DITM WHITE PAPER

Digital Infrastructure for Future-proof CCAM

Towards connected, cooperative and automated mobility through Key Enabling Technologies, shared data and validated use cases

Digital Infrastructure for Future-proof Mobility

Project information

Project period
1 October 2022 – 1 October 2026

Project partners
ElaadNL · ELEO · Geomaat · Infiniot · InQuisitive · Monotch · NKL · NXP · Siemens · Sioux · TNO · TomTom · TU/e · VDL ETS · V-tron

Project coordination
Brainport Development, RAI Automotive Industries NL, TNO

Funding
The DITM project is enabled by the Dutch Ministry of Infrastructure and Water Management (I&W), the European Union – NextGenerationEU and the DITM partners.

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Funded by the European Union
NextGenerationEU

Ministerie van Infrastructuur en Waterstaat

Digital Infrastucture for Future-proof Mobility

About this publication

The Digital Infrastructure for Future-proof Mobility (DITM) project brings together industry, knowledge institutes and public authorities to develop and validate the digital infrastructure needed for the next generation of mobility.

This publication presents the project's vision, results and lessons learned through two complementary whitepapers.

Whitepaper 1

Digital Infrastructure for Future-proof CCAM
Towards connected, cooperative and automated mobility through Key Enabling Technologies, shared data and validated use cases.

Whitepaper 2

Digital Infrastructure for Future-proof Energy in Mobility
Grid-aware charging infrastructure for reliable, secure and scalable electrification.

Executive summary

Mobility is entering a phase in which individual innovations are no longer enough. Vehicles, infrastructure, maps, cloud services, public authorities, logistics operations and energy systems increasingly depend on one another. DITM shows how an open public-private ecosystem can connect these layers through Key Enabling Technologies and digital infrastructure. The project has demonstrated feasibility in controlled use cases, while also showing that large-scale deployment requires further work on validation, governance, standards and investment.

The mobility system is changing faster than the structures around it. Electrification, automation, connected services and software-defined vehicles are advancing rapidly. At the same time, congestion, road-safety stagnation, grid constraints, workforce shortages and pressure on public infrastructure create a need for solutions that operate beyond the level of individual components.

The central insight of DITM is that the next step in mobility is not simply a smarter vehicle, a smarter road or a better app. It is the ability to connect vehicles, infrastructure, data platforms and operational systems into a coordinated environment. That environment must be technically reliable, secure, interoperable and governable. It must also be realistic about the difference between controlled demonstrations and large-scale deployment.

DITM - Digital Infrastructure for Future-proof Mobility - was created to explore and test that environment. A Dutch consortium of mobility industry partners and knowledge institutes jointly developed a system architecture for digital infrastructure. Within this architecture, partners advanced technologies such as localisation, traffic services, digital mapping, secure and automated data exchange, vehicle automation, remote operations and validation tooling. The goal is to accelerate the adoption of scalable Cooperative, Connected and Automated Mobility (CCAM) and to prepare for its interaction with a reliable energy system.


AIRBAG
11:57
YouTube Music
Zoekresultaten
Relaxing Jazz Music - Background
Chill Out Music - Music For Relax,S...
Cafe Music BGM channel
2:44:39 / 3:33:08

Automated yard manouvering

A system under pressure

The challenges facing mobility are familiar, but their combined effect is often underestimated. Urbanisation puts pressure on infrastructure that was not designed for current levels of intensity. Electrification is essential, but it creates additional dependencies on an already constrained electricity grid. Driver shortages affect logistics and public transport operations. Road safety improvements have slowed, while serious injuries remain a concern. At the same time, digital services and automated functions raise expectations about reliability, comfort, efficiency and accessibility.

Each challenge can be addressed individually with targeted measures. Together, they require a system response. More charging points will not solve mobility-related grid constraints if charging remains uncoordinated. Automated vehicles cannot reach their full potential if they rely solely on onboard perception and lack trustworthy environmental data. Traffic services remain limited if data cannot be exchanged across organisational boundaries. The issue is therefore not a lack of innovation, but the difficulty of combining innovations into a safe, reliable and scalable system.

This is where digital infrastructure becomes essential. It is not a generic IT layer added to mobility afterwards. In the context of this whitepaper, digital infrastructure for future-proof CCAM refers to the integration of advanced digital technologies within mobility and energy networks to create an interconnected ecosystem. This ecosystem leverages shared data and innovative solutions to enhance connectivity, optimise performance, improve sustainability, and strengthen resilience across mobility and energy systems. A set of digital technologies, standards, data-sharing environments, communication services, maps, digital twins and validation tools allows mobility actors and assets to coordinate their behaviour.

What DITM adds

DITM's distinctive contribution is not that it claims to have solved challenges in mobility as a whole. Its contribution is more precise: it demonstrates how Key Enabling Technologies can be combined, tested and connected through digital infrastructure in representative CCAM use cases. This creates traceability from technical development to operational value.

The project, therefore, does more than promote an ecosystem approach. It operationalises such an ecosystem through cross-sector collaboration between private companies, public authorities, knowledge institutes and service providers.
It also shows that integration itself is a technological challenge. While many core technologies already exist, combining them into reliable use cases requires work on data reliability, synchronisation, safety validation, cybersecurity, standards and governance.

In practice, DITM's mobility work concentrates on three interacting domains: vehicle technologies, digital infrastructure and tooling. Each domain matters on its own, but the value lies in their mutual reinforcement.

1. Vehicle technologies

Vehicle technologies in DITM were advanced for both public-road and private-yard environments. The work includes vehicle robotisation, the development and implementation of automated driving functions, localisation and sensor fusion, and the specification of software interfaces and architecture design.
A software-defined vehicle separates software capabilities from hardware constraints, making it easier to update functions, integrate services and adapt behaviour to new data sources.

Vehicle robotisation allows the vehicle to accept setpoints from Advanced Driver Assistance Systems (ADAS) and Autonomous Driving (AD) functions. The advantage of DITM is that this is done in the context of already homologated vehicles (the VDL CITEA platform), which makes re-homologation easier: a road authority can accept the delta with regard to the previously checked platform.

On public roads, novel localisation technologies were developed to support precise vehicle positioning. Feature-matching techniques use lane markings and landmarks such as lamp posts and traffic signs to achieve decimeter-level accuracy in real-world conditions. A proof-of-concept radar-based method was developed to detect, classify, and position environmental features, thereby increasing its relevance for current-generation vehicles. Inputs are combined via multi-sensor fusion, enabling the system to select the most reliable localisation source at any given moment.

On private yards, DITM worked on vehicle automation in controlled yet operationally relevant environments, such as bus depots. Here, vehicles must interact with depot systems and execute missions such as moving to a charger, stopping at a wash bay, entering a maintenance area or waiting for a new deployment. Because public-road reference features are often absent or less useful in depots, localisation can switch to sensor configurations suitable for enclosed spaces, including scan-matching techniques based on a lidar point-cloud map. When automated functions are unavailable or degraded, the same robotisation interface can support handover to a teleoperator.

2. Digital infrastructure

Digital infrastructure enables these vehicle technologies to operate beyond isolated demonstrations. For yard automation, a vehicle can receive a high-definition digital representation of the depot environment, determine where it is allowed to drive, and interact with a yard-management backend that determines operational priorities. The backend may know whether charging capacity is available, whether the wash bay is free, whether the vehicle should go to maintenance, or whether sensors need cleaning before a new mission.

For the public-road domain, DITM advanced the delivery and updating of HD maps through standardised open protocols such as NDS.Live. Open industry standards reduce vendor lock-in and support rapid iteration in open-innovation ecosystems. The project explored ways to connect mapping processes from the road infrastructure asset management domain with those of automated mobility. Publicly available mapping data, mobile-mapping outputs, satellite imagery, and vehicle observations can all help reduce the time between a real-world change and an updated map.

For Intelligent Speed Assistance (ISA), the applicable maximum speed is determined by combining multiple sources of information. These include state-of-the-art traffic-sign recognition, lane-level HD maps, road-operator data and variable-message-sign information. The goal is not to replace one source with another, but to increase robustness by combining them and assessing confidence. This is especially relevant for dynamic situations where lane-level context matters.

Data sharing was implemented through Eclipse Dataspace Components, aligning with emerging European standards for trusted data exchange. Through this data space approach, semi-static and dynamic information can be supplied to vehicles. Semi-static data includes legally applicable maximum-speed values. Dynamic data includes Green Light Optimised Speed Advice (GLOSA) messages from traffic-light controllers, as, for example, communicated through variable message signs. Trusted communication channels, including a dedicated 5G slice, were used to increase reliability and cybersecurity in selected demonstrations.

This does not mean that every mobility function should use the same communication paradigm. DITM points instead to hybrid architectures. Sensor-based approaches can provide immediate local benefit through onboard or roadside perception. Backend-based approaches can aggregate, fuse and distribute information through cloud services and cellular networks. Direct communication can provide short-range, low-latency exchange when necessary. Robust CCAM deployment will depend on selecting and combining these approaches based on use-case requirements, cost, security, scalability and time-to-value.

3. Tooling and validation

A critical part of DITM is the tooling needed to validate new technologies before deployment. The project used several methods for single-vehicle components, such as Software-in-the-Loop (SIL), Hardware-in-the-Loop (HIL), digital twins, and cybersecurity testing, aligned with safety-of-the-intended-functionality thinking.

Societal impact is based on macro simulations. Using digital twins, it's possible to test recognition and classification functions with synthetic datasets and validate robotisation components before physical deployment, thereby translating technical progress into broader network-level and societal-impact assessments.

This validation layer is essential because technical feasibility in a controlled demonstration does not translate to safe, robust deployment at scale. Digital twins and virtual validation environments help bridge the gap from desk-based design and development, via validation before demonstration in a controlled environment, to deployment at scale. Many of the tools developed or used in DITM are now integrated within the Mobility Applied Research Quarter (MARQ), creating a consistent environment for further experimentation, validation and deployment preparation.

Digital simulation environment at MARQ

DITM use cases: from technology to impact

The Key Enabling Technologies developed in DITM are best understood through the use cases in which they were combined. The use cases are not merely examples at the end of the project. They are the mechanism through which the value of digital infrastructure becomes visible.

USE CASE	OPERATIONAL GOAL	KEY ENABLING TECHNOLOGIES	DEMONSTRATION RESULT / REMAINING STEP
Yard Automation	Automated depot operation for public-transport vehicles, including mission execution and interaction with depot systems.	Vehicle robotisation; automated driving stack; HD maps; digital twins; accurate absolute and relative localisation; teleoperation; integration with logistics backends.	Automated demonstrations showed how a vehicle can be integrated with a yard-management backend. Next step: move from controlled demonstrations to operational validation with safety cases, reliability targets and integration into real depot workflows.
GLOSA	Enable vehicles to receive traffic-light information and adapt speed to reduce unnecessary stops and improve flow.	Cybersecure communication; trusted 5G slice; data-quality assessment; lane-level localisation; data exchange from physical intersection controllers; simulation and validation.	Intersections in the Helmond test environment were upgraded to deliver trusted GLOSA messages. Next step: broaden interoperability, followed by scaling system implementation to OEMs and Tiers and integrating it with a multi-channel approach, including 5G and DSRC.
Intelligent Speed Assistance	Determine the applicable speed at lane level, including dynamic information such as variable message signs.	Traffic-sign recognition; lane-level HD maps; authoritative road-operator data; variable-message-sign feeds; data-sharing interfaces; sensor fusion; confidence assessment.	A connected data source combines static and dynamic maximum-speed information with in-vehicle perception. Next step: further validate under diverse road conditions and define how we make sure we flag conflicting messages back to the original data sources.
Lane Navigation	Provide lane-level guidance and contextual navigation that can adapt to real-world changes.	NDS.Live map delivery; automated feature extraction; change-detection services; lane-level localisation; software-defined vehicle architecture; perception-enhanced user interface.	Map production and delivery processes were improved to reduce reality-to-map time and support lane-level navigation. Next step: integrate the map delivery pipeline into automotive hardware and add additional map layers using the same processes developed in DITM, but for specific use cases.

A more detailed example: Yard Automation

Yard automation illustrates the DITM logic particularly well because the use case requires vehicle automation, digital infrastructure, and operational governance simultaneously. A bus in a depot does not simply need to drive itself. It must know where it is, where it is allowed to drive, what mission has priority, whether a charger or wash bay is available, and what to do if an automated function is degraded.

The digital infrastructure provides the vehicle with an HD map of the depot environment, supports localisation through scan matching, and links the vehicle to a backend system that manages missions. That backend can connect to operational data: the end of a bus route, the next planned deployment, charger availability, maintenance needs, cleaning requirements or queueing positions. Remote monitoring and teleoperation provide a fallback and oversight mechanism. The added value of DITM lies in integrating these elements into a single traceable system rather than demonstrating autonomous driving in isolation.

This example also shows why claims about deployment should be nuanced. The demonstration proves that the combination of architecture and technology can work in a controlled environment. Large-scale use requires operational reliability, cybersecurity, human oversight, responsibility allocation, integration with existing depot systems and the business case for fleet operators.

Teleoperation as a fallback mechanism

AI, software-defined vehicles and map updates

AI, software-defined vehicles and map updates Artificial Intelligence should not be treated as a generic promise. Within the DITM context, AI is relevant where it supports perception, classification, decision-making and map updates. For example, real-time observations from vehicles and infrastructure can help detect changes in the road environment. Before such data can be used, however, it requires careful engineering: filtering, quality assessment, confidence scoring and integration into map-production workflows. Raw data is not yet a reliable infrastructure.

AI is core to the map updates. DITM has created pipelines that combine public data with private vehicle domains. With ecosystem interactions between partners typically working for government (like Geomaat - doing mobile mapping, feature extraction, and HD map generation according to public standards) and automotive (like TomTom, performing feature integration and data aggregation to semantics applicable in automotive), DITM pushes raw data into reliable infrastructure development.

This connects directly to software-defined vehicles. As vehicle functions become more software-based and better connected to cloud and edge services, new capabilities can be deployed more flexibly. But the same trend increases dependence on standards, cybersecurity, update mechanisms and validation methodologies. Digital infrastructure is therefore both an enabler and a control layer: it allows new functions to emerge while creating the conditions for trust and safety.

From demonstration to deployment

DITM demonstrates that connected, cooperative and automated mobility can operate within an integrated digital ecosystem. Vehicles, infrastructure, data platforms and operational systems can interact in real time in selected use cases. But deployment at scale is not effortless. It requires deliberate alignment in three areas.

1. Architectural alignment. Systems must be interoperable, based on open industry standards and able to exchange data across organisational boundaries. DITM's work with standards such as NDS.Live and dataspace implementations provides a basis, but broader adoption is needed. DITM has shown it's possible, so the next step is to embed these results more permanently and in a financially viable setting.

2. Validation alignment. Software, hardware, digital twins, and real-world testing must be combined to produce credible safety and performance evidence. The step from TRL-6 demonstrations to operational deployment requires proof under more diverse conditions and further integration with the relevant (back-end) systems and deployment environment.

3. Governance and investment alignment. Data ownership, responsibilities, cybersecurity, liability, public-private collaboration and investment models must be defined alongside the technology. From this technology perspective, digital infrastructure should be treated as a shared system asset, not as an add-on to physical infrastructure.

This also clarifies DITM's role in the next phase. The project does not shift the problem onto the government after the technology is completed. Instead, it points to a public-private roadmap in which industry, research organisations, service providers and public authorities continue to develop and validate the architecture together. That roadmap should remain as open as possible to avoid vendor lock-in, be robust enough for safety-critical applications, and be scalable for deployment in mobility, logistics, and adjacent markets such as defence.

Next steps for innovation and deployment

The next stage should build on the work already done while addressing the remaining gaps. The following priorities emerge from the DITM results:

- Deepen technical validation of Key Enabling Technologies, including localisation, map-update pipelines, data-quality assessment, cybersecurity, remote operations and sensor-fusion methods and work towards the deployment of some of them.

- Develop at least one use case into a fully elaborated deployment pathway, including KPIs for safety, reliability, operational efficiency, data latency, localisation performance, map update time, and cost-benefit assumptions. For example, a public transport pre-deployment pilot could be the next step, as that should increase Automated Yard manoeuvring from TRL6 to TRL8.

- Strengthen data space governance by clarifying data ownership, access rights, responsibilities, trust mechanisms and alignment with European cloud-edge and data-sharing architectures. Include who is hosting the platform in this governance scheme.

- Explore how the developed technologies would fit other domains as well, including the defence industry.

- Keep the mobility focus sharp. Although energy demand and supply remain strategically important in the mobility domain, the key focus must remain on CCAM, including vehicle automation and driver support technologies, maps, localisation, data exchange and validation.

What DITM has shown

The future of mobility will not be achieved by individual innovations alone. It will depend on the ability to connect those innovations into a system that is technically reliable, operationally useful, secure, validated and governable. DITM has shown how such a system can begin to work: by integrating Key Enabling Technologies, adopting open standards, exchanging trusted data, testing with digital twins, shifting to software-defined vehicles and evaluating representative use cases.

The next challenge is to turn this foundation into a deployment. That means continuing technological development, not declaring it finished. It also means developing governance, standards and investment models at the same pace. If the Netherlands and Europe succeed in doing both, the digital infrastructure can become the backbone of future-proof mobility.


MARQ
Mobility Applied Research Quarter
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Project note
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