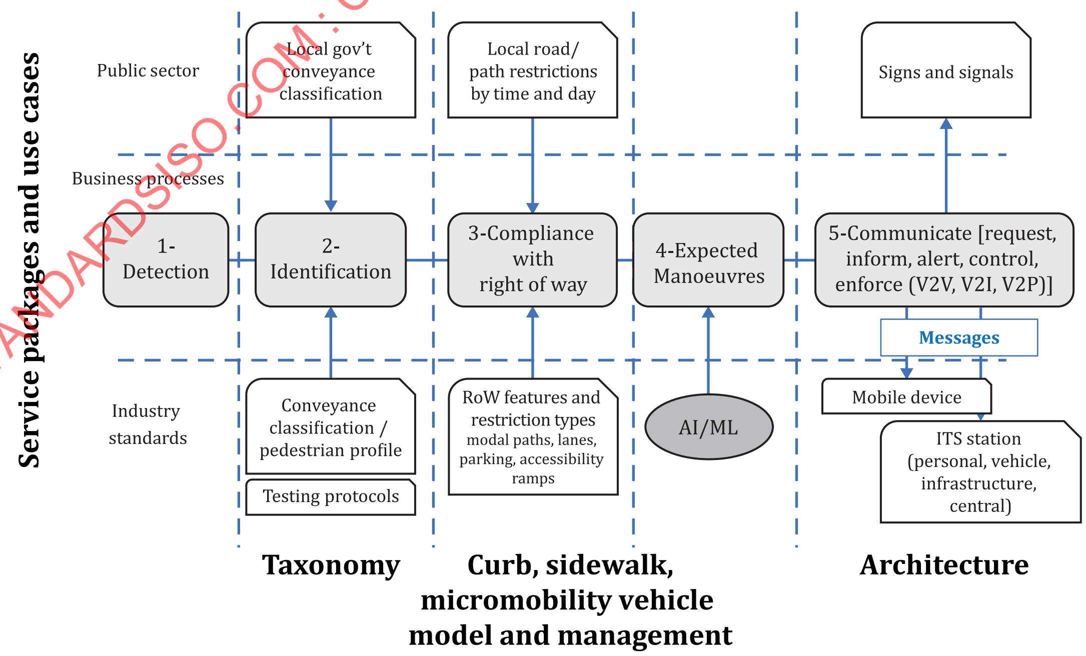


Figure 1 — General processes related to VRU detection and communications in the context of V2x, V2P and P2P

1) **Detection** — This process requires technologies to identify objects that are nearby. There are many such detection methods currently in use, including passive sensors that detect the presence of VRUs (e.g. lidar, wireless, and acoustic) or active communications between ITS-S devices (V2x or more appropriately VRU-2-x).

2) **Identification** — This process requires understanding the characteristics of the "threats". In this case, the process focuses on identifying the type of VRU. To aid in subsequent processes, such as determining compliance with rules and expected behaviours, the VRU characteristics are required to assess compliance and predict behaviour. These parameters include understanding maximum speed, dimensions, behavioural profile, restrictions and more. A VRU type and model will provide the appropriate information to feed these subsequent processes. See 5.1 for existing definitions and taxonomies that detail classification models for VRUs.

3) **Compliance with right of way** (RoW) — This process involves determining compliance with RoW restrictions. In some cases, this rule is targeted to the VRU, for example, no walk signals for people with a visual impairment. Compliance with RoW requires vehicles and VRUs to follow transport rules. For example, the infrastructure can detect a cyclist travelling on a restricted highway, an e-scooter parked in a pedestrian path impacting a person with visual disability, or a vehicle making a right turn onto a restricted road.

4) **Expected manoeuvres** — This process describes algorithms and models of VRU behaviour. These models provide scenarios which demonstrate, for example, the different expectations of intersection crossing by an adult walking with a young child versus a runner. Specific standards in this area are too new to determine. Research in "near miss collisions" particularly between VRUs (e.g. bikes/e-scooters and pedestrians) as well as predicting VRU behaviour (in groups as well as by individuals) using predictive analytics, machine learning and other artificial intelligence techniques will help identify information needed to support the emerging tools.

5) **Communicate** — This process describes the processes for alerting the ITS-S application associated with the appropriate threatened actor. For the VRU for example, this alert can be received and delivered by infrastructure (flashing sign), VRU vehicle (bicycle, scooter, motorcycle), or by a personal nomadic device.

Research, technologies and use case descriptions generally fall into these five categories. ETSI use cases describe additional complexities that augment understanding (see References [1], [2] and [3]).

4.2.3 C-ITS view of VRU

Many standards related to VRUs deal with vehicles or infrastructure sensing and avoiding the VRU. However, with new research and reduced costs of awareness sensors, an increasing number of VRUs are likely to possess personal devices with ITS-S applications. This document focuses on identifying the needs of the VRU including their integration into the C-ITS environment as an active rather than a passive participant.

At an early stage in the US Department of Transportation's "Vehicle to Pedestrian" program, the focus was on detection and communication. Three "technology categories" were used that included pedestrians (i.e. VRUs) as an active participant in the C-ITS environment:

1) **Unilateral pedestrian detection and driver notification:** Technologies that provide collision alerts only to the driver.

2) **Unilateral vehicle detection and pedestrian notification:** Technologies that provide collision alerts only to the pedestrian (i.e. VRUs).

3) **Bilateral detection and notification systems:** Technologies that provide collision alerts to both drivers and pedestrians (VRUs) in parallel.

Research in this area is listed in a related technology scan sponsored by the US Department of Transportation. The categories are in fact much more complex than the three listed above. For example, the unilateral vehicle detection and pedestrian notification category can include:

a) a personal device detecting and notifying the VRU of collision;

b) infrastructure detecting and notifying the VRU of collision (through audible or visual warnings);

c) infrastructure detecting and notifying the VRU's personal device of collision.

Existing standards have only addressed a limited subset of the needs identified. Furthermore, existing architectures (role-based and physical) have not fully embraced the categories or the complexities. In particular, the physical components, technologies and information flows vary for each of the three scenarios. To that end, the architecture needs to be technology and physical component agnostic. Even a VRU changes their role depending on travelling mode, and with them, the role of their personal ITS-S.

4.3 Definitions and taxonomy

4.3.1 Overview

The processes to detect and identify the VRU starts with understanding the type of VRU, and then determining the behaviour of that VRU. Identification is determined by a clear set of logical categories that describe critical characteristics of the observed VRU. This subclause describes various sets of taxonomies that relate to a VRU. These contribute to generating a comprehensive VRU profile that supports downstream processes. The areas include:

— definition and taxonomy for VRU (5.2.1);

— classification for VRU vehicles (VRV) and devices (5.2.2);

— combining VRU person and device/vehicle (5.2.3).

4.3.2 Definition of VRU

4.3.2.1 General

There is no consensus on terminology, classifications or scope in terms of a VRU. The only profiles of VRU found in automotive standards are for pedestrian and bicycle.[21],[16]

However, certain additional definitions are listed in the sources covered in the following subclauses.

4.3.2.2 SAE DSRC

SAE J2945/9 describes V2P safety warnings, where “P” implies a VRU. SAE J2945/9 defines the terms "VRU" and "VRU Device" as follows:

VRU

A road user, who is not occupying a vehicle such as a passenger car, a motorcycle, a public transit vehicle, or a train. Pedestrians, cyclists, children, elderly, people with disabilities and road workers are particularly vulnerable to serious injury or death if they are involved in a motor-vehicle-related collision.

VRU DEVICE

A device that transmits personal safety messages as defined in SAE J2735, and optionally can receive basic safety messages (BSM). The device can be capable of receiving other message types.

These definitions do not build a classification of a VRU. A VRU device is a connected device that is not associated with a specific class of VRU.

4.3.2.3 EU specifications

Within EU regulation 168/2013,[16] a VRU is defined as follows:

Non-motorized road users as well as L class of vehicles (for example mopeds or motorcycles). This includes:

— *Pedestrians (including children, elderly, joggers)*

— *Emergency responders, safety workers, road workers,*

— *Animals such as horses, dogs down to wild animals*

— *Wheelchairs users, prams*

— *Skaters, skateboards, scooters, potentially equipped with an electric engine*

— *Bikes and e-bikes, with speed limited to 25 km/h.*

— *High speed e-bikes speed higher than 25 km/h, class L1e-A.*

— *Powered Two Wheelers (PTW), mopeds (scooters), class L1e.*

— *PTW, motorcycles, class L3e.*

— *PTW, tricycles, class L2e, L4e and L5e limited to 45 km/h.*

— *PTW, quadricycles, class L5e and L6e limited to 45 km/h.*

4.3.2.4 ETSI

4.3.2.4.1 Definitions

The term VRU typically combines VRUs and their conveyances and assistive devices into a single term. ETSI definitions separate those into multiple terms. The following definitions are used in ETSI TS 103 300-2 and ETSI TS 103 300-2 V2.1.1.

— **VRU:** non-motorized road users as well as users of VRU vehicles.

NOTE 1 A VRU can only be a living being. This living being is only considered a VRU when it is in the context of a safety-related traffic environment.

— **VRU application:** application extending the awareness of and/or about VRUs such as motorcycles, bicycles, pedestrians and impaired traffic participants in the neighbourhood of other traffic participants.

— **VRU device:** portable device used by a VRU integrating a standard ITS station.

NOTE 2 The definition of an ITS station is given in ETSI TS 103 300-2. A VRU device can also integrate applications interfacing the ITS-S. For example, an application can improve the VRU trajectory prediction by learning continuously from its behaviour when sharing the space with other road users.

— **VRU ITS-S:** P-ITS-S/V-ITS-S capable of handling VRU-related ITS applications.

— **VRU system:** ensemble of ITS stations interacting with each other to support VRU use cases, e.g. personal ITS-S, vehicle ITS-S, roadside ITS-S or central ITS-S.

— **VRU vehicle:** L class of vehicles (for example mopeds or motorcycles, etc.), as defined in Reference [16] and light unpowered vehicles (bicycles, skates, wheelchairs, prams).

— **combined VRU**: combination of a VRU and a VRU vehicle (e.g. bicycle, wheelchair).

ETSI further specifies VRU device types to include:

— receive only;

— transmit only;

— ITS-S that receives and transmits;

— absence of a VRU device.

The terms used for VRU application, VRU device and P-ITS-S are consistent with those used by other ISO C-ITS standards including ISO 13111-1 which defines an ITS station (ITS-S), ITS-S application and personal ITS station (P-ITS-S).

Of particular interest in ETSI TS 103 300-2 is the description of a VRU ITS-S. When the station is connected to a VRU vehicle (VRV) the ITS-S is considered a V-ITS-S and when located on the person it is considered a P-ITS-S. ETSI TS 103 300-2 includes functionality to register and deregister the ITS-S to accommodate the fluidity of the road user's vulnerability.

Differentiating various components of the VRU (i.e. vehicle, application, device, system) provides a more flexible and complete approach to defining the VRU actor and accessories.

4.3.2.4.2 VRU profiles

In addition to the definitions, ETSI TS 103 300-2 and ETSI TS 103 300-2 V2.1.1 describe four VRU profiles:

1) pedestrian;

2) bicyclist;

3) motorcyclist;

4) animals presenting a safety risk to other road users.

The profiles are described by their maximum and typical speed values, transmission range, environment, weight class, trajectory ambiguity and maximum cluster size.[2] Even within each profile category, the dimensions and dynamics can differ widely: a runner will traverse an intersection much faster and more nimbly than person using a walker; the footprint of a mobility scooter will be much larger than a person on a skateboard. When the VRU does not have a VRU device or VRU ITS-S, then accurately identifying the VRU type becomes more important.

4.3.3 Classification for VRV/Devices

4.3.3.1 Overview

Few standards provide a classification system for distinguishing different types of VRU. However, several standards have been published describing low-powered vehicles (like the L Class vehicle classes; see Reference [16]). Other standards cover micromobility vehicles (MMV) and some specifications describe categories for wheelchairs and other mobility aids for people with disabilities. These documents and classification categories are listed in the following subclauses. They provide the foundation for creating "profiles" to detect and identify several types of VRUs.

4.3.3.2 Classification for micromobility vehicles (MMVs)

ISO 7176-2 includes a taxonomy for powered and human-powered vehicles. The classification scheme parameters consist of curb weight, vehicle width, top speed and power source. See Table 1.

Table 1 — Classification system for powered micromobility vehicles

Name	Code	Description
Curb weight		
Ultra lightweight	WT1	Curb weight ≤ 50 pounds (23 kg)
Lightweight	WT2	50 pounds (23 kg) < curb weight ≤ 100 pounds (45 kg)
Midweight	WT3	100 pounds (45 kg) < curb weight ≤ 200 pounds (91 kg)
Midweight plus	WT4	200 pounds (91 kg) < curb weight ≤ 500 pounds (227 kg)
Vehicle width		
Standard-width	WD1	Vehicle width ≤ 3 feet (0,9 m)
Wide	WD2	3 feet (0,9 m) < vehicle width ≤ 4 feet (1,2 m)
Extra-wide	WD3	4 feet (1,2 m) < vehicle width ≤ 5 feet (1,5 m)
Top speed		
Ultra low-speed	SP1	Top speed ≤ 8 mph (13 km/h)
Low-speed	SP2	8 mph (13 km/h) < top speed ≤ 20 mph (32 km/h)
Medium-speed	SP3	20 mph (32 km/h) < top speed ≤ 30 mph (48 km/h)
Power source		
Electric	E	Powered by an electric motor
Combustion	C	Powered by an internal combustion engine
SOURCE: SAE J3194:2019. [21]		

The purpose of the MMV taxonomy does not fully accommodate the requirement for building profiles for VRUs, even the human- and low-powered vehicles classes. Missing from the classification are categories inclusive of animals and mobility devices like wheelchairs and connected assistive technologies for people with disabilities.

4.3.3.3 Classification for VRU conveyance

Reference [40] includes the footprints (length, width, weight, turning radius) for mobility devices excluded from the MMV taxonomy. The wheelchair categories correspond to ISO 7176-21. The classification system is listed below.

- Wheelchairs
  - Manual wheelchair
  - Sports chair
  - Power chair
  - Power chair with special features (tilt)
- Mobility Scooters (w/o front and rear accessories)
  - 4-wheel scooter (regular / oversized)
  - 3-wheel scooter (regular / oversized)
  - Segway (w and w/o seat)
- Person with guide dog
- Person with a walker
  - Manual walker

  - Wheeled walker
- Person with crutches
- Stroller plus person
  - Single
  - Single jogger
  - Twin side by side
  - Twin tandem
  - Triple side by side
  - Triple tandem

Standards that describe wheelchair and mobility scooter classes include ISO 7176-5 and ISO 7176-26. Both documents describe the terms and vocabulary associated with wheelchairs and scooters, as well as how to measure "full overall length", "ground clearance", "pivot width", "ramp transition angle", "required corridor width for side opening" and other concepts that enable a safe and unobstructed trip to people with ambulatory disabilities.

The definition of VRU devices and conveyances are not complete without including assistive devices used by people with mobility disabilities.

4.3.3.4 Classification of VRU device

A class of VRU devices are emerging that support VRU communications within the C-ITS environment. These have several names:

- Personal ITS-station[4]
- Nomadic devices[4]
- Personal safety devices[19]
- Mobile unit (MU) to mirror the OBU/RSU nomenclature.

In addition, additional devices that are either connected to a mobile device or connected to a cloud through one of a myriad of communication technologies are deployed or under test. For example, a bike helmet alert sensor activated when a cyclist crashes; a vest or hard hat worn by a work zone worker; a medallion worn by a person with disabilities; smart watch; glasses; or other nomadic devices. These do not yet play a major role in the C-ITS environment, but the popularity of these devices, the inconsistencies in their naming, and their absence from C-ITS architectures and use cases represents a gap in the current body of standards.

4.3.4 Profiles related to VRU classifications

No single taxonomy covers all the categories needed to describe the people and devices representing VRUs, and the variety of footprints. However, most VRUs currently have an existing standard taxonomy that contributes to VRU profile descriptions. The taxonomies are summarized in the list of VRU classes below.

a) **People, animals (VRU)**

   1) Pedestrians (stationary, walking, running, older adults, children, adults with children, person with disabilities, person pushing carts/prams, pets/animals, wild animals, service workers including road, safety, enforcement, and horse/buggy).

2) No standard describes non-powered VRUs, particularly differences in speed, dimensions, abilities.

b) **People using human-powered conveyances (VRV)**

1) SAE J3194:2019:[21]

i) Human-powered vehicles such as bicycles, tri-cycles, skateboards.

ii) This taxonomy does not include MMV with trailer combinations.

2) TCRP Report 171 for Mobility Devices for People with Disabilities:[40]

i) This is a research report, not a specification or standard.

c) **People using powered MMVs designed to be used on paved roads and paths (VRV)**

1) Powered bikes, powered boards, powered skates, seated/standing scooter (fully or partially powered).

2) *"A category of powered vehicles that have a curb weight of less than or equal to 500 pounds (227 kg) and a top speed of 30 mph (48 km/h) or less."*[22]

d) **People using powered wheelchair and mobility scooters (VRV)**

1) TCRP Report 171 for Mobility Devices for People with Disabilities[40].

e) **People using "low-speed vehicles"**

1) Defined in regional RoW regulations such as U.S. Code of Federal Regulations Title 49 CFR § 571,3[41] and EU regulation 168/2013.[16]

f) **People using motorcycles, mopeds and motor-driven cycles**[21]

1) Vehicles exceed a curb weight of 500 pounds (227 kg) and/or a top speed of 30 mph (48 km/h).[22]

2) Similar to "low speed vehicles", defined in regional regulations and codes.

4.4 Architecture

4.4.1 General

There are several types and variations of architectures associated with C-ITS. Some include VRUs explicitly and some include them in a generic form. The majority of current C-ITS and C-ITS related architectures focus on the communications layers, components or functional architectures.

4.4.2 C-ITS role-based architecture

A role-based architecture is described in ISO 17427-1, although it does not show specific functional operations for VRUs, their fluidity, or how their responsibilities can be integrated into the generic functional operation as illustrated in Figure 4. In Figure 4, the VRU is assumed to be a "traffic participant", although this role does not completely cover all VRU, VRV and VRU device categories.

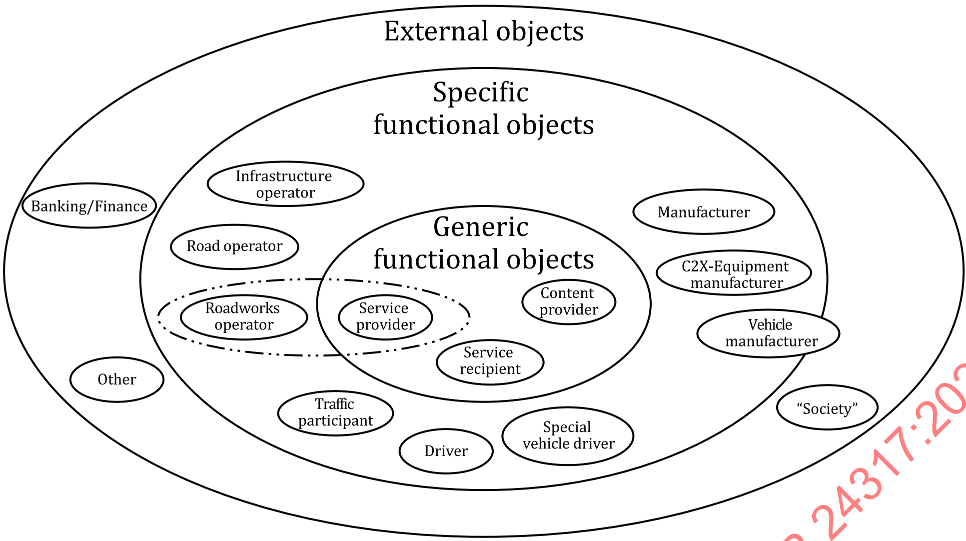


Figure 2 — Relation between generic and specific operation (ISO 17427-1:2018)

A role-based architecture can be appropriate for development given the changing role of the personal ITS-S. The following roles and functions can be considered.

— Role of nomadic devices, particularly when deployed in running shoes, smart work zone or bicyclist technologies (instrumented hard hat/vest), smartwatches or smart glasses.

  — In pilot deployments of smart watches, both the smart phone and watch had a secure element and virtual card installed. Although the watch was tethered to the phone, both were charged for payment.

— Fluidity of the P-ITS-S (nomadic device) when adopting to different anchor nodes, segments and flows (as described by ISO 24102-6), for example, when nomadic devices serve role of "secondary" devices when docked with a VRV.

  — The appropriate approach when a VRU with a personal ITS-S uses a non-instrumented VRV (e.g. e-scooters, bikes without ITS-stations).

Recommendations for filling gaps in ISO 17438-1 include the following:

— Expand generic functional operation roles to cover VRUs.

— Add specific functional operation to include VRU (not just traffic participant).

— Add specific functional operation to include VRV.

Add scenarios for various types of VRUs with/without VRU device and VRV.

4.4.3 ITS-S VRU architecture model

The reference model for the ITS-S is described in the ISO 21217 for vehicles. Figure 3 is a model that depicts functions and communications connections for the ITS-S. Several standards augment the architecture to directly incorporate additional capabilities for VRUs, including ETSI TS 103 300-3. Most of the functions are similar to those described in ISO/TR 10992-2, although using different sensors, platforms and human machine interface (HMI) with varying accuracy and precision performance methods. A VRU functional architecture augmented for VRUs developed by ETSI is depicted in Figure 4. One of the major additions to the architecture is the device setting role function. The device setting role identifies the role (e.g. exposed as a VRU vs. in a "protected area" as in a vehicle). If acting as a VRU, there are several profiles the role can choose from that match a transmit–receive profile:[2],[4]

— VRU-Tx with the only communication capability to broadcast message.

— VRU-Rx with the only communication capability to receive messages.

— VRU-St with full duplex communication capabilities.

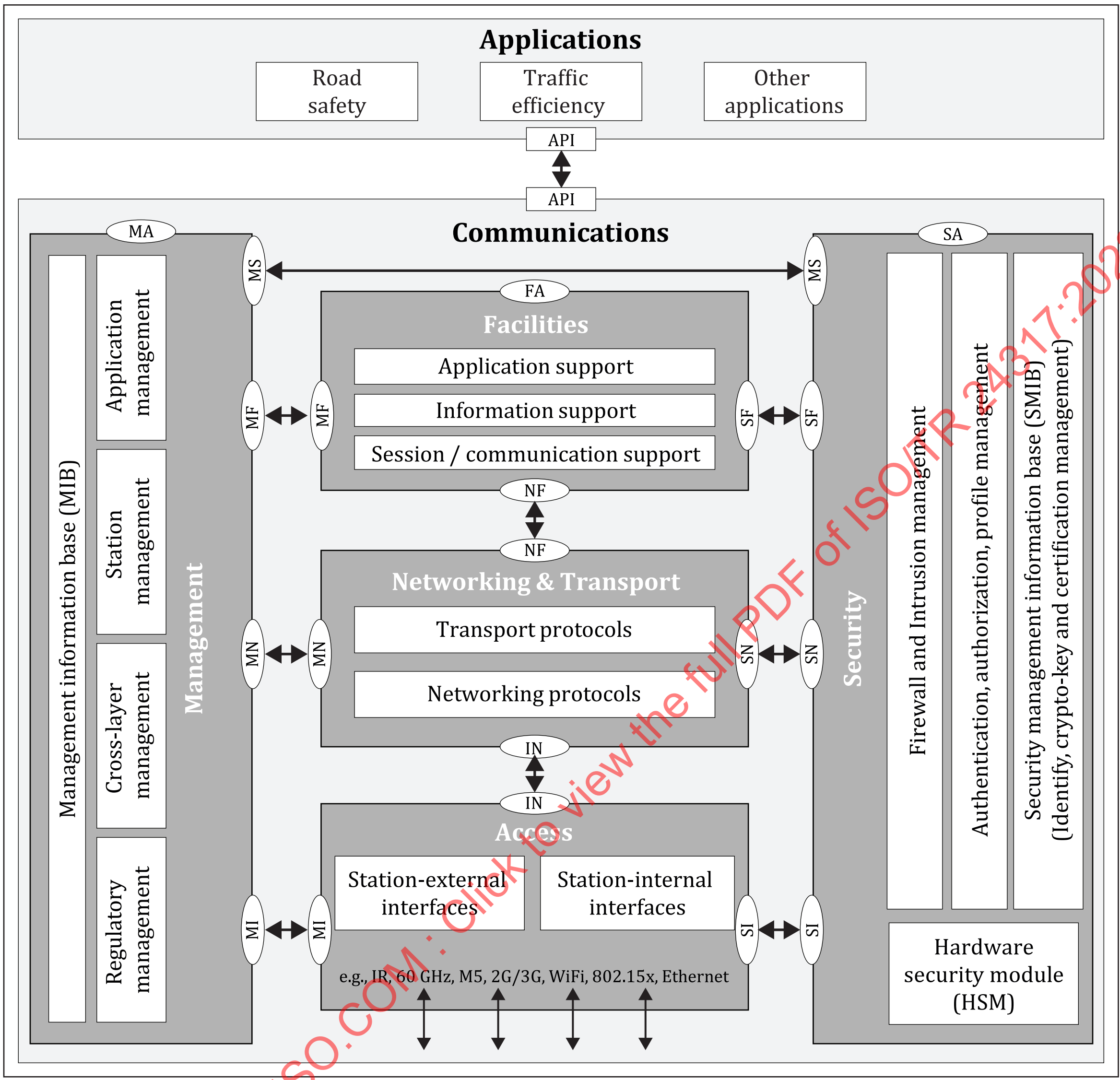
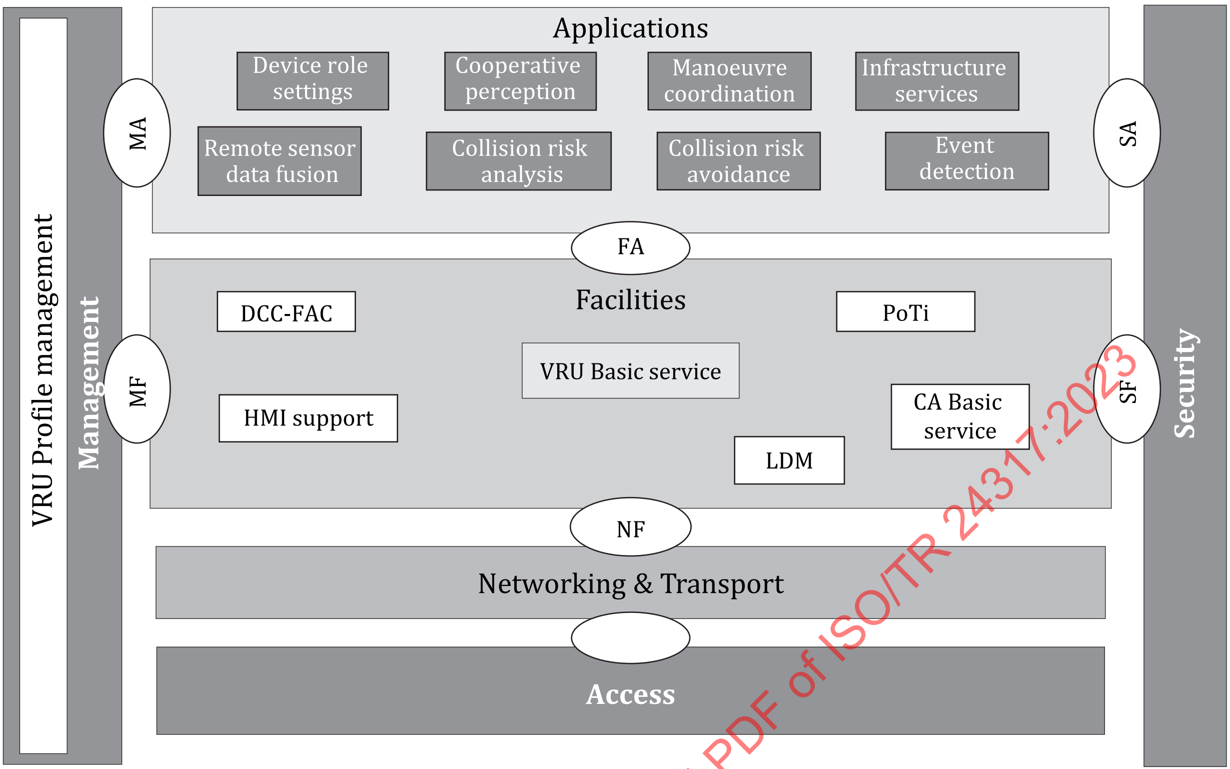


Figure 3 — ITS-S reference architecture (source: ISO 21217:2020)



NOTE This figure is adapted from ETSI TS 103-300-2-V2.1.1:2020

Figure 4 — VRU functional architecture mapped to ITS station architecture

4.4.4 Communications architectures and VRUs

4.4.4.1 ITS-station communications path and flow architecture

The ISO 24102 series describes the architecture and management of ITS stations for communications access for land vehicles (CALM), as depicted in Figure 5. ISO 24102-6 describes the path and flow management and provides a reference to communication profiles that support each path:

— ITS-S Flow (flow type)

— ITS-S Path

— ITS-S Anchor nodes

— ITS-S communication profile

The conceptual model includes some possible profiles and paths that personal safety devices or nomadic devices can use, but the profiles are not always consistent with the devices that VRUs use.

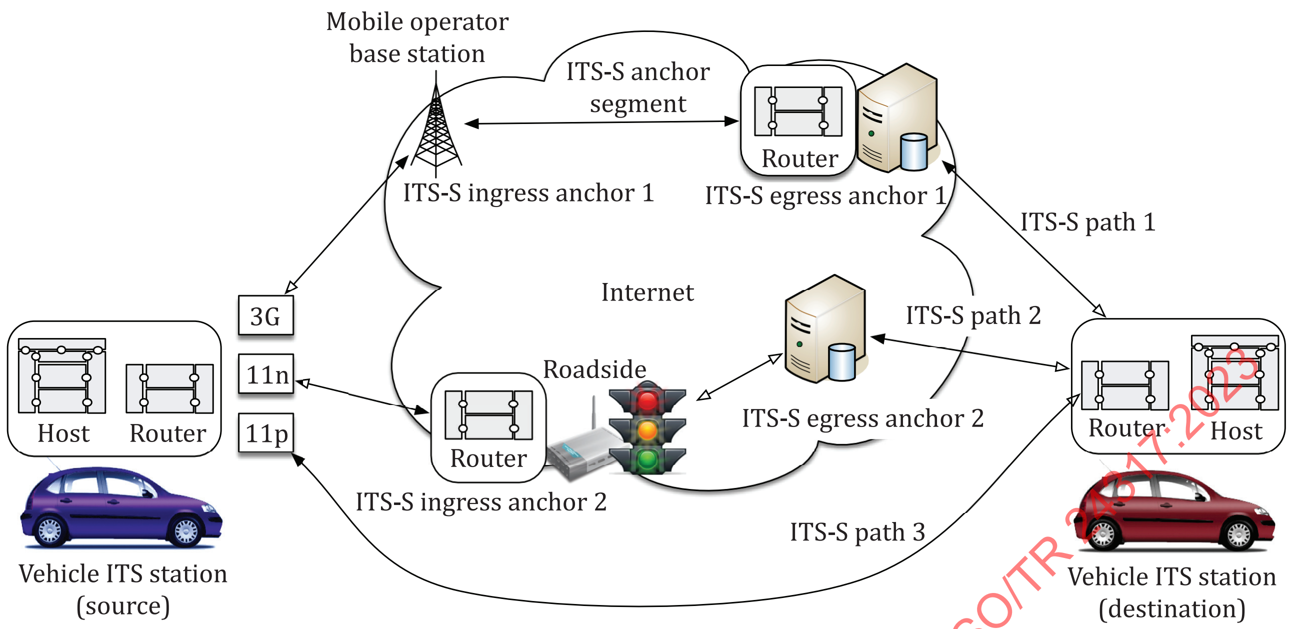


Figure 5 — Overview of the concept of ITS-S path and ITS-S anchor segment (ISO 24102-6:2018)

Yet, the reference architecture does not include VRUs. An extended model that does include VRUs is shown in Figure 6. In this model, there are additional paths that are not defined and their management and communications profiles (see "ITS-S path x") are not well defined. These include:

— VRU devices (including nomadic devices) communicate directly to a PSD, another ITS-S, or the infrastructure or C-ITS cloud.

— VRU devices (nomadic devices, mobile units) that are connected to a VRV and then connected to another PSD, ITS-S or ITS-S cloud.

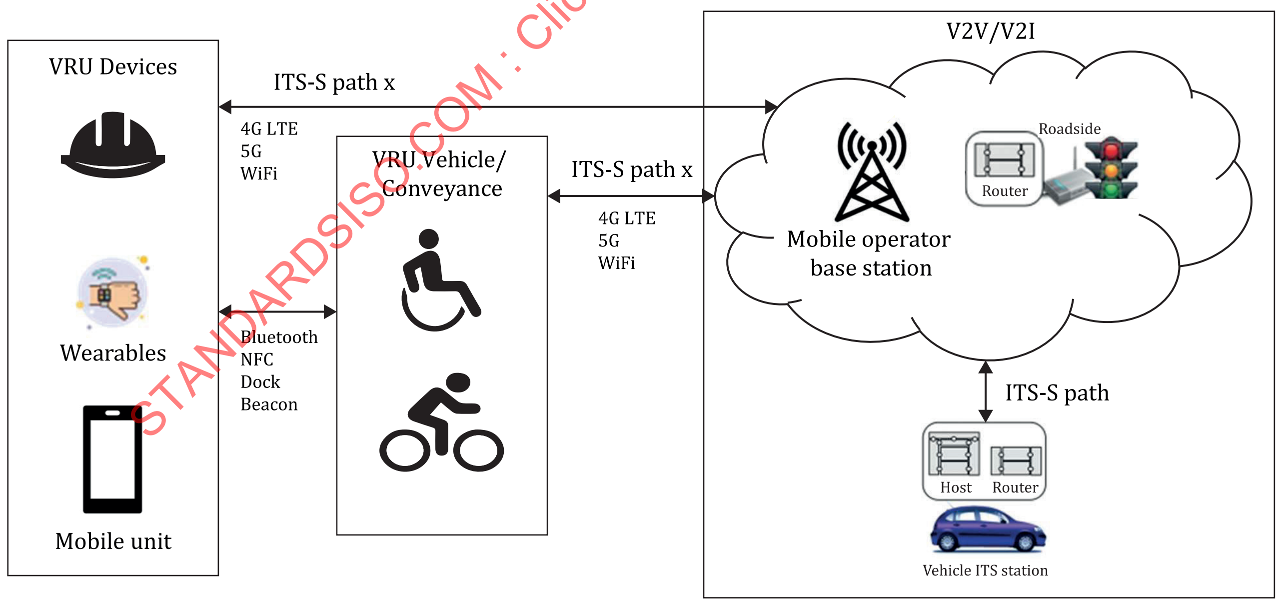


Figure 6 — Extended concept of ITS-S path and ITS-S anchor segment model for VRUs

4.4.4.2 Other physical device reference models

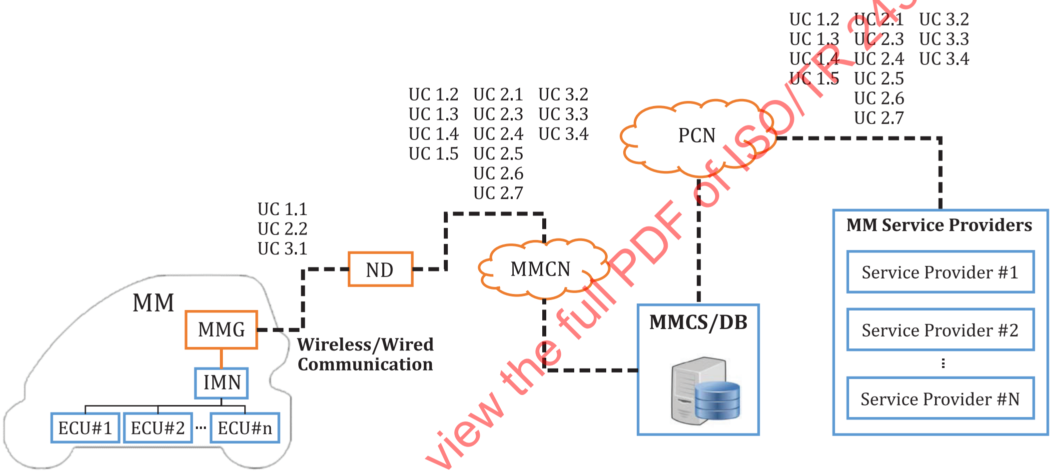
Other documents also describe other reference models that include V2P, Vehicle to Nomadic Device, or Vehicle to VRU within their framework. These architectures typically describe high level component models which are not as detailed as in ISO/TR 10992-2. That is, they do not show the flow between the VRU (or nomadic) device and the vehicle and infrastructure. The architectures include the following standard publications:

— SAE J2945/9:2017[19] (see Figure 2),

— ISO 13111-1,

— ISO/TR 22085-1.

In particular, Figure 7 shows a set of use cases that apply to each flow. Use cases will be explored in more detail in 5.5.2.



Key

MM micromobility
MMG micromobility gateway
ND nomadic device
IMN in mobility network
MMCN micromobility communication network
MMCS micromobility cloud server
PCN public communication network

Figure 7 — ITS station architecture for micromobility devices (ISO/TR 22085-1:2019)

4.5 Service packages and use cases

4.5.1 Relevant service packages

Several regions have published service packages that deal with types of VRUs. The architectures are reviewed with service packages that involve a VRU. A set of service packages contained in architectures from the US, EU and Japan are identified in Table 3.

Table 3 — Service packages from national ITS architectures related to VRU safety

Architecture Reference for Cooperative and Intelligent Transportation Version 8.3 (US)	— Mobile accessible pedestrian signal system — Advanced railroad grade crossing — Route ID for the visually impaired — Pedestrian and cyclist safety — Transit pedestrian indication — Blind spot warning — Lane changing warning — Vehicle turning right in front of bus warning — Intersection movement assist — Speed compliance in work zones — Pedestrian in signalized crosswalk
C-Roads Version 1.4(CEN)	— Animal or person on the road (HLN-APR) — Road Works – Mobile (RWW-RM)
Universal Traffic Management System – UTMS (Japan)	— Driver Safety Support Systems — Pedestrian Information and Communications Systems (PICS)

4.5.2 Relevant use cases

The use cases best describe gaps in the current body of standards. Generally, a use case identifies actors, roles and information flows based on different configurations of responsibilities and capabilities. The high-level business use cases best describe the needs, capabilities, actor roles and responsibilities while technical use cases describe requirements and performance metrics for information flows and functions. The majority of the use cases contained in standard organization technical reports and specifications are more technical in nature. However, for under-served travellers, people with disabilities, older adults, children and MMV-carrying children, the business use cases that generate needs have not been fully enumerated.

Standards and the scope of the use cases that cover VRUs are listed in the next subclauses.

4.5.2.1 ETSI TR 103 300

4.5.2.1.1 Use case categories — ETSI TS 103 300-2 V2.1.1[1]

The VRU awareness series from ETSI identifies six categories of use cases to describe the needs for data flows and capabilities with VRUs.

— Category A: direct VRU communication.

— Category B: direct VRU to vehicle communication.

— Category C: assistance of a third party (a vehicle) detecting a hidden VRU and signalling it to other vehicles.

— Category D: assistance of a third party (a road side equipment or RSE) detecting a hidden VRU and signalling it to approaching vehicles.

— Category E: assistance of a third party (a control centre or cloud server) monitoring the evolution of VRUs.

— Category F: Assistance of a third party (an RSE) monitoring the evolution of VRUs equipped with an ITS-S complying with VRU standards, detecting risks of collisions with monitored vehicles and then acting to avoid collision (sending alarms or collision avoidance instructions).

4.5.2.1.2 Use cases — ETSI TS 103 300-3[2]

ETSI TS 103 300-3 identifies use cases from other ETSI specifications as well as the message and data standards that support information exchange requirements. The use cases that are reviewed include:

— A1 Sharing pavement between pedestrian and cyclists

— A2 Pedestrian crossing a road with an e-scooter approaching

— B1 Active roadwork

— UCB2 VRU crossing a road

— UCB3 Rider is ejected from their motorbike

— UCB4 Emergency electronic brake light

— UCB5 Motorcycle approach indication/motorcycle approach warning

— UCC1 Signalling VRU hidden by an obstacle

— UCD1 Signalled few VRUs in a protected area

— UCD2 Non-equipped VRUs crossing a road

— UCD3 VRUs crossing at a zebra protected by a traffic light

— UCD4 Scooter/bicyclist safety with turning vehicle

— UCE1 Network assisted vulnerable pedestrian protection

— UCE2 Detection of an animal or pedestrian on a highway

— UCF1 Signalled many VRUs in a protected area

— UCF2 Intelligent traffic lights for all (P2I2V)

In addition, ETSI TS 103 300-3 describes scenarios for VRU clustering. Clusters typically travel at different rates of speed, and the dimensions of the cluster will change as it moves. Although a more comprehensive treatment heretofore, the cluster use cases will need to address heterogeneous VRUs in the cluster, as well as additional scenarios for different types of VRUs such as intersection crossings, travel along a roadway (e.g. bicycle lanes), along a pedestrian right of way.

One of the results of this analysis is a proposal for a VRU awareness message (VAM). The message can be generated by the VRU ITS-S or another ITS-S that senses the VRU or VRU cluster. The message content (see Table 4) covers multiple use cases, some from the vehicle or infrastructure point of view, others from the VRU viewpoint. From the description, some of the elements still need more specificity, like VRU type weight class, and size class.

Table 4 — VRU awareness message content

VRU awareness message content	Compliance
VAM header including VRU identifier	Mandatory
VRU position	Mandatory
Generation time	Mandatory
VRU profile	Mandatory

Table 4 *(continued)*

VRU awareness message content	Compliance
VRU type e.g. VRU profile is pedestrian, VRU type is infant, animal, adult, child, etc.	Mandatory
VRU cluster identifier	Optional
VRU cluster position	Optional
VRU cluster dimension (geographical size)	Optional
VRU cluster size (number of members in the cluster)	Optional
VRU size class	Mandatory if outside a VRU cluster, Optional if inside a VRU cluster
VRU weight class	Mandatory if outside a VRU cluster, Optional if inside a VRU cluster
VRU speed	Mandatory
VRU direction	Mandatory
VRU orientation (mandatory)	Mandatory
Predicted trajectory (succession of way points)	Optional
Predicted velocity (including 3D heading and average speed)	Optional
Heading change indicators (turning left or turning right indicators)	Optional

4.5.2.2 ISO 13111-1

ISO 13111-1 includes general use cases for travellers using nomadic devices. These devices contain personal ITS-S. The architecture shown in Figure 7 supports the ten use cases contained in the document.

— UC1 Access a roadside station through the P-ITS-S and R-ITS-S interaction interface

— UC2 Slow transport and local transport network data

— UC 3 Evacuation information and emergency service for P-ITS-S user

— UC 4 Transfer information service in the parking lot

— UC 5 Requesting the transfer information in an integrated transportation hub

— UC 6 Traffic and public transport information service

— UC 7 Trip planning for travellers with a P-ITS-S

— UC 8 Vehicle service through the P2V interaction interface

— UC 9 Share location between the P-ITS-S users

— UC10 Team travel (similar to cluster use cases from ETSI 103 300-2)

4.5.2.3 UTMS

UTMS supports two major use cases for VRUs:

— Driver safety support systems: use case to inform a right turn vehicle driver of the existence of pedestrians at a cross walk of a signalized intersection using an on-board unit.

— Pedestrian information and communications systems (PICS): use case for visually impaired persons to access to a pedestrian traffic signal using a smartphone.

4.5.2.4 SAE J2945/9

One of the first C-ITS standards that dealt exclusively with VRUs is SAE J2945/9.[19] The use cases in this document handle several scenarios of interactions between VRUs and vehicles (although these can be extended to VRU to VRU). There are many assumptions about activation of the VRU device that notifies a vehicle of its presence (and intention):

— VRU crossing across the road while vehicle is approaching on the road;

— VRU crossing while vehicle is turning right;

— VRU crossing while vehicle is turning left;

— VRU traveling in or next to the road, along the road.

The personal safety message described in ETSI TS 103 300-2 V2.1.1 is defined in SAE J2735.[17] It is a less precise version of the BSM broadcast by a vehicle. In the BSM, the basic position (reference point) is defined as the point (latitude, longitude, and elevation) at the centre of the rectangle “projected onto the surface of the ground plane with reference to the WGS-84 coordinate system and its reference ellipsoid”.[17] The designation goes on to state that this is the position of the VRU, rather than the VRU device which can be mounted “several decimeters away”.

In addition to basic time, position, speed, acceleration, heading and path history and prediction elements (that mirror the basic safety message included by vehicles), the BSM describes additional values such as:

— Propulsion: human, motorized and animal, information.

NOTE 1 "human" indicates manually powered including on foot, skateboard, push off scooter, wheelchair, etc.

NOTE 2 Motorized does not differentiate between different classes of motorized devices by weight, footprint or maximum speed type like SAE J3194.[21]

— Use state: describes level of pedestrian distraction.

— Cross request and state: request to crossing signal; crossing in progress.

— Cluster size and radius: number of participants in a cluster and radius of cluster.

— Event responder type: indicates a VRU of type public safety or work zone.

— Activity type and subtype: indicates the activity of the event responder.

— Assist Type: identifies the disability of a person – vision, hearing, movement, cognitive.

— User size and behaviour: can designate one or more of the following: small, large, erratic, slow.

NOTE 3 The values conflate user size (small, large) and movement (erratic, slow).

— Attachment: includes stroller, bike trailer, cart, wheelchair, other walking assistive attachments, pet.

— Attachment radius: describes radius of the attachment.

4.5.2.5 Additional related standards

There are several additional standards that include related use cases, performance and testing requirements for VRU devices or detecting VRUs (pedestrians or bicycles). These are listed below

— ISO/TR 10992-2:2017;

— ISO 19237:2017;