Selected C-ITS Use Cases in Cities

About the C2C-CC

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

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

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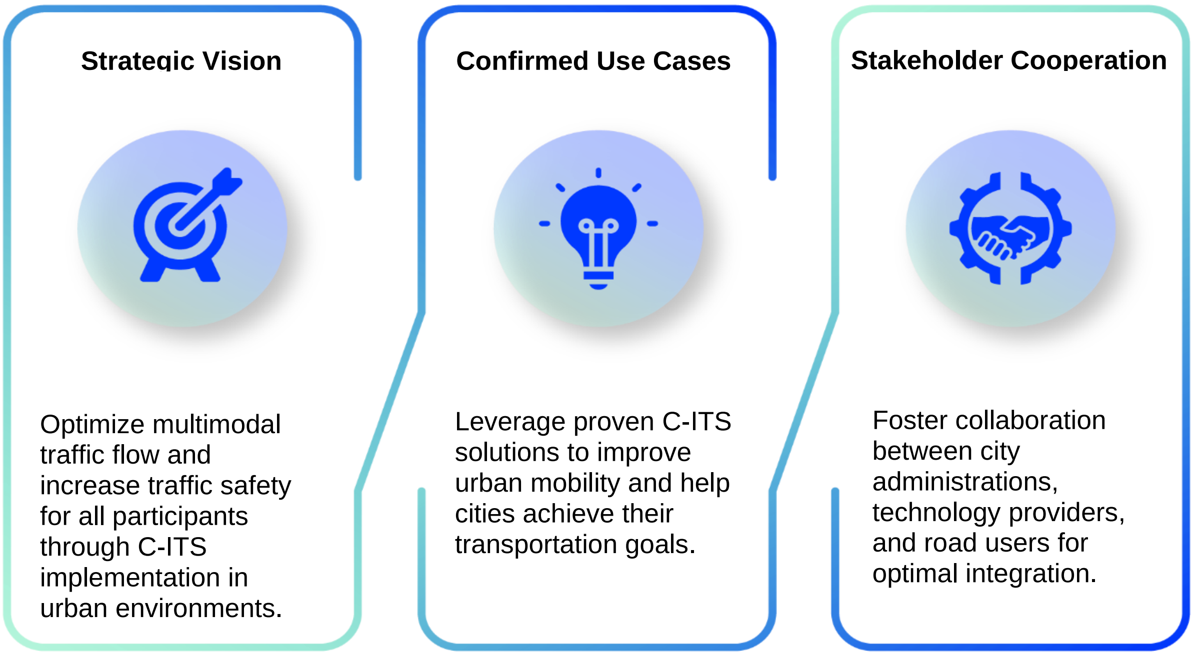
Justification of the Work Item

This work item focuses on city-based Cooperative Intelligent Transport Systems (C-ITS) services, emphasizing simplified requirements for cities on Traffic Management Centers (TMC). The initiative aims to interpret existing standards for city services, ensuring requirements are accessible for cities lacking dedicated TMC departments while considering relevant framework conditions.

It acknowledges that traditional traffic use cases may not meet all cities' needs. Importantly, this work item does not describe results of automated driving functions for cities (Day2, Day3, etc.) due to the absence of various regulatory, legal, and technical framework conditions that would be necessary for such implementations.

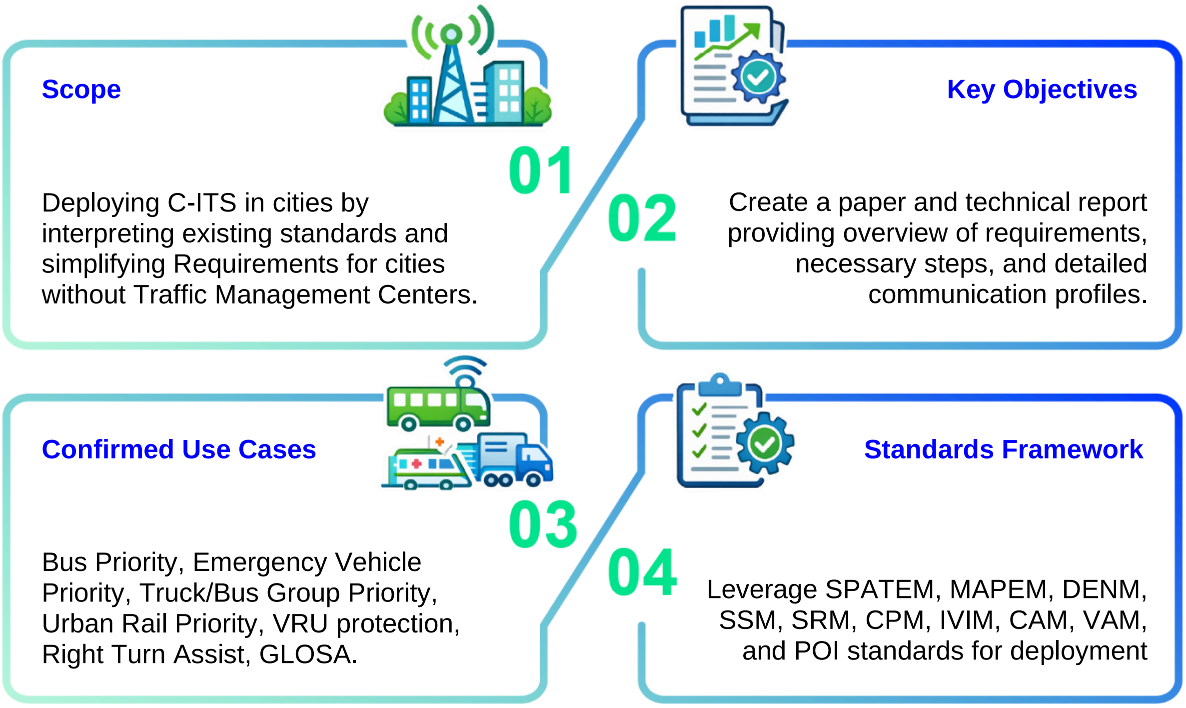
Description of Objectives



This document provides a detailed analysis of implementing Cooperative Intelligent Transport Systems in urban environments, highlighting strategic approaches required to achieve sustainable and safe mobility. While many cities have clear mobility goals, not all are fully aware of how to utilize C-ITS systems effectively. The focus is on informing urban road authorities about available options and helping them implement these solutions successfully.

Through joint initiatives and cooperation between different stakeholders, C-ITS technologies can be optimally utilized and integrated to create a modern, intelligent, and sustainable transportation infrastructure that serves the needs of all urban mobility participants.

Comprehensive Overview



Collaboration & Harmonization

Essential collaboration between C-Roads, C2C-CC, ETSI, CEN, and ISO ensures harmonization of existing specifications and identification of missing information.

This cooperative approach creates a feasible framework for joint deployment across different regions and organizations.

Collaboration
C-Roads · C2C-CC · ETSI · CEN · ISO

Identification
Aligned specifications· Missing information

Joint Deployment
Scalable & feasible framework

What exits and how can it be used

Existing C-ITS Infrastructure and Standards

The existing C-ITS infrastructure and standards provide a comprehensive foundation for urban deployment. These proven technologies and frameworks have been tested and validated across multiple implementations, offering cities a reliable starting point for their C-ITS journey. The visual examples above demonstrate real-world applications and system architectures that cities can adapt to their specific needs and requirements.

V2X Communication for Public Transport

V2X communication revolutionizes public transport operations by enabling seamless interaction between vehicles and infrastructure. This technology creates an intelligent network that optimizes traffic flow, reduces delays, and improves the overall efficiency of public transportation systems in urban environments.

MAPEM Reception

When a public transport vehicle approaches a signal head controller, the OBU continuously receives MAPEM messages transmitted by the RSU.

Trigger Detection

At a predefined position (trigger area), RO9 information is transmitted from the OBU to the RSU via CAM or SREM.

Signal Processing

The RSU forwards the RO9 telegram to the signal head controller, which processes the request and initiates signal prioritization.

Confirmation

The RSU confirms the request to the OBU via SSEM and optionally transmits SPATEM containing signal timing information.

Source: IC^{3}AT

V2X-Based Public Transport Signal Priority

01

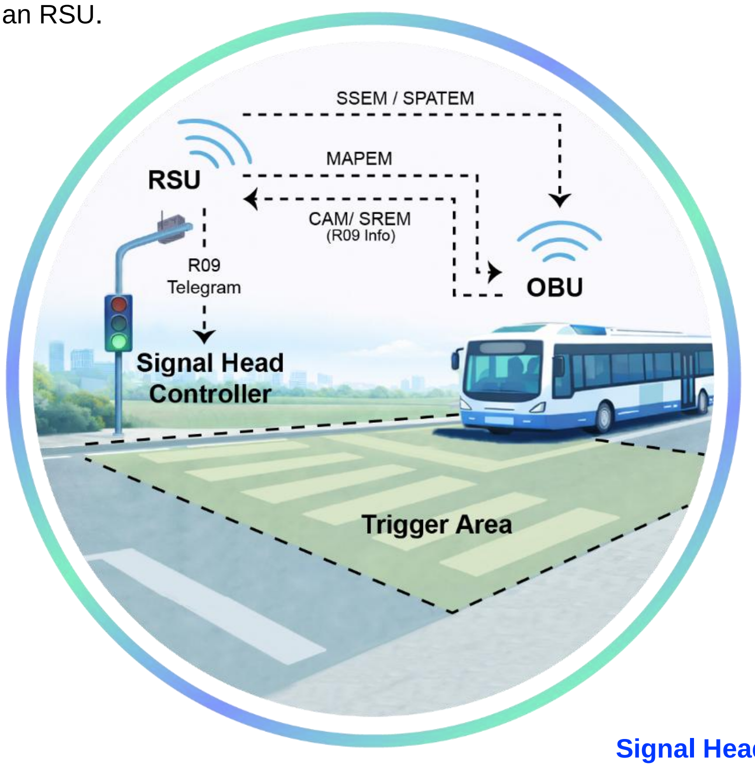
MAPEM Reaction

When a public transport vehicle approaches a signal head controller, the OBU receives a MAPEM continuously transmitted by an RSU.

02

MAPEM Reaction

At a predefined position (trigger area) R09 information is transmitted from the OBU to the RSU via CAM or SREM.



03

Signal Head Processing

The RSU transmits the R09 telegram to the signal head controller, which processes it and initiates prioritization.

04

Confirmation

The RSU confirms the request to the OBU via SSEM and optionally transmits the SPATEM with signal timing information.

Traffic Assistance Systems

Speed Assistant

Defines the maximum speed per road section, compares with GNSS-determined speed, and warns if exceeded

Traffic Light Phase Assistant

Calculates the optimal speed for green wave driving using switching time forecasts

Weather Traffic Management

Monitors weather conditions to adjust traffic flow during rain, snow, or low temperatures

Environmental Traffic Management

Uses pollution monitoring data to reroute traffic and reduce environmental impact

Environmental Traffic Management

Pollution Control

- Uses pollution monitoring system Benefit traffic and reduce environmental impact in urban areas
- Real-time data from environmental sensors enables dynamic traffic management decisions

System Benefits

- Optimize traffic flow based on environmental Conditions
- Reduce emissions through intelligent system management
- Improve safety with real-time data integration
- Leverage V2X communication for driver information

V2X-Based Use Cases for Public Transport

V2X networks vehicles with infrastructure and enables cooperative traffic management. The RSU sends time-critical information, such as current signaling status, directly to vehicles and cooperative traffic management systems. This technology intermodally networks public transport vehicles including buses, trams on roads, and trams on dedicated tracks, enabling innovative V2X-based public transport use cases.

Reduced Stops

Reduction in the number of stops for public transport vehicles

Enhanced Comfort

Improving passenger comfort in public transport vehicles

Better Punctuality

Increasing the punctuality of public transport services

Reduced Travel Time

Reduction of travel time for public transport vehicles

Lower Emissions

Reduction of emissions from public transport operations

Improved Security

Increasing IT security through digital technology and standardization

Public Transport Prioritization

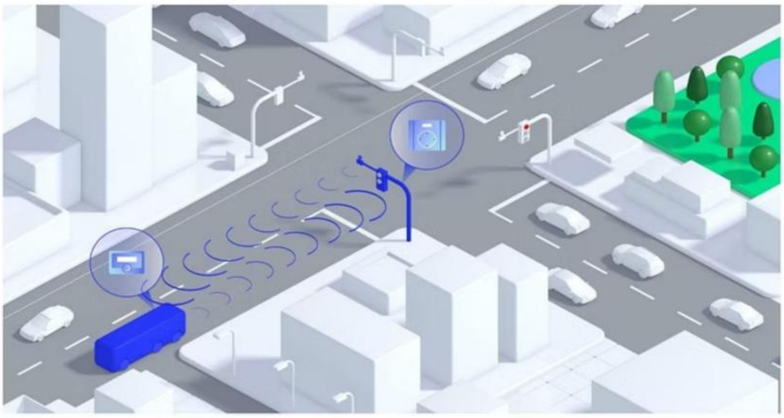
Public transport prioritization favors public transport over private transport at traffic lights. The aim is to reduce energy consumption, emissions, and travel times of buses and trains to increase the attractiveness of public transport. The reduction of travel times can make it possible to increase frequency with the same resources. Additionally, prioritization avoids unnecessary braking and acceleration, which increases passenger comfort and safety.

Historical Context

Public transport prioritization was introduced in the 1980s using analogue radio technology. Buses or trams approaching a signal head controller receive clearance via R09 or KAR telegrams sent through analogue radio to the signal head controller for pre-announcement, registration, and de-registration.

Modern Evolution

Communication via analogue radio is now obsolete. Technological constraints, such as discontinuation of analogue radio systems and open communication vulnerabilities, combined with innovative expansion potentials, drive conversion to digital technology. Many manufacturers have discontinued production of analogue professional radio systems.



Digital Communication Pathways

In recent years, two digital communication channels for public transport prioritization have been developed and implemented in many projects. There is a local and a central communication path, plus their combination, to implement necessary modernization.

Local Prioritization

Connects the OBU in the public transport vehicle to the signal head controller via RSU, shown in blue in the diagram above

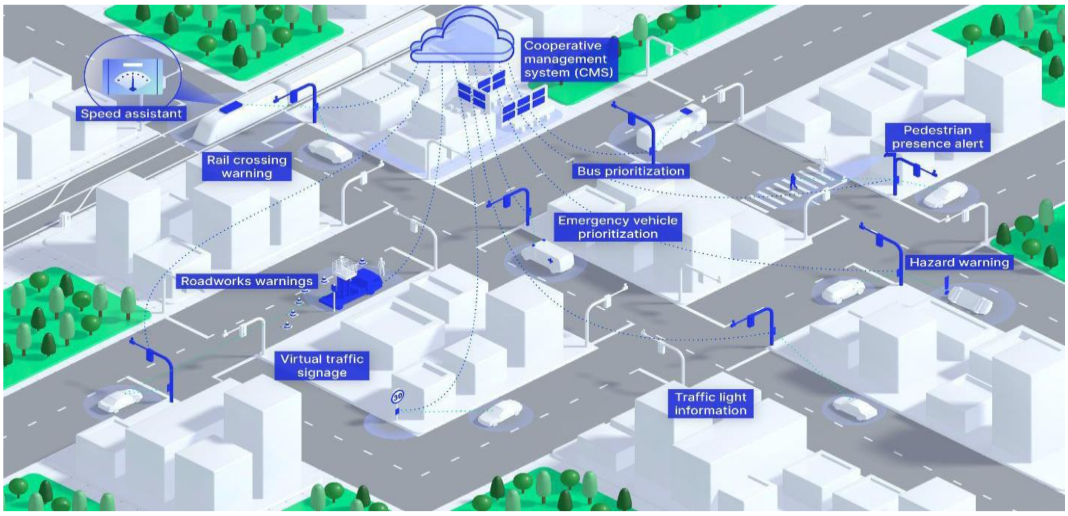
Central Prioritization

The OBU communicates with the signal head controller via the cooperative traffic management center, shown in green

Combined Approach

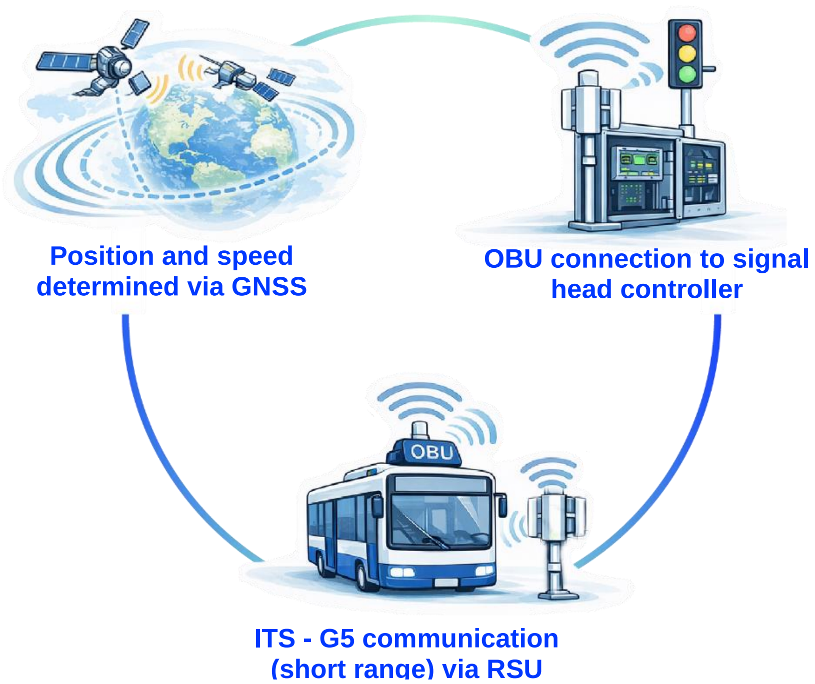
Local + central prioritization uses both communication channels, combining their advantages for optimal performance.

The BASt report V 353 presents a recommendation for action on the use of V2X communication technology for public transport prioritization at signal head controllers. Beyond radio signals, prioritization also works via detection through magnetic coils in the road and touch detection on overhead wires.



Source: Yunex Traffic

Overview of Local Public Transport Prioritization

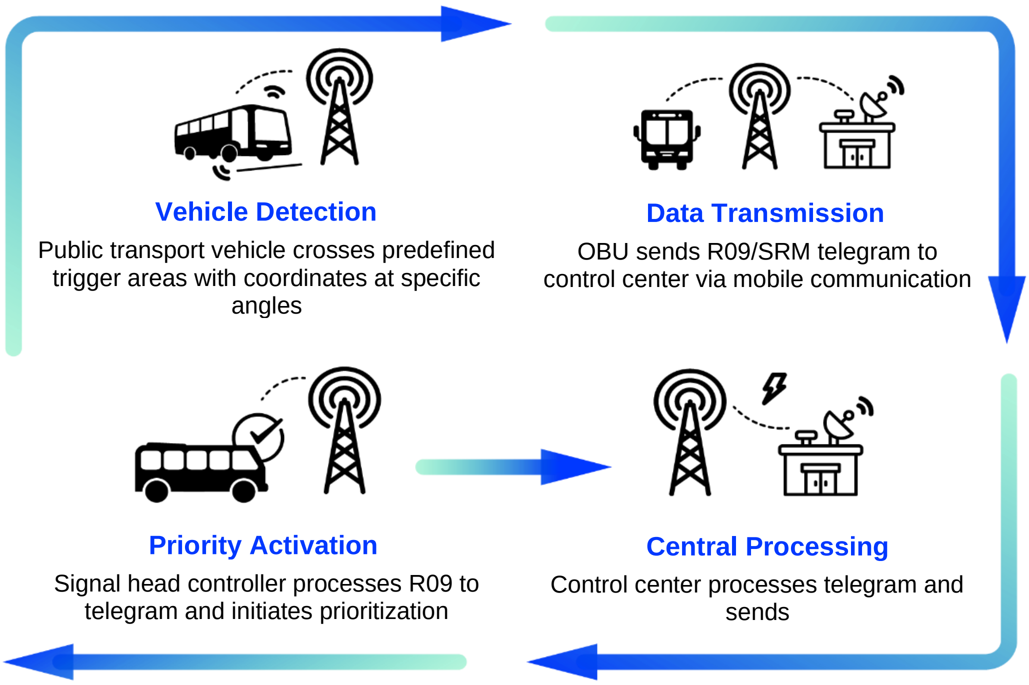


Key Advantages

In local prioritization, communication with the signal head controller takes place via Wi-Fi from the OBU through an RSU installed in the signal head controller. This prioritization system offers higher functional reliability and lower latency times, making it ideal for critical intersections with high public transport frequency.

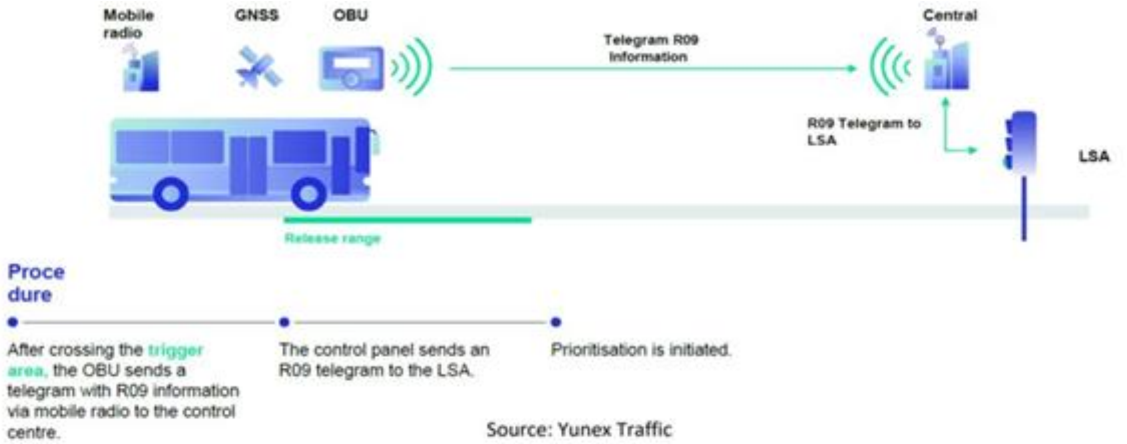
Central Public Transport Prioritization

With central public transport prioritization, the position and speed of the public transport vehicle is determined via GNSS, as with local prioritization. When the public transport vehicle approaches a traffic light, public transport prioritization is initiated with the help of virtual triggers.



This prioritization system has the advantage that infrastructure investment is lower. The OBU triggering areas are managed centrally, and in the event of changes, OBUs are updated via mobile radio.

Central + Local Public Transport Prioritization



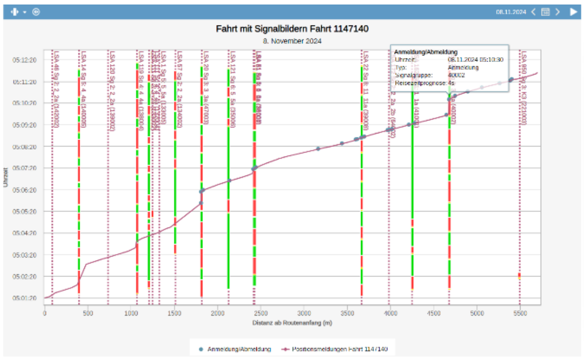
The Traffic Management system enables two-way communication and combines the advantages of central and local public transport prioritization. The central system can be used for peripheral devices while the local system can be used for important public transport nodes.

Optimal Resource Utilization

Signal head controllers in the peripheral area of a city can be prioritized centrally. At intersections where many public transport lines meet, centrally and locally within range prioritization can be used, reducing latency times and ensuring direct communication independent of mobile phone providers.

Two-Way Communication

Signal head controllers requiring pre-announcement well before stop lines can be prioritized centrally first, then locally within RSU range. This approach makes optimal use of a municipality's financial resources while maintaining system reliability.

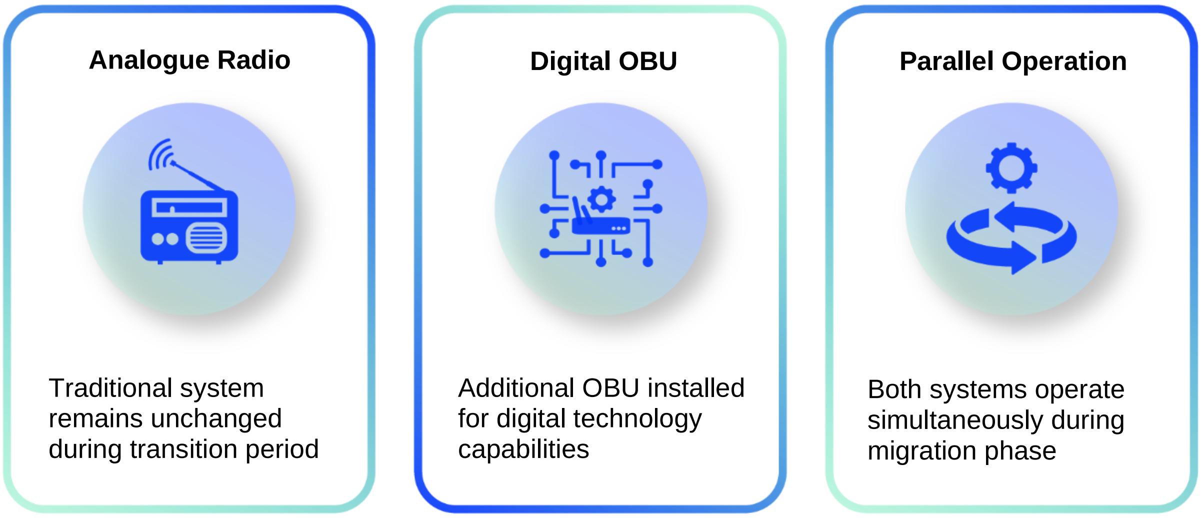


Source: City of Kassel

The system integrates with the public transport network operation support system and TMS. The first requests priority from the second at the appropriate moment, considering buses that are ahead of or behind schedule.

Hybrid Solution

In the C-ITS sector, a hybrid solution represents two-way communication (local + central public transport prioritization). In the VDV context, the term hybrid solution is used when analogue radio and digital communication are operated in parallel at a signal head controller. For this reason, we use the term two-way communication for parallel operation of local + central prioritization.



With traffic management technology, we support both two-way communication and hybrid operation of analogue radio and digital communication at a signal head controller. In this hybrid operation, the analogue radio system remains unchanged and an additional OBU is installed for digital technology.

Local Public Transport Prioritization Process

01 MAPEM Reception

OBU receives MAPEM and optionally SPATEM continuously transmitted by RSU at signal head controller.

02 Trigger Detection

At predefined position, RO9 information is transmitted from OBU to RSU via CAM or SREM.

03 Signal Processing

RSU transmits RO9 telegram to signal head controller which processes and initiates prioritization.

04 Confirmation

RSU confirms request to OBU via SSEM and optionally transmits SPATEM with timing information.

Via V2X technology, public transport vehicles are given priority at signal head controllers. This seamless communication process ensures efficient traffic flow while maintaining safety and reliability for all road users.

Virtual Login Signal

V2X technology can reduce infrastructure construction costs significantly. Currently, in many cities, sign-on signals are installed at traffic lights to give public transport drivers visual feedback when public transport prioritization is initiated.

In the future, this use case can be virtualized, and the registration signal can be shown on the vehicle display. This innovation eliminates the need for physical infrastructure while providing drivers with the same critical information in a more flexible and cost-effective manner

Cost Savings

Virtualizing login signals reduces infrastructure installation and maintenance costs while improving system flexibility and reliability.

SREM/SSEM Communication Protocol

V2X communication offers the innovative possibility to digitalize communication technology and optimize public transport prioritization. The use of V2X protocols Signal Request Extended Message (SREM) and Signal Status Extended Message (SSEM) enables public transport prioritization via the approach of vehicles instead of via reporting points.

01

Continuous Determination

Arrival time (estimated time of arrival) of public transport vehicle continuously determined

02

Shorter Interventions

Enables shorter intervention times in traffic flow

03

Reduced Conflicts

Reduces conflict of objectives between public transport and private transport

04

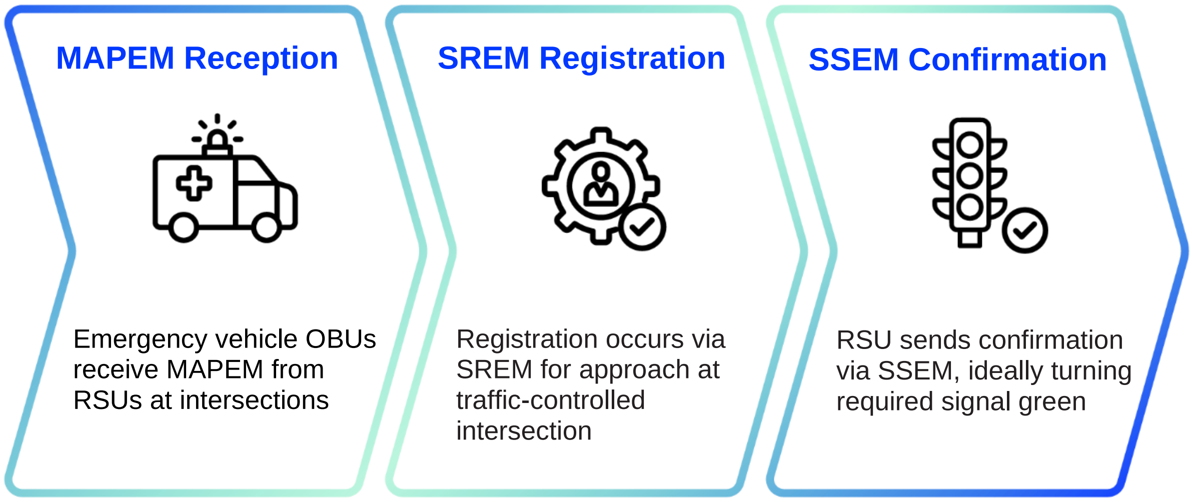
Improved Performance

Reduces number of stops and travel time

In the first stage of V2X technology introduction, R09 information is transmitted via SREM or CAM. In the second stage, the approach of the public transport vehicle will be transmitted and processed in the signal head controller. The technology of the second stage is currently still being tested and has not yet been conclusively standardized.

Emergency and Rail-Based Use Cases

Emergency Vehicle Priority



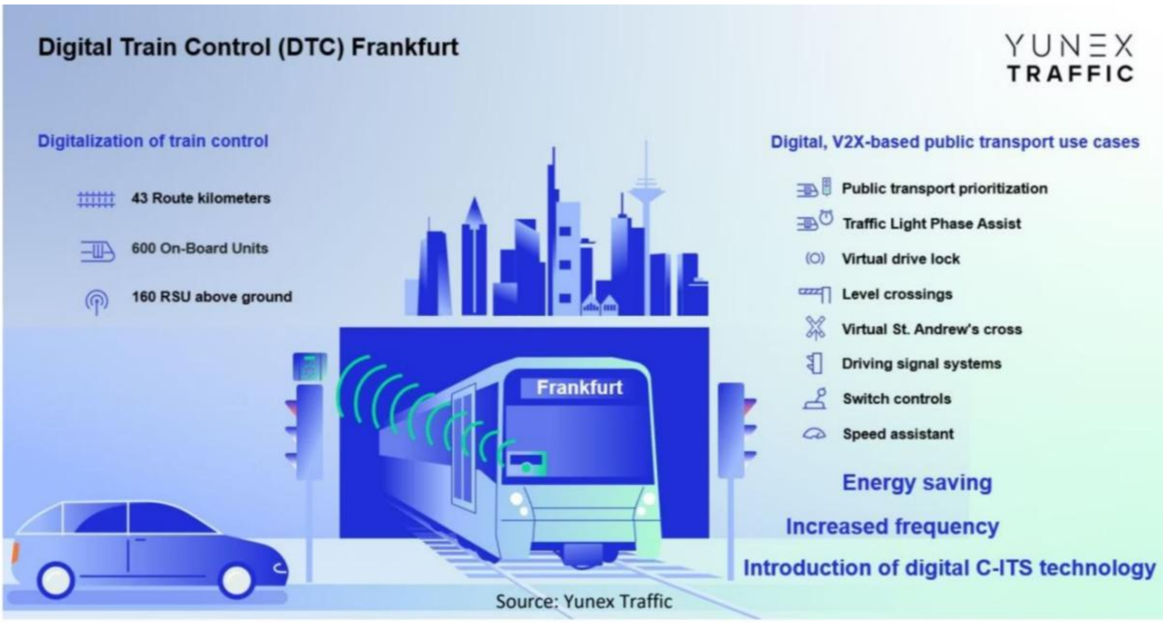
Emergency Vehicle Approach (EVA)

Accompanied with the EVA service, this use case can additionally reduce accidents during blue light drives. With EVA, drivers receive relevant information in their dashboard to stop or clear the road for emergency vehicles.

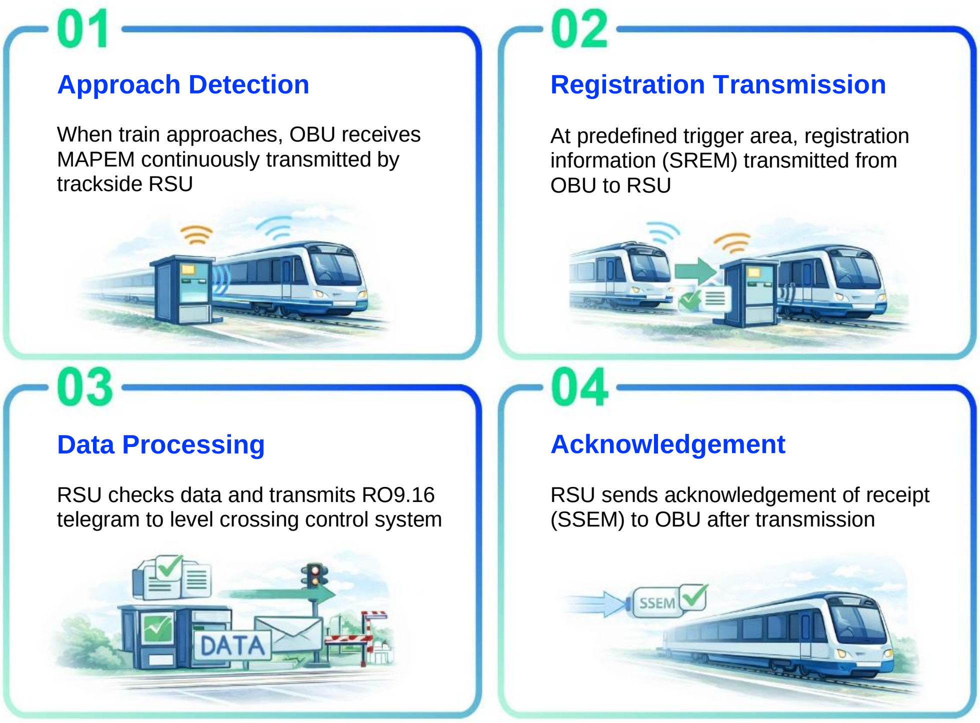
DENM Broadcasting

The DENM message is broadcasted by emergency vehicles and received by the OBU of any equipped vehicles nearby, creating a safety corridor and maximizing response efficiency.

Level Crossing Protection

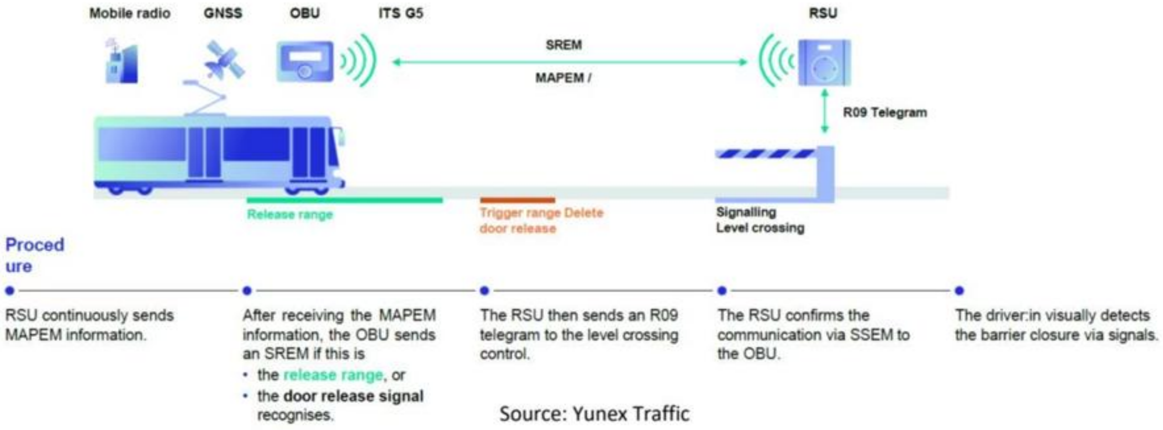


V2X supports the registration of rail-based traffic at digital level crossings, initiating barrier closure when a train approaches. With V2X-enabled vehicles, V2X communication with infrastructure is used as a digital replacement for existing analogue radio frequencies or trackside readers.



At level crossings near stops, barrier closure can be initiated by closing doors. The OBU sends SREM with additional "regional extension" data (line, route, course) required in downstream control systems.

Virtual St. Andrew's Cross



Source: Yunex Traffic

Warning System

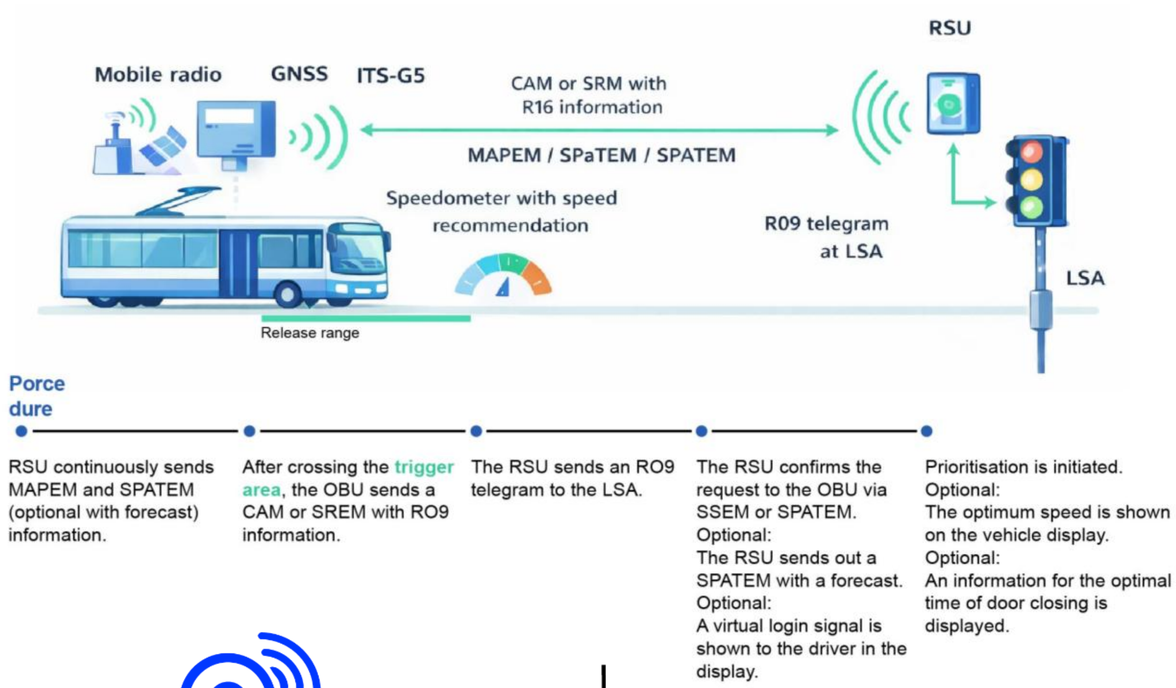
V2X technology is used to warn vehicles of trains at level crossings. A train equipped with an OBU approaches a level crossing and crosses the trigger area, prompting the OBU to send an SREM to the RSU at the level crossing.

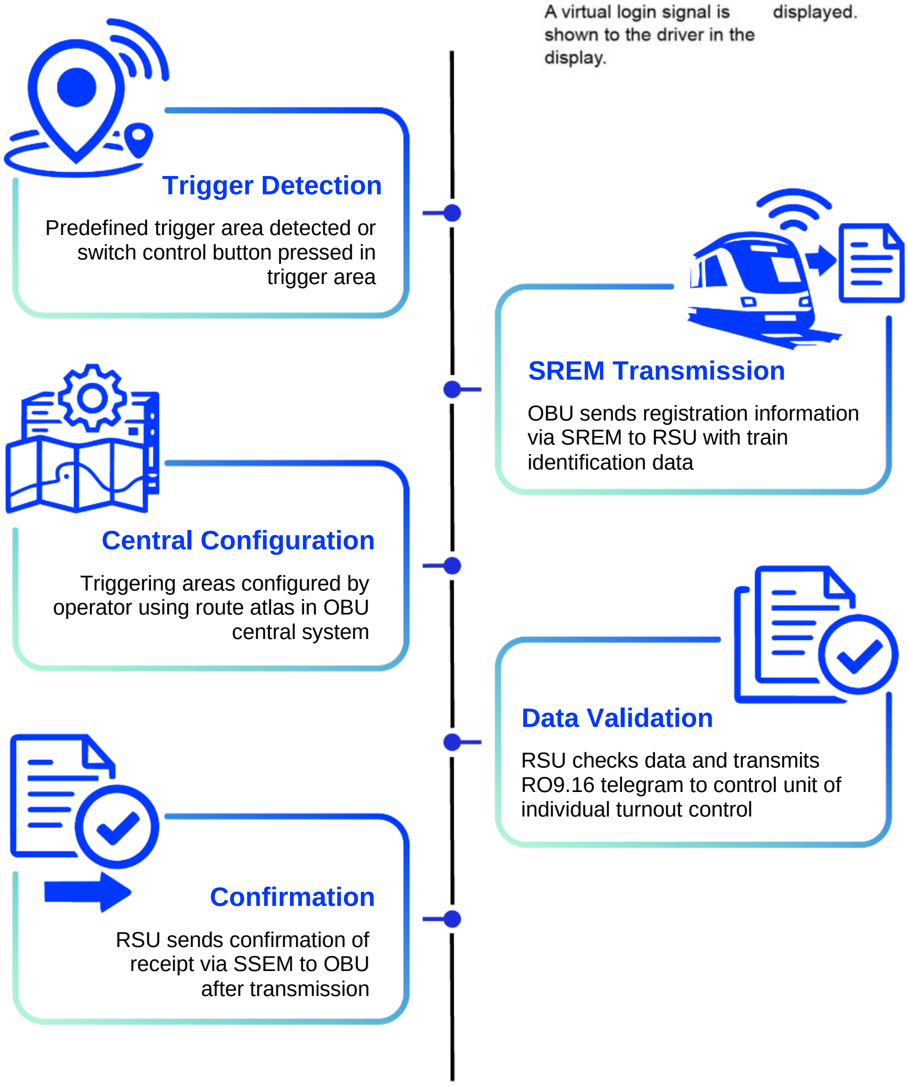
Vehicle Notification

The RSU then sends a DENM to all vehicles equipped with V2X technology. The vehicle warns drivers waiting at the level crossing of the approaching train via the display, enhancing safety and awareness

Individual Switch Control

V2X technology enables individual switch control for rail systems. V2X-equipped vehicles use V2X communication as a digital substitute for traditional control methods. When a train approaches individual point control, the OBU receives a MAPEM continuously transmitted by a trackside RSU.


RSU
Mobile radio
GNSS
ITS-G5
CAM or SRM with R16 information
MAPEM / SPaTEM / SPATEM
Speedometer with speed recommendation
R09 telegram at LSA
LSA
Release range
Porce dure
RSU continuously sends MAPEM and SPATEM (optional with forecast) information.
After crossing the trigger area, the OBU sends a CAM or SREM with RO9 information.
The RSU sends an RO9 telegram to the LSA.
The RSU confirms the request to the OBU via SSEM or SPATEM. Optional: The RSU sends out a SPATEM with a forecast. Optional: A virtual login signal is shown to the driver in the display.
Prioritisation is initiated. Optional: The optimum speed is shown on the vehicle display. Optional: An information for the optimal time of door closing is displayed.


Trigger Detection
Predefined trigger area detected or switch control button pressed in trigger area
SREM Transmission
OBU sends registration information via SREM to RSU with train identification data
Central Configuration
Triggering areas configured by operator using route atlas in OBU central system
Data Validation
RSU checks data and transmits RO9.16 telegram to control unit of individual turnout control
Confirmation
RSU sends confirmation of receipt via SSEM to OBU after transmission

Registration with Interlockings and Traffic Signal Systems

V2X technology is also used for signaling at interlockings or traffic signals to replace analogue radio frequencies or trackside readers. When a train approaches an interlocking or traffic signal system, the OBU receives a MAPEM continuously transmitted by a trackside RSU.

Registration Process

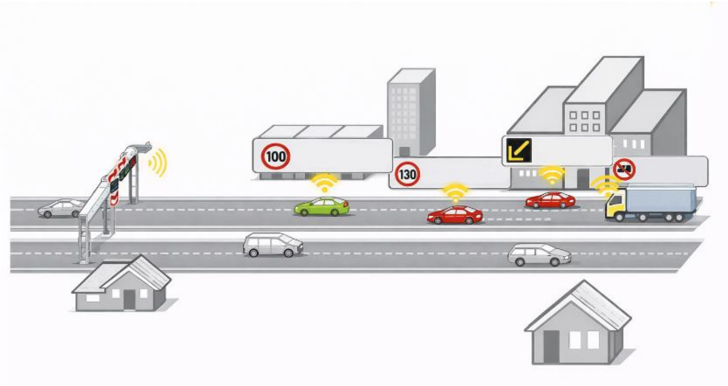
When the train crosses the trigger area, the OBU transmits registration information via SREM to the RSU. the RSU. This data is needed to inform and identify trains in downstream control systems. Trigger areas can be configured by an operator using a using a route atlas in the OBU central system.

Data Transmission

The RSU checks the data sent by the OBU and transmits the R09.16 telegram created from it to the interlocking or movement signaling system. After transmission, the RSU sends an acknowledgement of receipt (SSEM) to the OBU.

Speed Assistant Use Cases

Speed Assistant



Central Configuration

Operator defines or edits specified maximum speed per section in central supply system for defined routes using route atlas

Data Transfer

Information transferred to OBU via mobile radio for radio for real-time speed monitoring

Continuous Comparison

OBU continuously compares speed determined via GNSS with defined maximum speed

Warning System

If maximum speed exceeded, warning tone emitted and speed displayed on vehicle display

The permitted maximum speed is shown in addition to the current speed, depending on the position of the vehicle, in the speedometer of the vehicle display. In the event of a malfunction (e.g., no GNSS reception), a corresponding message is shown on the display to ensure driver awareness.

Traffic Light Phase Assistant

The traffic light phase assistant uses intelligent algorithms to calculate the optimal speed for driving on the green wave. Switching time forecasts (e.g., remaining red times) and speed recommendations are displayed to drivers, allowing them to optimally adjust speed and stopping time. This reduces the number of braking operations and increases energy efficiency and passenger comfort.

Real-Time Data

Riders receive switching time forecasts in real time via smartphone app for public transport, private vehicles, and cycling.

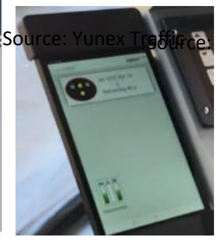
Intelligent Algorithms

APP solutions derive nearest signal groups in direction of travel, current distance, and remaining travel time from position data.

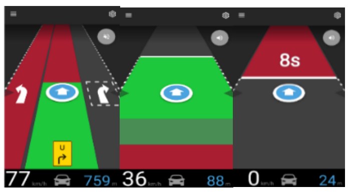
V2X Integration

Uses MAPEM, SPATEM, and GLOSA communication protocols for accurate predictions.

Source: Yunex Traffic



Source: Kapsch TrafficCom

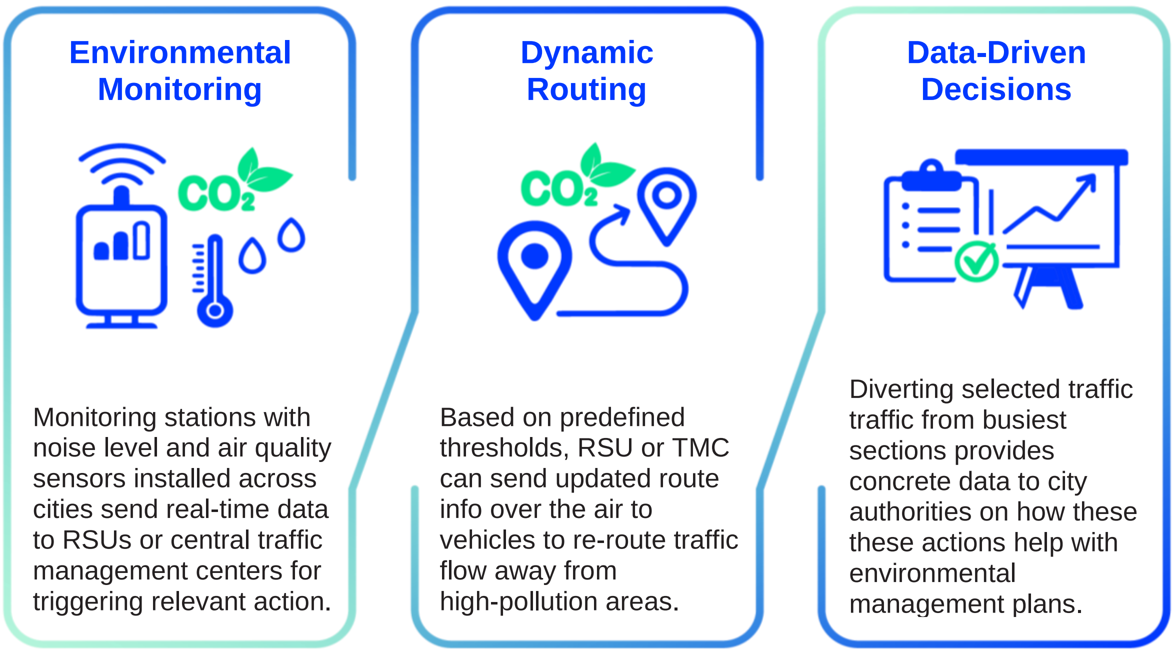


The app is logged on to a web server via secure connection and receives relevant data on predicted switching times every second. GPS position and direction of travel identify the next intersection and relevant lanes. For data protection, GPS position remains on the end device and is not streamed to the app server.

Environmental Traffic Management

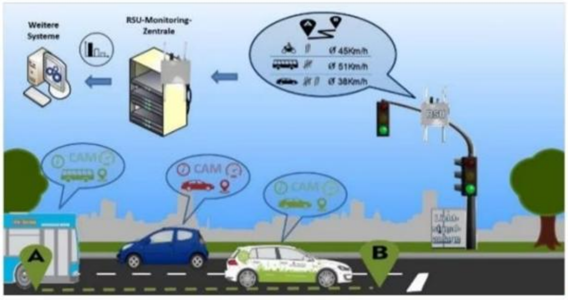
Source: Kapsch TrafficCom

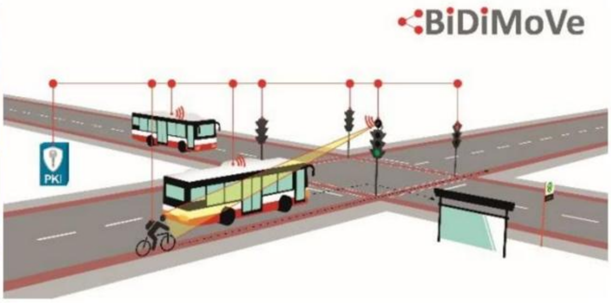
More and more cities are implementing low emission zones and are concerned about growing pollution levels. The proposal is to manage traffic flow of private vehicles to minimize pollution – both air and noise.



This approach helps to manage pollution, reduce traffic congestion, and provide good environmental conditions for city residents.

Probe Vehicle Data (PVD)





The PVD service is based on CAMs or, more precisely, on a stream of CAMs, which provides real-time traffic information. By processing timestamps, position, heading, and speed information, details about the traffic situation can be gathered.

Road users must be equipped with an OBU, which periodically sends CAMs. The triggering conditions are defined in ETSI EN 302 637-2. In simple terms, the generation frequency is 1 Hz or additionally triggered by changed vehicle heading, position, or speed.

Key Applications

• Traffic count and classification (considering equipment rate)

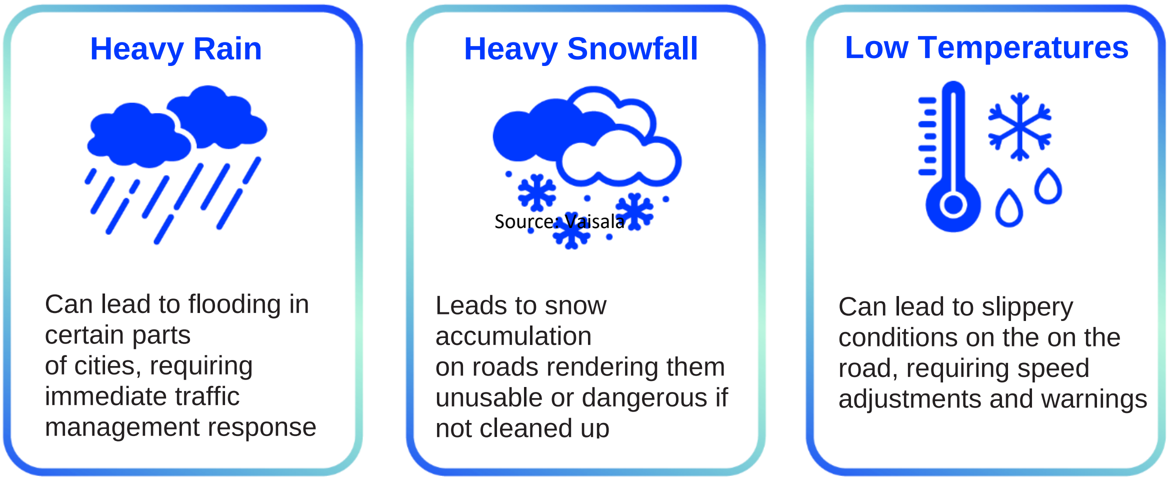
• Traffic light influence via virtual request loops in RSU

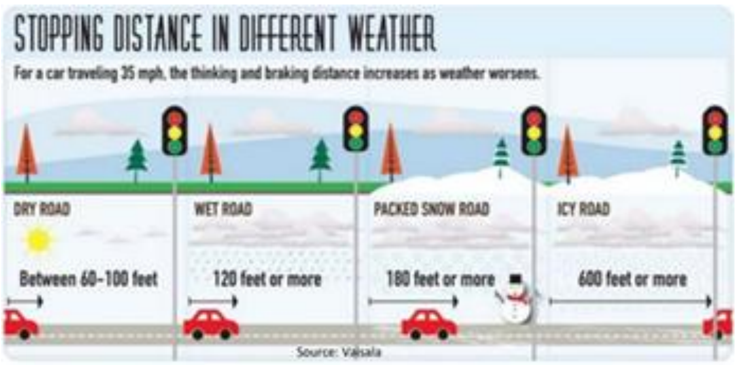
• Data interpretation for traffic management

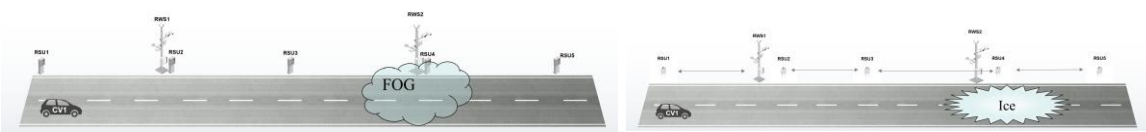
• Traffic situation calculation and forecasting

Weather Traffic Management

Weather impact on traffic can be more severe in cities compared to highways, due to higher number of vehicles per square kilometer, higher population density, and usual buildings and surrounding infrastructure. Weather-related incidents that can impact city traffic include heavy rain, heavy snow, or very low temperatures.





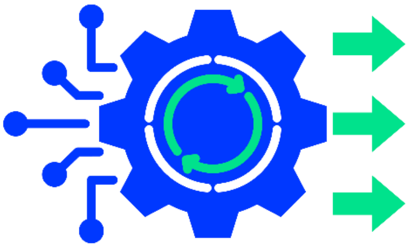


Source: Vaisala

Weather monitoring stations with relevant sensors for detecting water level, snow height, or road surface condition send real-time data to RSUs or central traffic management centers. Suggested actions include reduced speed warnings, road closures for selected vehicle types, or priority for certain vehicles.

Migration Concept

The analogue prioritization technology has been in operation for several years and has been expanded and adapted during this time. The conversion to digital technology is a great challenge for operators and must be implemented gradually with a migration concept adapted to each respective operator.



Parallel Operation

We ensure that analogue and digital technology can be operated in parallel. For example, it is possible to accelerate public transport vehicles at a traffic light using both analogue and digital technology, meaning not all buses or trams need OBUs simultaneously.

Simplified Transition

In a first stage, the planning of public transport acceleration can be maintained. This simplifies the way into the digital world and reduces implementation complexity for operators.

This challenge was described in the BASt booklet V 353, p. 36, where migration paths are shown. Our approach acknowledges these challenges and provides flexible solutions that accommodate different operator needs and timelines.

Funding Opportunities

Horizon Europe

Key EU funding programme for research and innovation in mobility and transport, facilitating collaboration and strengthening impact.

EIT Urban Mobility

Committed to decarbonizing the mobility sector and accelerating transition to sustainable urban mobility.

CCAM Association

Represents 230 innovation stakeholders in connected, cooperative and automated mobility field.

UITP Advanced Public Transport

EU funding opportunities specifically for local public public transport initiatives.

Federal Funding

The Federal Ministry for Economic Affairs and Climate Protection provides a funding database with search function. The BMDV promotes innovative developments and digital networking in public transport, particularly projects strengthening switch from individual to public transport.

Regional Support

Federal states have funding options for digitalization of public transport. For example, Lower Saxony funds construction and technical measures to accelerate public transport. The European Regional Development Fund (ERDF) finances economic catching-up processes in regions with structural problems.

Confirmed Main Use Cases

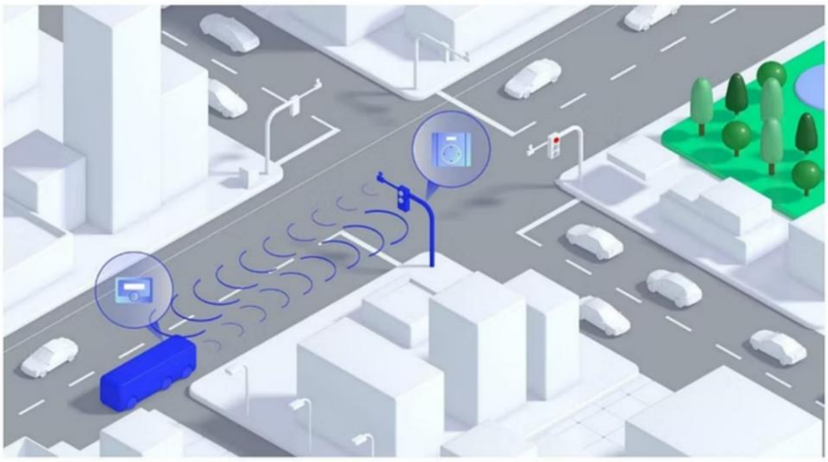
Technical Aspects

- Bus Priority / Tram Priority
- Emergency Vehicle Priority
- Truck / Bus Group Priority
- Urban Rail and Tram / Tube Priority (CBTC)
- VRU protection
- Right Turn Assist
- Green Light Optimal Speed Advisory

Functional Aspects

- Bus Priority / Tram Priority
- Emergency Vehicle Priority
- Reliable schedule of priority on Traffic Light
- Truck / Bus Group Priority
- Urban Rail and Tram / Tube Priority (CBTC)
- VRU protection (F0016)
- Right Turn Assist (F0016); Bike D0027 – without RSU
- Green Light Optimal Speed Advisory

9.1 Vehicle Based & TMC Based Scenarios



These confirmed use cases represent the foundation of C-ITS deployment in urban environments, covering both vehicle-based and Traffic Management Center-based scenarios for comprehensive mobility solutions.

List of Abbreviations & Definitions

Term	Explanation
APHA	Traffic light phase assistant
ASFINAG	Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft (Motorway and Expressway Financing Company)
BASt	Federal Highway Research Institute
BMDV	Federal Ministry for Digital Affairs and Transport
CAM	Cooperative Awareness Messages
CBTC	Communication-Based Train Control
C-ITS	Cooperative Intelligent Transport Systems
DENM	Decentralized Environmental Notification Message
DTC	Digital Train Control
ERDF	European Regional Development Fund
ETSI	European Telecommunications Standards Institute
EM	Extended Message
EN	European standards
FCD	Floating Car Data
GLOSA	Green Light Optimal Speed Advisory
GNSS	Global Navigation Satellite System
GoA0	Grade of Automation; on-sight train operation
IEEE	Institute of Electrical and Electronics Engineers
IV	Individual transport
KI	Artificial intelligence
CRITIS	Critical infrastructure
signal head controller	Light signal system; colloquially traffic light
MAPEM	Road/lane topology and traffic maneuver message
MIV	Motorized private transport
OBU	On-Board Unit
OCIT	Open Communication Interface for Road Traffic Control Systems
PUBLIC TRANSPORT	Public transport
RSU	Roadside Unit
SAE	Society of Automotive Engineers
SOA	Service-oriented architecture
SPATEM	Signal Phase and Timing Extended Message
SREM	Signal Request Extended Message
SSEM	Signal Status Extended Message
V2X	Vehicle-to-Everything
VDV	Association of German Transport Companies
WLAN	Wireless Local Area Network
4G/5G	Fourth/fifth generation of the mobile radio standard