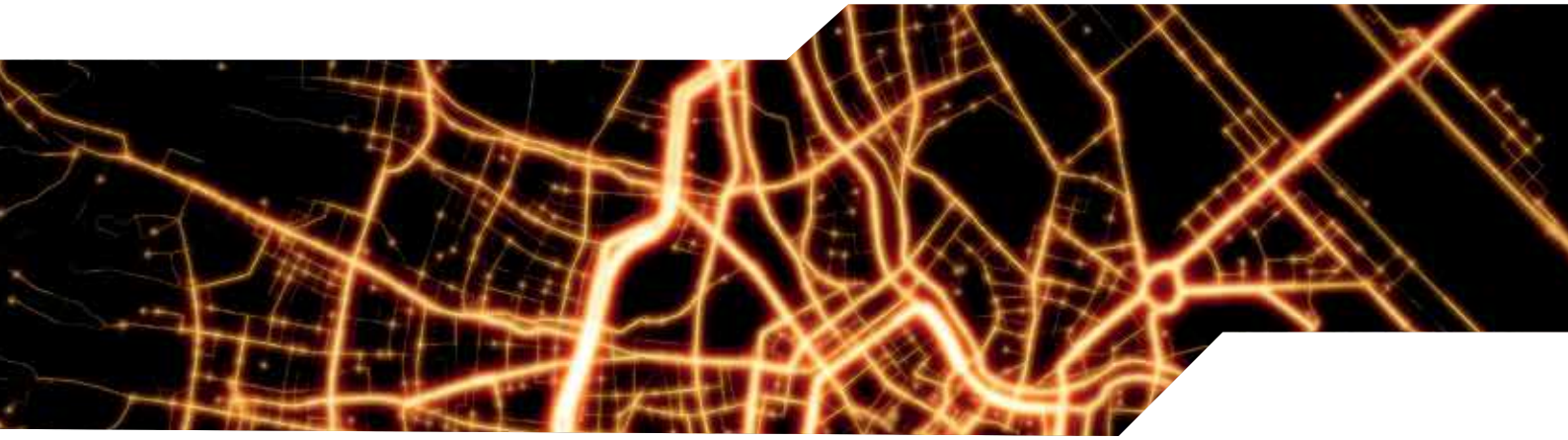
infra 4D future

Coordinating Transport Infrastructure Innovation and Implementation



Synthesis report

This project has received funding from the EuropeanUnion's Horizon 2020 research and innovation programme under grant agreement No 824269.

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Transport Infrastructure
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Welcome note from the Coordinator

Dear reader,

This synthesis report provides an overview of the most important achievements and results of the infra4Dfuture (i4Df) initiative. i4Df concerns a Coordination and Support Action (CSA), funded by the H2020 programme with a duration of 24 months (1 October 2018 – 30 September 2020).

Facing a variety of emerging challenges, such as climate change, resilience, ageing infrastructure, maintenance, digitalisation, automation, energy and electrification, National Transport Infrastructure Authorities (NTIA) have an urgent need to modernize their transport infrastructure and smarter manage infrastructure innovation and implementation. A transition towards new business models and organisational structures is necessary. In view of the long cycle times in infrastructure management and the rapid mounting pressure from these challenges, there is a need for fast delivery of ready-to-implement, cost-effective innovative solutions matching the requirements of the NTIA that jointly build the TEN-T network.

Challenges cannot be overcome on national level alone or within only one mode or sector. Transnational, cross-modal and new public – public cooperation approaches are needed as well as consolidation of partnerships and alliances from NTIAs with industry and the research community. From this background 19 NTIAs from 17 countries joined forces in the i4Df initiative. i4Df focuses on transport infrastructure innovation and implementation for road, rail, waterborne and airborne transport of passengers and goods from origin to destination.

To gather proper input and support and to achieve its ambitious goals, i4Df organized various consultations which relevant stakeholders and experts through e.g. conferences and workshops. From these, a demand-driven overarching strategy and cross-modal coordination mechanism for the modernization of transport infrastructure emerged, including a shared strategic vision on future infrastructure capabilities, resulting innovation focus areas and related competences. Moreover, i4Df has delivered common pathways for innovation development and implementation towards 2040. Elements from the latter will feed into the CEF and Horizon Europe programming.

The package comes with an organizational skeleton, a ready to implement cross-modal coordination mechanism for the modernization of transport infrastructure. The mechanism and its operationalisation is supported by a toolkit containing a wide array of deliverables from i4Df. Although the project faced quite a few obstacles due to COVID-19, all deliverables and milestones were timely delivered, goals achieved and alternatives were found for cancelled events.

30 September 2020, the end of the CSA, will mark the end of an intense and successful project. But the further implementation and operationalisation of the cross-modal coordination mechanism, for which there is wide support from all involved NTIA and relevant stakeholders, will only start now. The mechanism is ready for take-off.

We invite everyone to watch the *i4Df video*, visit the *i4Df website* and above all, to jointly breath life into the coordination mechanism and to implement it.

With warm regards,

Peter Wilbers
i4Df Coordinator
Rijkswaterstaat / Ministry of Infrastructure and Watermanagement

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Abbreviations

i4Df	infra4Dfuture
H2020	Horizon 2020
NTIA	National Transport Infrastructure Authorities
IPO	Innovation Programme Owners
ILS	Industrial Lead Suppliers
RP	Research Providers
CSA	Coordination and Support Action
CEDR	Conference of European Directors of Roads
EIM	European Rail Infrastructure Managers
IFA	Innovation Focus Areas
TRL	Technology Readiness Level
CEF	Connecting Europe Facility
TEN-T	Trans-European Transport Network
ITS	Intelligent Transport Systems Conference
SGPR	Stage Gate Review Process
ToR	Terms of Reference
HCD	Human Capital Development
LCM	Life Cycle Management

Introduction

This synthesis report constitutes a general overview of the infra4Dfuture (i4Df) initiative, outlining the project vision, its development and findings, as well as the initiative's future implementation pathways towards 2040. The i4Df project is a Coordination and Support Action (CSA) funded by the H2020 programme (Grand Agreement No 824269). This initiative is aimed at developing a demand-driven overarching strategy and coordination mechanism for the modernization of transport infrastructure, by building a vision on transport infrastructure innovation and implementation towards 2040 in consultation with relevant stakeholders.

Throughout the duration of i4Df project, a number of events and activities were accomplished, targeting diverse background audiences such as National Transport Infrastructure Authorities (NTIA), Innovation Programme Owners (IPO), Industrial Lead Suppliers (ILS), Research Providers (RP) along with the general public. All these activities built stakeholders' awareness, vision, understanding and endorsement through knowledge sharing sessions and productive discussions. They also created strong partnerships and alliances between transport infrastructure stakeholders, building the joint vision on transport infrastructure innovation towards 2040.

Transport infrastructure innovation will be achieved by demand-driven pathways between NTIA and ILS, by close collaboration of NTIA and RP, by coordinated actions of different NTIA across Europe and by transnational innovation programmes of specific objectives by the European Union.

To achieve innovation goals in transport infrastructure, a cross-modal coordinated mechanism has been established through a structured dialogue among stakeholders from public authorities, industry and research. In this dialogue, the demand side for innovation and implementation is represented by the public infrastructure managers as the 'issue owners', and the supply side, by the Industrial Lead Suppliers (ILS). Funding tools, such as European and transnational innovation programmes, provide financing possibilities. The role of supporting research providers, such as universities, research institutes and specialized laboratories is also important in this structured dialogue.

infra4Dfuture at a glance

The infra4Dfuture (i4Df) project is a Coordination and Support Action (CSA) funded by the H2020 programme (Grant Agreement No 824269), with a duration of 24 months (01/10/2018-30/09/2020). The main aim of infra4Dfuture initiative is to develop a demand-driven overarching strategy and coordination mechanism for the modernization of transport infrastructure including a shared strategic vision on future infrastructure capabilities and common pathways for innovation development and implementation. The mechanism and strategy are being developed with common, long-term vision on future infrastructure capabilities (until 2040) and comprise the most important innovation focus areas and prospective innovation goals to be considered for financing and implementation.

infra4Dfuture initiative focuses on transport infrastructure innovation and implementation for road, rail, waterborne and airborne transport of passengers and goods from origin to destination.

Facing a variety of emerging challenges, such as climate change, resilience, ageing infrastructure, maintenance, digitalisation, automation, energy and electrification, the National Transport Infrastructure Authorities (NTIA) have urgent requirements for infrastructure innovation. In view of the long cycle times in infrastructure management and the rapid mounting pressure from these challenges, there is a need for fast delivery of ready-to-implement, cost-effective innovative solutions matching the requirements of the NTIA that jointly build the TEN-T network.

The infra4Dfuture consortium encompasses 20 partners from 17 countries, 19 of them being National Transport Infrastructure Authorities (NTIA) joining forces to develop:

- a strategic coordination mechanism for demand driven infrastructure innovation, aiming to deliver a concerted cooperation and collaboration between relevant stakeholders, across a portfolio of relevant European and transnational innovation programmes and initiatives,
- a shared strategic vision on future infrastructure capabilities, and corresponding key focus areas for innovation each. The i4Df initiative has a duration from 1 October 2019 to 30 September 2020 and it is supported by the Conference of European Directors of Roads (CEDR) and the European Rail Infrastructure Managers (EIM).

infra4Dfuture is based on a sound and coherent consultation and dialogue process with relevant stakeholders. This process has been structured in a sequence of strategic, decision-making conferences and a supporting, tactical sequence of expert workshops and regional events.

The partners of infra4Dfuture initiative are presented in Figure 1 below.

Figure 1: The infra4Dfuture Partners

The geographical coverage of infra4Dfuture initiative spreads among EU Member States - Sweden, Finland, The Netherlands, Germany, France, Italy, Spain, Portugal, Latvia, Italy, Belgium, Greece, Poland and Austria, as well as FP7 associated countries - Norway, Turkey and Israel.
The geographical coverage of the infra4Dfuture consortium is depicted in Figure 2.

Figure 2: infra4Dfuture geographical coverage

The activities within the framework of infra4Dfuture project have been grouped through work packages (Figure 3):

- WP1: Strengthening transport infrastructure partnerships and alliances
- WP2: Developing structures enabling effective transnational coordination of existing and f uture innovation programmes
- WP3: Collaborative professional competence building
- WP4: Encouraging innovation and implementation through communication, exploitation and dissemination
- WP5: Project management

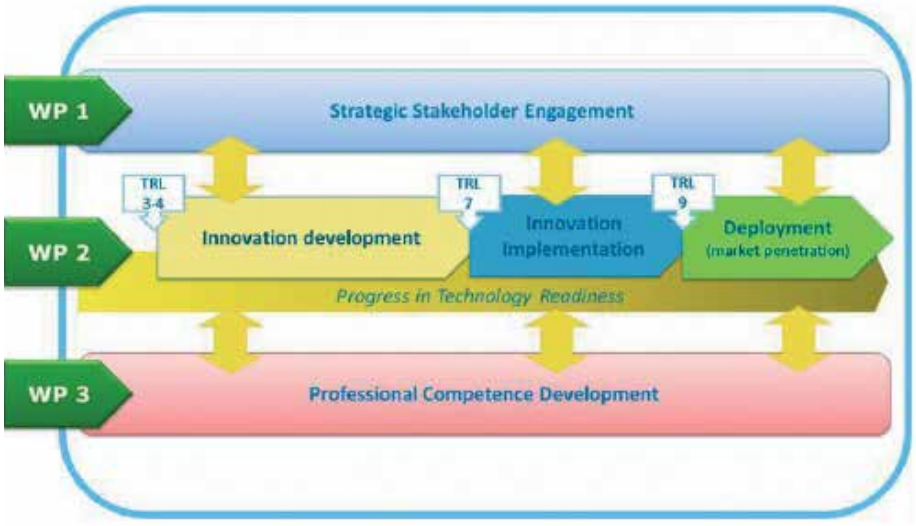


Figure 3: infra4Dfuture work packages

Within the duration of the project, a number of events and activities have taken place, aiming to engage the stakeholders and invite them to further share their ideas and expectation, thus setting the stepping stones towards the innovative transport infrastructure of 2040.

In total, 2 expert workshops, 3 stakeholder conferences and 4 regional outreach events that have been organized and accomplished with great success in 4 different destinations with the aim to emphasize the importance of the participation of local stakeholders through infra4Dfuture platform.

These activities contributed to shaping the shared strategic vision on future infrastructure capabilities and common pathways for innovation development and implementation.
Finally, a number of dissemination tools have been created within the framework of infra4Dfuture project, such as infra4Dfuture leaflets, posters and newsletters that were actively disseminated among the partners. Digital dissemination platforms such as the

Twitter and LinkedIn were also used for communicating the project progress, activities and achievements. The project website was developed as well, and can be found at http://www.i4df.eu/.

Strengthening transport infrastructure partnerships and alliances

The infra4Dfuture initiative has the objective to develop an effective, structured and sustained dialogue between key stakeholder groups involved in infrastructure innovation development and implementation in order to raise their awareness, trust, understanding and commitment to the coordination mechanism, including its key elements such as structures to coordinate a portfolio of professional competence building.
The infra4Dfuture initiative focuses on commonalities in the management of tangible infrastructure networks for surface transport. Infrastructure is defined as physical/ "hard", consisting of structures and facilities, and organizational/ "soft", logistics and practices, all needed for the operation of the transport network. This includes the linear links and intersections, the corresponding buildings, the power and data/communication supplies and interconnections to all internal and external stakeholders and end users, as well as the governance and management structures and procedures across the line of sight from ministry to market. The objective is to drive demand-driven innovation, spanning the entire process of research and deployment towards larger network scales. The i4Df initiative focuses on establishing a coordination mechanism for demand driven infrastructure innovation in a European setting, including associated countries from the wider European research area.
The infra4Dfuture coordination mechanism suggests voluntary alignment of national, regional and European activities according to the required scale and respecting the principles of subsidiarity, its foundation is a structured dialogue between all relevant stakeholders (Figure 4). This dialogue builds from achieving a set of common objectives of the various NTIAs as public issue owners that have an urgent need to a common agenda for infrastructure innovation and implementation. This common agenda serves as a guiding actionable perspective for the other stakeholders, notably:

- the **public innovation programme owners** that from a shared interest may fund items from that common agenda. Examples of bilateral, multilateral and European cooperation are: the European Commission, from well-known programmes such as Horizon-Europe, CEF; CEDR, from its transnational research programme; and other EU-regional cooperation such as the Nordic Council on the Nord-FU programme, and Germany, Austria and Switzerland on the DACH initiative.
- **the industrial lead suppliers** of innovative solutions.
- **the supporting research providers** (including education and training).

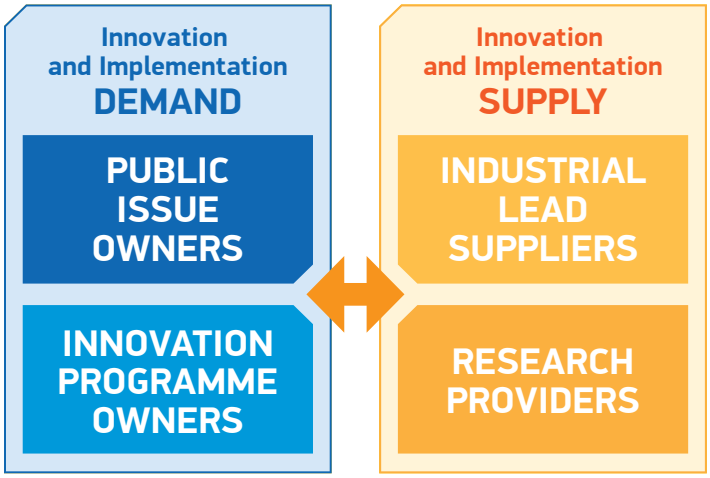


Figure 4: Demand and Supply of Innovation and implementation

Infrastructure capabilities for 2040

In the context of the i4Df initiative, transportation networks are a spatial framework of routes linking locations, enabling transport of people and goods from origin to destination. The routes can be tangible, such as is the case with roads, rails, waterways, or less tangible, such as is the case with air and sea corridors. In terms of geographical setting and functionality, the initiative focuses on the TEN-T comprehensive networks, including relevant supporting sections of the non-TEN-T networks, that carry most of the traffic and are strategically most important (Figure 5).

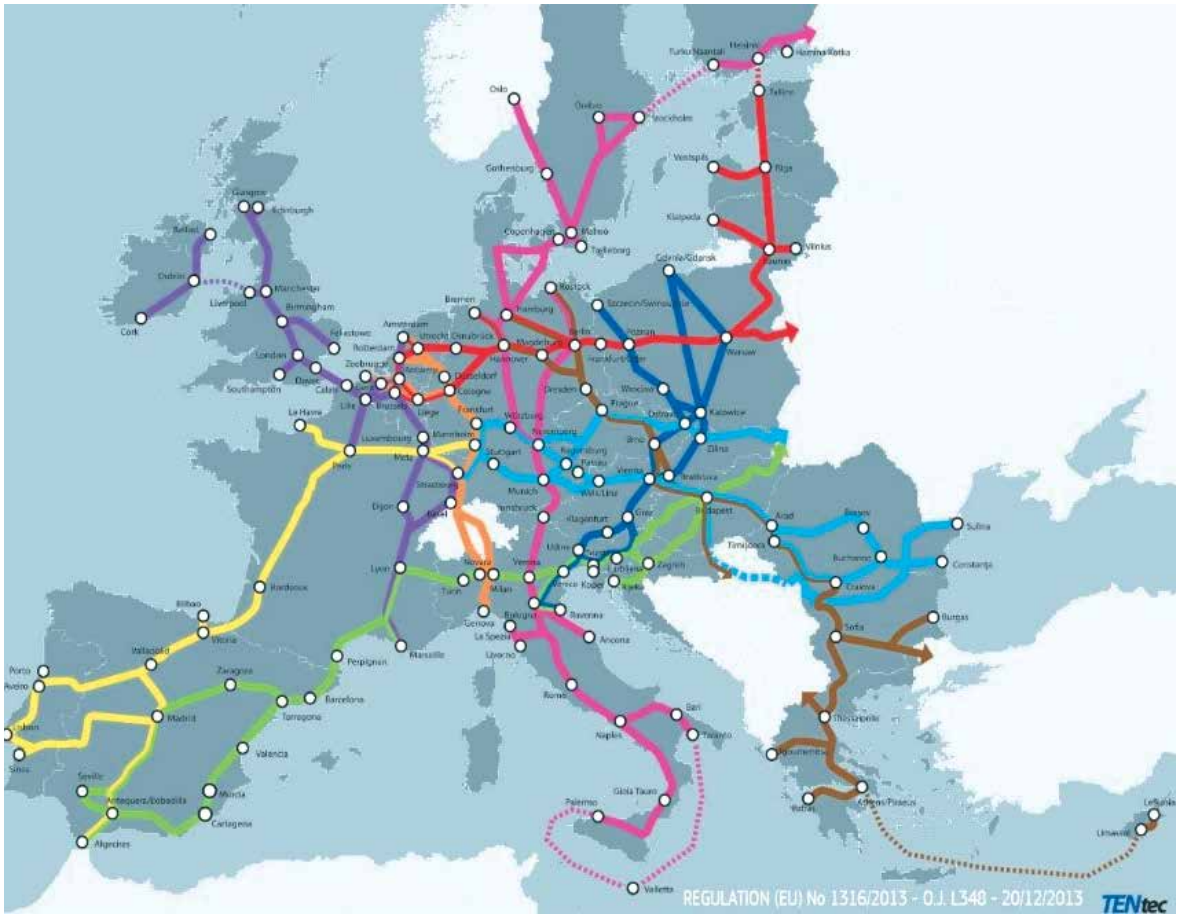


Figure 5: TEN-T Networks

With a focus on the links, municipal networks, airports and waterborne ports are regarded as singular nodes in the network for which the key issues to address are: accessibility, availability and reliability of the (inter) links. These urban and economical nodes have an essential role in enabling effective and efficient distribution of transport flows of freight and passenger transport across the cross-modal European transport area. They can be of different scale and organization, but are typically set in the densely populated areas and economic centres of Europe. Their utilization is typically to the maximum service capacity i.e. they are typically highly congested. The main actors of these infrastructure networks include the direct users of the network and stakeholders who provide energy, data, information, transport and mobility services to the direct users. However, the importance of these networks lies on their social impact: the end-users are the citizens, either direct network users or simply inhabitants in the urban and peri-urban area.

Key drivers and enablers of infrastructure innovation

Infrastructure managers provide a broad range of services to the end users. Currently, the European mobility system is in rapid transition towards the provision of higher service quality to the end user from the perspective of an increasingly integrated system, enabling seamless and highly informed movement of passengers and freight from origin to destination across different modes. Key challenges to this service provision are: the requirements of construction, replacement and renewal; the intense competition for space and fiscal budget; demands and opportunities from new mobility business models, and digitalization for economy and society, such as mobility as a service; the sensitivity to economic and social pressures from disruption (e.g. end of life cycle, natural and man-made events); liveability and sustainability; adaptation to climate change; and the opportunities to synergize with data and energy network management (e.g. with TEN-E, the Trans-European Networks for Energy, in greening/decarbonizing the transport energy pool); the security of the infrastructure service provision to the end-user, regarding man-made attacks and natural hazards; safety of infrastructure workers and end users. The manifestation of these trends will be particularly noticeable on the 'soft' side of infrastructure as about 90% of the future physical infrastructures already exist today whereas this is only the case for approximately 10% of the organizational structures. For example, the impact of digitalization will be a game changer throughout the current infrastructure management and operation as the rapid ingress of data will affect every aspect in the operational processes. On top, digitalization will drive new, currently unknown business models which, subsequently, will drive profound changes in societal attitudes and behavior, affecting, in turn, the current role and position of infrastructure managers.

Key infrastructure capabilities

In order to coordinate infrastructure innovation and implementation across a portfolio of EU and national programmes and initiatives, infrastructure managers need a common reference to future 'capabilities' outlining the expectations from a societal-friendly transport of the future.

The infra4Dfuture initiative has elaborated on 3 interdependent capabilities:

- **Infrastructure optimally meeting end user needs.** The ability to provide optimal transport infrastructure network capacity in order to accommodate increasing transport needs, and balancing cost, performance, safety and risk to provide infrastructure as a high-quality service to end users.
- **Infrastructure meeting environmental and social sustainability needs.** The ability to embed transport infrastructure networks in their immediate surroundings, optimally balancing interests from economy, society, and environment.
- **Infrastructure achieving added value from digitalization.** The ability to harvest the benefits from digitalization in internal processes of transport infrastructure management (e.g. planning, design, construction, operation, end-of-life) as well as in the relation between transport infrastructure management and its end user (smart mobility and logistical services, individual end users). Use digitalization to support the achievement of sustainability targets and provide a better service to infrastructure end users.

Each capability is spanned by a set of guiding objectives that set the agenda for the infrastructure innovation demand. The guiding objectives for 2040 are listed below:

Capabilities	Guiding objectives for 2040
Capability 1: Infrastructure optimally meeting end user needs	• Full accommodation of the anticipated development in transport demand across the network, achieving effective alignment between the surface infrastructure networks through interoperability and synchromodality. • Effective management of resources and assets, and high availability throughout the whole infrastructure lifecycle, from planning and design to end of life. • Effective, adaptive integration and rapid implementation of innovations across the delivery process chain. • Significant reduction of Total Cost of Ownership (TCO), e.g. reduction by 30% for infrastructure managers. • Zero fatalities and severe injuries of infrastructure workers and end users through Vision Zero. • Resilience to natural and man-made hazards, including adaptation to climate change. • An affordable high capacity infrastructure that supports end users' service combinations of mobility and logistics. • Comprehensive and consistent framework of performance indicators for the management of the integrated, multi-modal network, available by 2030.
Capability 2: Infrastructure meeting environmen-tal and social sustainability needs	Compliance with COP21 and Agenda 2030/UN targets for sustainable development in the context of European objectives and targets. • Minimise carbon footprint of the whole service-life of infrastructure, including the infrastructure delivery process chain. This includes achieving energy neutrality of the infrastructure management operations (e.g. lighting, signaling, data collection, information provision, lifting and ventilation) up to larger network scales. • Facilitate the transition in the energy pool of the transport modes and supporting measures to improve energy-efficiency of mobility services (passengers, freight). • Collaborate on the minimisation of the impact on the environment, in particular concerning the impact of noise, vibration and pollutant emissions. This concerns the share of the impact that is contributable to infrastructure management. • Collaborate on the optimal net benefit from embedding infrastructure in the spatial setting. This concerns the 'how' in infrastructure governance, balancing benefits for the economy, society and environment in the planning and approval stage.
Capability 3: Infrastructure achieving added value from digitalization	• Facilitate the transition towards smart mobility concepts (freight and passenger) fore merging concepts for automated mobility, e.g. Connected Cooperative and Automated Mobility (CCAM) for road and Automatic Train Operation (ATO) for rail. • Proactive position of the infrastructure manager within the infrastructure related data-driven ecosystem, including clearly defined data flows between cross-modal, national and sectoral stakeholders and a clear business model and case for investment in and maintenance of digital and virtual infrastructure. • Ability to process internal and external raw data into smart data that can optimize infrastructure management processes, including maintenance and construction of infrastructure. Provide seamless data and information use and provision across the transport infrastructure network and logistics chain to the end user. • Facilitation of the alignment of TEN-T core network with data and energy networks to benefit from multi-purpose digitalised networks that can cater for future digital needs, e.g. Internet of Things (IoT) and smart grid based electric mobility. • Increase the use of automated, semi-automated and remote-piloted solutions for infrastructure maintenance and construction to improve safety for workers and reduce costs.

These Innovation focus areas have been discussed by various stakeholders throughout the duration of infra4Dfuture project and in various events within the framework of the project reaching a final form.

The combination of capabilities and their innovation focus areas is presented below:

INNOVATION FOCUS AREAS FOR INFRASTRUCTURE INNOVATION AND IMPLEMENTATION

Capability 1: Infrastructure optimally meeting end user needs

The ability to provide optimal transport infrastructure network capacity in order to accommodate increasing transport needs, and balancing cost, performance, safety and risk to provide infrastructure as a high quality service to end users.
Innovation Focus Area (IFA 1.1): Network performance management
Innovation Focus Area (IFA 1.2): Integrated infrastructure network management

Capability 2: Infrastructure meeting environmental and social sustainability needs

The ability to embed transport infrastructure networks in their immediate surroundings, optimally balancing interests from economy, society, and environment.
Innovation Focus Area (IFA 2.1): Decarbonisation of infrastructure management
Innovation Focus Area (IFA 2.2): Preserving the environment
Innovation Focus Area (IFA 2.3): Integrating multi-layer networks and nodes

Capability 3: Infrastructure achieving added value from digitalisation

The ability to harvest the benefits from digitalisation in internal processes of transport infrastructure management (e.g. planning, design, construction, operation, end-of-life) as well as in the relation between transport infrastructure management and its end user (smart mobility and logistical services, individual end users). Use digitalisation to support the achievement of sustainability targets and provide a better service to infrastructure end users.
Innovation Focus Area (IFA 3.1): Smart data and information ecosystem for accommodating automated and connected transport
Innovation Focus Area (IFA 3.2): Information provision for process optimisation in infrastructure management

IFA 1.1: Network performance

Transport infrastructure owners and their end users are currently facing a rapid change in the mobility and the transport infrastructure sector. Digitalization is one of the main causes for these rapid changes as it enables infrastructure owners and their end users to benefit from new information sources. This enables the users to make more informed decisions about the services that owners provide in support of the decision making by the end users on their planned journey. In addition, end users are also becoming more conscious about the use of the transport infrastructure and they put more value on aspects such as sustainability and access to digital services whilst using the infrastructure.

The infrastructure owners need to broaden their understanding of end user needs (i.e. mobility and logistics) and the possibilities to influence in order to provide satisfactory services and access to infrastructure. From an end user perspective, the division line between modes becomes more blurred as new information sources influence daily mobility decisions.

Current key performance indicators (KPIs) and assessment techniques used by infrastructure owners do not accurately reflect the changes. This puts infrastructure owners into the

position to develop new dynamic KPIs taking into consideration the needs and requirements of the end users. Regardless of digital layers, transport infrastructure has to offer the necessary availability and service for the end user in a reliable and safe way.
To cope with increasing traffic volumes calls for a better ability to plan and organize construction and maintenance work with minimum interruptions regarding duration and impact, especially for critical nodes i.e. bridges, tunnels, intersections and locks. For management of accidents and incidents as well as for interruptions due to man-made or natural events, emergency plans are necessary to keep interference with traffic flow to a minimum. Services required by private users and industrial use may be different and can be used to define priorities.

- Innovations in this area are expected to facilitate infrastructure owners to respond to the emerging end users' mobility and logistics needs and infrastructure availability. Among others, this will result in the development of new cross-modal KPIs, data collection approaches, analysis techniques and assessment tools.

Innovation and implementation

- Intelligent prediction of maintenance: Models for a systematic cross modal and cross border infrastructure management are required to achieve a proactive network maintenance planning, avoiding unplanned maintenance measures and developing sound alternatives for the overall traffic volume.
- Accident/incident management: Predicting the probability of accidents/incidents to forecast and/or assess the impact of such events is an important ability for infrastructure authorities. New technologies that allow emergency plans for timely interventions have to be developed from both a cross-border and cross modal perspective.
- Ergonomically optimized infrastructure design: The concepts of "forgiving infrastructure" and "self-exploring infrastructure" are principles to be further developed to minimize impact and duration of disturbances on the infrastructure network.
- New materials, systems, and techniques: Smart design and construction materials as well as non-destructive testing methods through sensor technology will help to improve intelligent prediction the infrastructure state.
- Big data: Real time remote condition monitoring and robotics automatically generate data. Data sharing is also required to reach goals as intelligent prediction of maintenance as well as suggesting efficient routing. A key focus should be given to data openness.
- Adopting cross-sectoral innovations
- Understanding the end user: Infrastructure authorities need to develop updated definitions of their end users (groups) and assess their changing needs and requirements until 2040. These definitions need to recognize and appreciate the varying acceptance and user needs for solutions across the EU. A dynamic exchange with end users is required to reflect the fast-changing needs in the coming years.
- Consistent framework of performance indicators, through reviewing and updating KPIs used in infrastructure management, to reflect should reflect a wide set of end user needs, also including needs from the logistics sector.
- Interoperability: Integrated logistics planning and electronic transactions, along the logistics delivery chain need to be developed.

IFA 1.2: Integrated infrastructure network management

Infrastructure management needs to take the next step towards achieving a truly integrated, cross-modal network across Europe delivering high quality services to its end

user. A key factor in this step is the introduction of life-cycle management (LCM) as an integrating framework for the management processes of the individual bodies. The benefits of an integrated infrastructure LCM from planning, building, operating to decommissioning are widely accepted, but the deployment of this approach needs to be facilitated further. There is a need to balance the use of affordable technical assets and good value services for maintenance and operation to ensure a high service quality to end users at a justifiable cost.

In general, transport infrastructure must become more reliable with higher service quality at lower costs. This can be achieved by using new technologies and methods to improve traffic flow, safety level and maintenance operations with the right action at the right time. More value from data can help with the underlying information base. Improved interconnection between hard and soft transport sub-systems through integrated mobility management and information to end users approaches has a high potential in contributing to the guaranteed availability of transport infrastructure.

During the operational phase, infra managers need to consider approaches to ensure their networks' safety, security and resilience against serious natural or man-made incursions. It is therefore necessary to engage in a holistic examination and appraisal of the transport infrastructure to establish key risks for the networks operations, such as, the degree to which procedures are in place for preparing, planning, coping with and adapting to unexpected and adverse events. Following the results of this risk analysis, proactive measures to prevent these threats may be planned and taken, but also, procedures to face occurrence of hazards must be elaborated and activated.

Use of new technologies and innovative technological tools will ensure integrity of the transport infrastructure and safety of end users in a most effective way.

IFA 2.1: Decarbonization of infrastructure management

In itself, the share of infrastructure management in the total carbon emissions from the transport system is very limited. Nevertheless, the transport infrastructure authorities will need to deliver their share in the transition towards a circular and decarbonized society. In addition, infrastructure management holds significant leverage on the energy transition and efficiencies in the other components of the transport system; on transport means; on transport operations for passengers and freight. Furthermore, the surface area and adjacent areas of transport infrastructure offer opportunities for harvesting energy. Infrastructure authorities across Europe and beyond have already invested significantly in these developments. However, this mostly concerned limited projects and programmes, often aiming at proof of concept or demonstration. In individual cases, countries have established larger scale action programmes for their networks.

Innovation and implementation

- Framework and strategies for the distribution of costs, benefits and risks across the actors in the manufacturing and delivery chain: Developing approaches for deconstruction/ recycling during the planning and design phase of the lifecycle, at minimal energy costs and in compliance with technical requirements.
- Next generation common toolbox for applying circular economy principles at low carbon energy costs, such as methods for manufacturing, refurbishing or rehabilitating transport related infrastructures with the objective to significantly extend functional life spans of infrastructures and its key elements, as well as performance-based design models and

manufacturing techniques aimed at reducing material consumption.

- Assessing the sustainability of scaled-up approaches integrating circular economy principles.
- Developing methods, models and guidelines for sustainable procurement practices, with Public authorities' involvement considered as a key element.
- Foster best practices as new standards and share a cross-modal strategic programming approach, through development of supporting policies, including the fostering of new or harmonization of existing standards.
- Support of the social acceptance of the transition process.

IFA 2.2: Preserving the environment

In itself, the impact of infrastructure management on the environment is very limited in comparison to that of the transport process itself. Nevertheless, the transport infrastructure authorities will need to deliver their share in reducing that impact. In addition, infrastructure management holds significant leverage on the level of impact from the other components of the transport system, including the manufacturing construction industry.

Innovation and implementation

- Reduction of noise and vibration, through implementing next generation of source measures, next generation noise abatement techniques, systems and materials
- Reduce costs of noise mapping activities through automation of noise mapping processes, enabling a comprehensive overarching insight of the environmental impact of combined national infrastructure networks, including relevant regional sections.
- Reduction of NOx, PM10, PM2.5 emissions to air, soil and water.
- Treatment of emissions through exploring and implementing the possibility to keep treatment options as natural as possible, considering the related space consumption and considering biodiversity.
- Preservation of habitats and biodiversity. Based on a common understanding of what the habitats are and how they are affected by infrastructure and transport, it is necessary to connect the whole habitats, to allow the migration of species. Integrated solutions need to be considered reflecting the various aspects related to environmental impacts.
- Introduction of new transport concepts, based on environmental impact assessment (emissions, noise, safety, security, spatial).

IFA 2.3: Integrated multi layers and nodes

The Trans-European Transport Network (TEN-T) is the main action plan for comprehensive transport infrastructure development throughout the European Union and, in combination with national transport and infrastructure policies, is essential for the ambition to create a single transport area in Europe. While responding to economic and private users' needs, this infrastructure development must fulfil key societal requirements, such as balanced accessibility and sustainability. Nodes are key elements of the TEN-T network should respond to growing mobility needs and increasing freight transport by implementing new logistic concepts, ensuring transport modes' seamless interconnection and accommodate spatial-economic growth and urban expansion (housing, working, facilities). An effective integration of a node in the TEN-T core network corridors is complex. Different spatial scales, modalities, sectors and stakeholders are concerned and all have to be considered when optimizing the integration of solutions for accessibility and profitability of mobility on the

one hand with vitality and liveability of nodes becoming increasingly important on the other. Mobility and infrastructure demands grow and innovate fast, increasingly impacting socio-economic development as well as accessibility and spatial and environmental quality of nodes. Thus, there is a need of multilayer approach that includes spatial, network, temporal, value, institutional and implementation issues that need to be resolved simultaneous on three levels: local, urban-regions and trans-national (TEN-T Network).

Innovation and implementation

- Integrated investment perspectives. Cooperation between government levels (local, regional, national, EU), government agencies, expert networks and (market) stakeholders, aimed at producing innovative mobility solutions, which will lead to more integrated perspective at investments in mobility, infrastructure, passenger transport and freight logistics from (inter)national (corridor), regional and local perspectives;
- Integrated policy perspectives. More sustainable and efficient (TEN-T and comprehensive) networks and an optimal integration between infrastructure planning and spatial planning. Increasingly involvement and coordination between freight and logistic operators, port authorities, infrastructure providers, spatial planners and financiers the planning processes for transport infrastructure on the three different levels (local, national, European).

IFA 3.1: Smart data and information ecosystem for accommodating automated and connected transport

The entire mobility system is currently in a transition phase towards higher levels of digitalization: This will result in more connected and automated functionalities, both for vehicles using the infrastructure and the infrastructure itself. The division line between "intelligence/knowledge" in the vehicle or infrastructure will become blurrier, which will have a multitude of effects on the relationship between vehicle owner, vehicle manufacturer and infrastructure manager. The coming decades will be a period for infrastructure owners and managers with guaranteed uncertainty regarding, among others, vehicle penetrations rates, automated functionalities and digital and physical infrastructure requirements. The key challenge for infrastructure owners will be to navigate these uncertain times by developing suitable governance models that foster an institutional readiness to tackle a variety of interdependent issues that infrastructure owners and managers are currently facing. Data is becoming a more and more important resource for infrastructure owners and managers, but current data-related research activities have mainly focused on data provision and exchange to the benefits of service providers and end users. The role of infrastructure managers and owners in a cross-modal and transnational data sharing eco-system needs to be defined and developed to enable infrastructure owners and managers to benefit more from digitalization and big data in their internal processes, whilst securing a high level data security and privacy.

Innovation and implementation

- New and evolving role of infrastructure owner in the context of deploying connected and automated vehicles: The development of an impact assessment on the core business activities of infrastructure owners.
- Secure, resilient and smart data and information ecosystem across cross-modal and transnational networks for all users: Creating a strategic vision for the role of the infrastructure owner and manager in the evolving eco-system that clearly highlights the benefits of data sharing for internal and external, including the development of new governance models that enable cooperation across institutional, modal and national boundaries.

IFA 3.2: Information provision for process optimization in infrastructure management

For a long period of time there has been an ongoing evolution in infrastructure management towards automated design, construction control and inspections, involving sensors and continuous and non-destructive measurements. Infrastructure owners and managers have to adjust their working approaches to benefit from the possibilities offered by this data-driven eco-system. New (big) data from external data providers will offer new potential to benefit from digitalization, which can contribute to significant cost savings and optimization in work processes. Artificial Intelligence (AI) can assist in this development by processing and interpreting the already existing data that is currently not being used to any satisfactory extent, and may also eventually provide an important decision-support tool for infrastructure asset management. Virtual training, digital verification and validation can add tremendously to the availability and safety of the network, especially for critical nodes such as tunnels and bridges. The use of robotised equipment, drones or other (semi)-automated remote-piloted solutions and artificial intelligence (AI) is developing fast and applications are likely to become mainstream within the next years. Workers will work side-by-side with different forms of robotized equipment and get decision-making support from artificial intelligence. A transition phase, where old and new techniques are co-existent, is unavoidable.

Innovation and implementation

- Data-driven and digitalized asset management, through Incorporation of data from sensors mounted in vehicles, trains and vessels along with data from external sources into Asset Management Systems, use of AI to process and interpret infrastructure data, especially for data that has previously been labor intensive and time consuming (e.g. GPR-data, crack and damage detection from photos), automated asset management system incorporating data automatically loaded from sensors, automated decision tool and maintenance action ordering.
- Advanced approaches and strategies for automated construction, maintenance, strengthening and inspection of infrastructure by artificial intelligence. Infrastructure managers need to review legal requirements and organizational structures to enable the certification of data that is processed by AIs. Certification and Quality Standards can support an AI-based data ecosystem with a common “language”, which can extend across the value chain of construction, maintenance and inspection processes. New validation and calibration techniques for inspection data can support the acquisition of data from new and not widely used data sources. Data catalogues, data ownership and data exchange procedures will enable infrastructure managers to exchange data with contractors along the value chain. An assessment of the barriers for the use of robotization in the construction processes could facilitate infrastructure managers to foster an innovation friendly environment that enables contracts to invest in more robotized equipment. Enabling activities such as the use of digital twins, modular construction, mobile factories, 3-D printing, gaming, and Augmented Reality and Virtual Reality can support wider robotization of construction processes.
- The implementation of Innovation Focus areas is expected to have a positive impact on the infrastructure. The infra4Dfuture vision towards 2030 presents the following impacts are presented below.

Capabilities	IFAs	Expected Impact 2030
Capability 1: Infrastructure optimally meeting end user needs	**IFA 1.1: Network performance management**	• Routine alignment of relevant service levels defining the common performance requirements. • Wide adoption of a common consistent framework of corresponding KPIs, logically linked to relevant elements in the set of aligned service levels. • Adequate reflection of (correlation with) end users' needs and requirements for the provision of infrastructure services • Uniform information backbone suitable for linkage with third party systems and Applications. • Greening of infrastructure construction and maintenance as well as reduction of the environmental footprint of the usage of infrastructure. Reduction of externalities is a crucial element in infrastructure decision making. • Improve resilience of transport resilience. Significantly improved ability to dynamically reroute strategic transport flows over the integrated networks in case of natural or manmade events, such as extreme weather incidents and unavailable/blocked assets etc.
	IFA 1.2: Integrated infrastructure network management	• Significant improvement and uniformity in decision making in the management of national networks across Europe. This will be enabled through the delivery of a comprehensive and consistent common framework approach that is life-cycle and risk based, and that is supported by a comprehensive and consistent toolbox of methods, models and systems. This enables cross-border assessment of both ongoing concern investments in maintenance, replacement and renewal and eventual natural and manmade incursions. • Significant improvement of reliability, availability, maintainability, safety, sustainability and economy of the infrastructure networks across Europe through the increase in integration within and across the modes. This enables scales of economy through cross border optimisation of performance, cost and residual risk. • Significant network scale support to digital end user oriented applications for transport services through the delivery of a seamless digital services platform that is rooted in the primary processes in the infrastructure delivery chain and that ensures seamless comprehensive and consistent data/information approaches, systems and structures across the national and cross border networks
Capability 2: Infrastructure meeting environmental and social sustainability needs	**IFA 2.1: Decarbonization of infrastructure management**	• Better economies of scale from common objectives and perspectives for the energy transition in infrastructure by providing larger opportunities for industry as well as infrastructure managers. The innovation focus is on delivering a validated, next level suite of models, methods and data. • The increased production of renewable energy on transport infrastructure's assets. • The wider use of electric road systems across national and European transport networks. • The seamless legislative integration of new processes that foster the energy transition. • The reduction of carbon emissions of infrastructure management processes through more efficient technological operations, e.g. operating tunnels with LEDs.

Capabilities	IFAs	Expected Impact 2030
Capability 2: Infrastructure meeting environmental and social sustainability needs	**IFA 2.2: Preserving the environment**	• Improvement of human health, in particular in the immediate surroundings of the infrastructure networks. • Improvement of environmental performance of the transport system as well as improvement of habitat quality and biodiversity.
	IFA 2.3: Integrated multi layers and nodes	• The delivery of a TEN-T that is sustainable in the economic, societal and environmental sense, and that is responsive to relevant developments and trends, offering Europe's citizens optimal performance continuously. • Maximum support from society for upcoming replacement and renewal of transport infrastructure on basis of transparent alignment of relevant stakeholder interests and boundary conditions. • Optimal social-economic revenues at the national and European scale as well as significantly improved liveability in the functional urban areas involved • Optimal performance on predefined indicators from economy, society and environment in the EU-regions under consideration. For example, concerning the implementation of the Green Deal ambitions. • Harmonisation of national transport policies across the TEN-T. • Optimal prioritisation of infrastructure investment plans with reference to the network functionality across the scales (local intra-urban; functional urban area; TEN-T).
Capability 3: Infrastructure achieving added value from digitalization	**IFA 3.1: Smart data and information ecosystem for accommodating automated and connected transport**	Innovation, in this area will facilitate infrastructure managers to become institutionally ready to better plan and deploy strategies towards the accommodation of connected and automated transport on their infrastructure. This will result in new governance structures that are based on new stakeholder processes across the value chain of connected and automated vehicles. The structures and processes are established through a thorough understanding of potential impacts on the core business of the infrastructure managers that arise through varying penetration rates of mixed CAV fleets. This should place the infrastructure manager in an assertive position with a suitable business case. Aim is to deploy and manage infrastructure elements of a complex Operational Design Domain (ODD) that enables CAVs to fulfil the expected positive effects on safety, traffic efficiency and other core business activities of infrastructures owners. Innovations in this area should facilitate infrastructure owners to use data as a valuable resource, which can optimise processes across the entire organisation and lead to cost savings, better decision making and new cooperation approaches with professional stakeholders (e.g. engineers, start-ups and researchers). Further, this can create a cross-modal and transnational digital layer that interlinks various transport activities to support EU-wide services for infrastructure owners.

Capabilities	IFAs	Expected Impact 2030
Capability 3: Infrastructure achieving added value from digitalization	**IFA 3.2: Information provision for process optimization in infrastructure management**	Innovations in this area should facilitate infrastructure managers to use data as a valuable resource, ultimately resulting in cost efficient and intelligent maintenance planning. Data acquisition through sensors in or attached to the infrastructure, remote sensing by drones or high speed inspection vehicles and in-car data will gradually replace visual inspection and static extraction of specimens to control the specification and mechanical and chemical behaviour. This transition requires a relative long transition period in which data acquainted by new techniques must be validated and calibrated with respect to current techniques. The governance structures of infrastructure managers will be adjusted to include AI into decision making processes across the entire organisation. Innovations in this area will facilitate infrastructure managers, among others, to improve workers health, reduce costs, and avoid traffic hindrance. It is expected that there will be a significant reduction of the labour shortage in the road construction and maintenance sector by developing less labour intensive processes for construction and maintenance. The quality of inspections can be improved, because up until now non-accessible locations (small pipes, under water, underground etc.) and (almost) continuous and instant monitoring opens the doors to very accurate big data analysis.

NTIA priorities for innovation and implementation delivery process

Through a dialogue between the stakeholders of infra4Dfuture initiative, a timeline for innovation and implementation has been developed. The definition of the three stages is based on the ranges in the technology readiness level scale (Figure 6).

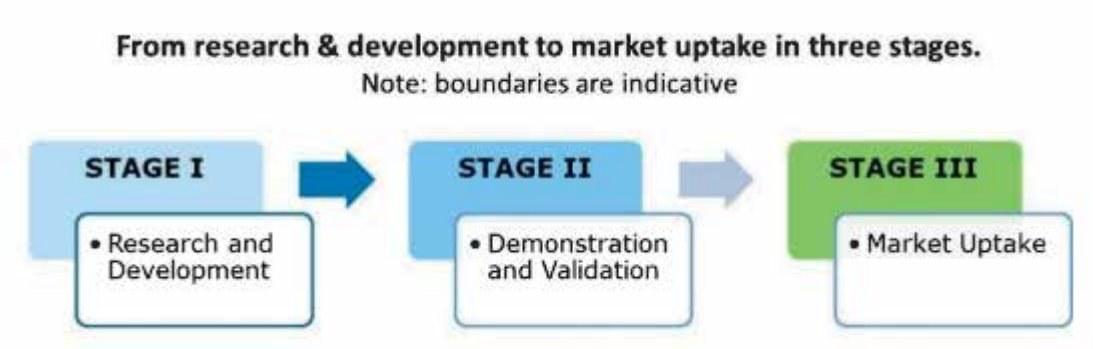


Figure 6: Stages from R&D to Market uptake

Stage I: is concerned with research and development of potential solutions in laboratorial or managed situation, and ranges roughly from TRL 4 to TRL 7.

Stage II: is concerned with demonstrating and validating promising results from stage I in (representative) practical situations in infrastructure management, and ranges from TRL 8 to TRL 9. This stage is essential in order to yield common specifications and guidelines the NTIAs as issue owner and procuring clients can choose to adopt in their procurement frameworks.

Stage III: is concerned with picking up the cost-effective business cases from stage II and foster market introduction up to larger network scales (e.g. through launching customer/ innovations procurement).

The overview of priorities in Figure 7 presents the indicative timelines for the NTIA priorities on innovation and implementation:

IFA	Overall NTIA priorities for innovation	Until 2025	Until 2030	Until 2035	Until 2040	Until 2050
1.2	*TEN-T demonstration and validation tracks*	II	III			
	Common 'line of sight' for the TEN-T core	I	II	III		
	Alignment in sustainability targets in infrastructure management	II	III			
	Building digital twins on the EU-regional scale	I	II	III		
	Integrated mobility management systems	II	II	III	III	
	Future proofing of infrastructure planning	I	II	II	III	III
1.2	*Life-cycle costs analysis in innovative contracting*	I	II	III		
	Risk sharing approaches	II	II	III		
	Simulation models in procurement	I	II	III	III	
	Innovative financing schemes	II	II	III	III	
2.1	*Electric road systems: cross-border demonstrators including pre-standardisation*	I/II	III			
	Energy Harvesting: Development of a European portfolio of demonstrated/proven technologies	II	III	III		
	Development of new legal and governance models for the emerging new cross-sectoral (e.g. energy and transport) and cross-modal technologies and collaborations	I/II	III			
2.2	*Automation of noise mapping*	II	III			
	Next generation impact assessment tools	I	II	III		
	EU-regional scale monitoring network	I	II	III		
	Improved understanding of dose-response relationships	I	II	III		
	Source measures for noise abatement	II	III			
	Next generation noise abatement techniques	I	III	III		
	Introduction of drones in monitoring, inspection	I	II	III		
	Common pricing techniques	I	II	III		
	Assessment of natural water treatment solutions	I	II	III		
	Habitat reconnection measures	II	III			
2.3	*Data warehouses at the Functional Urban Area (FUA) scale.*	I/II	II/III	III	III	
	Mobility labs at the Functional Urban Area (FUA) scale.	I	II/III	III	III	
	Multi-scalar infrastructure planning.	I	II/III	III	III	
	Integration of transport energy distribution.	I/II	II/III	III	III	
3.1	*Large-scale demonstrations focusing on the needs of the infrastructure owners/managers.*	I/II	II	III		
	Physical and digital infrastructure.	I	II/III	III	III	
	Governance models for infrastructure owners and managers to accommodate CCAM.	I/II	II/III	III	III	
3.2	*Dynamic Asset Management Systems*	I	II	III		
	Synthetic digital twin.	I	II/III	III		
	Dynamic and Automated AMS for network maintenance decisions.	I	II	III		
	Legal and Technical issues around Artificial Intelligence	II/III	III			
	Robotisation: avoiding barriers	II	III			

Figure 7: Priorities timeline

Timelines for innovation delivery

In line with the updated strategic objectives and impacts of the EC and member states, the focus in the timelines is on what is expected to achieve TRL9 by 2030 (i.e. end of stage II) making them available for voluntary deployment on the infrastructure networks (i.e. stage III).

Necessary actions for implementation and deployment of innovation

The NTIAs are pressed for innovative solutions that support their strategic goals, and that they can deploy in their infrastructure management processes on the short term "more, faster and fit for purpose". As such the emphasis in their structural dialogue with relevant stakeholders from industry, and supporting research including education and training is on driving promising innovation development from higher technology readiness levels to ready to deploy, cost-effective solutions that are appropriately documented in order to enable

swift adoption in their procurement frameworks. As a consequence, NTIAs should consider necessary measures to remove barriers to innovation and to proceed to effective deployment of validated innovative solutions.

In this context, the following measures are considered necessary:

- Broaden NTIA endorsement for the i4Df results
- Emphasize demonstration and validation activities (TRL 8-9)
- Identify large scale TEN-T testbeds
- Converge towards collaborative programme governance and management
- Co-fund NTIA collaboration from EC framework programmes
- Provide European anchor points for high level NTIA and stakeholder support and commitment.
- Build a NTIA coordinated, common information base of proven innovations

Description of the coordination mechanism

The description of the i4Df cross-modal cooperation mechanism has been drafted on the basis of multiple rounds of consultation within the i4Df consortium:

- The original concept for the i4Df coordination mechanism as agreed at the 4th i4Df Governance Board meeting in November 2019 in Vienna.
- The suggestions from the i4Df Governance Board for the further operationalisation of the i4Df coordination mechanism received after the meeting in Vienna.
- The comments received from the i4Df Governance Board members on the further elaborated, refined and detailed operationalisation of the mechanism in May/June 2020.
- Final comments received at and after the final i4Df Governance Board meeting of 9-10 September 2020.

The IFA collaboration ecosystems and their context

Figure 8 presents the full context of the i4Df cross-modal coordination mechanism with the IFA collaboration ecosystems at its core.

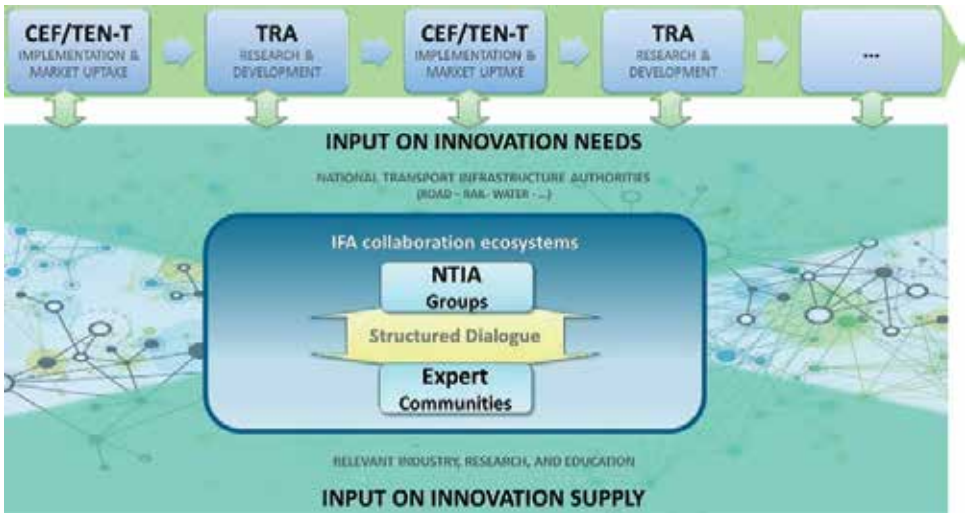


Figure 8: The i4Df coordination mechanism for demand driven transport infrastructure innovation and implementation (schematic). The mechanism is centred around a structured dialogue between the (public) national transport infrastructure authorities (NTIAs) as the procuring clients for innovation, and their relevant stakeholders from industry as the lead suppliers of fit for purpose, cost-effective solutions, and from supporting research and education. Exchange on the outcomes of the coordination mechanism with the wider stakeholder setting will be done through a variety of European, regional and national research and innovation events of which the apex events are shown: CEF/TEN-T days and TRA.

A leading principle is that the coordination mechanism builds up from the innovation activities level, and is centred around a structured dialogue between groups of advisors from the (public) national transport infrastructure authorities (NTIAs) that represent the common public need (demand side) for innovation, and experts from the relevant stakeholders from industry, research and education that represent the supply side of the delivery chain, following on the common demand for appropriate (i.e. fit for purpose and cost-effective) solutions. This structured dialogue builds from a willingness from both groups to explore opportunities for cooperative and collaborative innovation activities that they can subsequently recommend to their strategic representatives for endorsement.

In practice, this dialogue is framed in a series of thematic settings reflecting the common issues the NTIAs need to address in view of their vision for 2040. In that regard, the i4Df initiative has identified seven innovation focus areas (IFAs) considering the guidance of high level NTIA representatives and the various strategic research agendas from public, industry and research.

As such, the NTIA advisor groups and expert communities engaging in their structured dialogue resemble thematic collaboration ecosystems, i.e. one for each IFA. Each of these IFA collaboration ecosystems are concerned with concerting between a variety of innovation activities from the various European and national programmes and initiatives. Their objective is to identify and scope opportunities for further and closer cooperation and collaboration, all on a voluntary basis.

These IFA collaboration ecosystems can only be successful in coordinating across these opportunities when they experience appropriate, strategic endorsement and commitment from their respective organisations and enterprises, setting a clear need, on a relevant scale, and over a longer time span. Therefore, it is advisable that the results from the IFA collaboration ecosystems are shared with and transferred to the wider European stakeholder setting in order to optimise their effectiveness across the combined European transport infrastructure networks for road, rail, water etc. For this, the IFA collaboration ecosystems will use appropriate European, regional and national events, aiming at the widest outreach across the continent possible.

Principle workings of the IFA collaboration ecosystems

For each of the seven IFAs the i4Df initiative has identified, a collaboration ecosystem should be established from senior advisors from the NTIAs and senior experts from relevant industry, education and research (see figure 9). With endorsement and input from their organisation and enterprises, they can engage in a structured dialogue aiming to coordinate and collaborate on a common portfolio of infrastructure innovation and implementation activities.

Figure 9: IFA collaboration ecosystems fostering a structured dialogue between advisors from national transport infrastructure authorities (NTIA) and experts from relevant industry, research, and education. The dialogue builds on common (public) needs for innovation and implementation, and a corresponding industrial supply fit for purpose, cost-effective innovative solutions.

The IFA collaboration ecosystems are in essence self-organising and autonomous within the framework of the cross-modal collaboration mechanism. As such, they have great flexibility to define their own working methods, internal procedures, organisation etc. Nevertheless, a certain extent of unity and consistency between the different IFA collaboration ecosystems is essential. Therefore, the ecosystems should respect some common/general elements and requirements to ensure appropriate recognisability and interlinkage in compliance with (the networks of) their organisations. For this, the initiative has drafted some basic terms of reference (ToR). These are primarily concerned with ensuring transparency, internal resourcing, and compliance to legal and administrative frameworks (e.g. for the pooling of funds), and avoiding conflicts of interest:

- The IFA collaboration ecosystems are NTIA coordinated.
- Participation in the open setting of NTIA collaboration groups.
- 'Bring your own programme or initiative'.
- In-kind participation by principle.
- Pooling of funds within the IFA collaboration ecosystem.
- Safeguarding transparency and avoiding conflict of interest.
- Participation of experts from industry, research and education.
- Participation criteria.
- Collaboration is cross-modal by principle.

TEN-T-days and TRA as common anchor

A wide variety of international, national and regional events are related to transport infrastructure innovation and implementation, and can be used by the IFA collaboration ecosystems to share their developments/progress/results, and engage with the wider (multi-sectoral) stakeholder environment. The IFA collaboration ecosystems are responsible for identifying the events relevant to their focus areas and to engage with these events on content.

In order to guarantee common opportunities and preserve a certain coherence between activities in the IFA collaboration ecosystems, there is need for common apex events/anchor points in which the combined IFA collaboration ecosystems can share and exchange in a coordinated, coherent way with the wider stakeholder setting as well as engage with attending decision making representatives from the NTIAs, to discuss progress made and future needs for innovation collaboration. Common apex events/anchor points will ensure an appropriate setting for periodic guidance on key challenges and subjects for the IFA collaboration ecosystem activities from a representative, cross-cutting and cross-modal, multi-stakeholder setting.

Common apex events/anchor points will ensure an appropriate setting for periodic guidance on key challenges and subjects for the IFA collaboration ecosystem activities from a representative, cross-cutting and cross-modal, multi-stakeholder setting.

In view of their interlaced bi-annual timing and complementary agendas, the i4Df initiative considers the CEF/TEN-T days and TRA conferences to provide these common anchor points in time (see figure 10). Next to representing a representative, cross-cutting, cross-modal, multi-stakeholder setting from the European innovation arena, both events also recognise the need to drive promising results from research and development implementation and deployment up to larger network scales.

Figure 10: ***Intermittent sequence of CEF/TEN-T days and TRA conferences as the common apex events for the IFA collaboration ecosystems.*** *Where the CEF/TEN-T days provides a strategic setting for the IFA collaboration ecosystems from common national and European objectives and frameworks, the TRA conferences provide the subsequent elaboration into concrete planning and delivery of collaboration activities.*

Common Facilitating Services and Toolbox

The i4Df cross-modal coordination mechanism envisages common facilitating services in support of the different i4Df IFA collaboration ecosystems. More specific the common services are concerned with:

- Encouragement, coordination and monitoring of the cross-cooperation between the different IFA collaboration ecosystems
- Accommodation and facilitation of relevant exchange on cross-cutting themes
- Facilitation and collaboration of the overall workflows of the IFA collaboration ecosystems, such as on common planning, communications
- Updating and disseminating the common toolbox (guidelines, ToR, programmes, templates, legal and regulatory frameworks, event calendar etc.).

It is imperative that these common services are 'neutral' (i.e. does not interfere with) to the activities in the IFA collaboration ecosystems.

Concerning the common toolbox: The Common Facilitating Services will supply the IFA coordination ecosystems with a common toolbox that is derived from relevant i4Df deliverables and from evolving practices within the IFA collaboration ecosystems. The IFA coordination ecosystems are free to select what they need from the tool box, as well as to adopt any other tool they deem 'fit for purpose' in the context of achieving their specific goals and ambitions. However, in order to drive optimal consistency between the different IFA collaboration ecosystems and foster 'learning from each other's strengths', such other/additional tools will be made available to all the IFA coordination ecosystems through the common toolbox.

Competences for an effective coordination across a concerted portfolio of innovation programmes and initiatives

The research and innovation-oriented network of the infra4Dfuture initiative was extended in search of best practices of network coordination and governance mechanisms as well as of crucial competences for successfully running the network.

The network success stories were derived from the extensive interview data of a total of eight research and innovation-oriented networks operating on European or in more limited regional level. The partners of the project have jointly agreed on the approach of collecting the respective data, which was gathered in a qualitative data format by conducting interviews (Figure 11).

The network evolution approach was selected after examining the earlier studies dealing with network coordination and governance mechanisms as well as models for collaborative innovation-creation.

The recommendations are drawn from the vast knowledge embedded in the network stories and given by the interviewees.

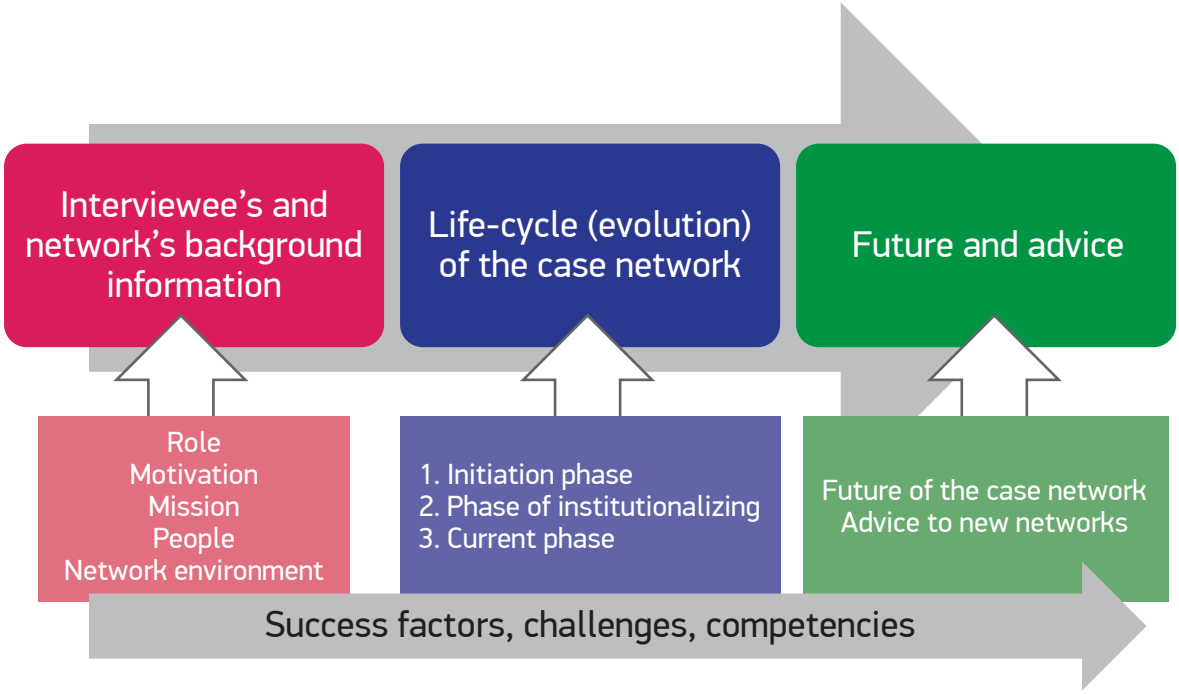


Figure 11: Outline of the interview questions

The interview process was carried out in close collaboration between the task core partners, by developing the interview questions, selecting the case networks for interviews and conducting interviews. The interviews have taken place during the period of October - December 2019 (Figure 12).

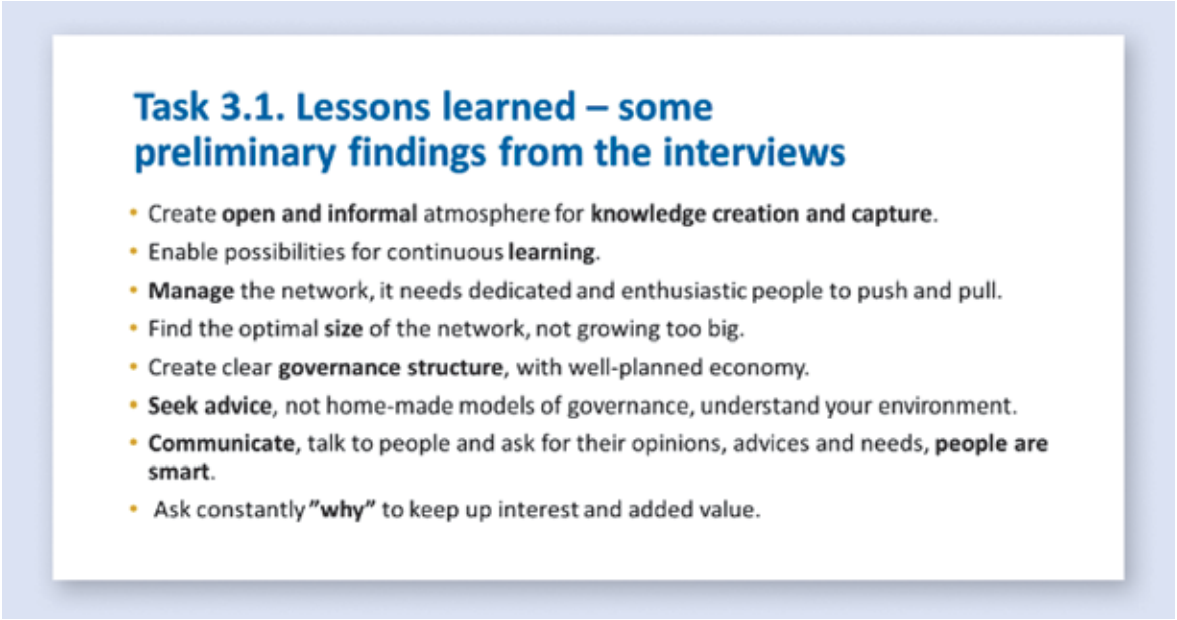


Figure 12: Preliminary findings from the interviews as slogans

The recommendations focus on the most central factors in effective and well-functioning network coordination, and especially on the key competences required both from the coordinator or manager as well as from the network members, not forgetting the importance of the member organizations' support:

1. Key competences of the network coordinator or manager: enthusiasm, persistency; management, communication and language skills, interest in people;

2. Interest and time: topical issues for discussions, relevant research ideas, dedicated time, mentoring for new members;
3. Network governance: clear focus, commonly agreed rules, roles and funding mechanism, active communication, well-established agreements;
4. Network environment: transparency, openness, equality and trust, combination of work and fun, understanding and accepting the cultural and procedural differences.

On the one hand, the success stories give inspiration and guidance for networks in their efforts in any phase of network collaboration. On the other hand, the challenges experienced when running the networks provide knowledge on the matters that are most likely to produce difficulties for the network functioning.

The main outlines from the interviews were:

Value gained in network cooperation

The network has to deliver value to the participants. An open and transparent network sharing knowledge is most likely to succeed. The network needs to be clearly focused; by focusing the results are gained easier and faster. Learning from failures is crucial so that they can be avoided in the future. Participation in the network is most often voluntary and participation itself is already one of the most powerful ways of developing and embedding knowledge. Topical issues brought to the common discussion are motivators themselves, and typically the strong link between research and practice is needed; pointing out the issues that give a headache in real life. Collecting feedback is a functional means of measuring the value of the network. Further, a clear sign of successful and well-established network is the interest of stakeholders and potential new members towards the network.

Success through communication and openness

Communication with people, testing the ideas and asking for advice is always a good idea; usually people like to give their opinion. Communication is important to break down possibly existing mental barriers. Working together is working together beyond the borders of your expertise. It has to be kept in mind that each culture has a different level of openness, and also the culture of discussing about the challenges, and what has gone wrong, is different. Strong focus on communicating about the activities and achievements of the network is always a wise move. Everyone is interested in real stories, also about those that have not been very successful in order to avoid similar failures.

Right competences are a necessity

The people involved are the most crucial strength of the network. The participants have to possess in-depth knowledge, but networking skills, openness and curiosity are being more and more important. Just being a specialist simply is not enough. Looking beyond the borders of one's own expertise is a necessity in really facing and understanding the challenging questions. The network operation and success will be based on a suitable setting of different fields of expertise for working together. Thus, the skills for collaboration and project management are very much needed. Normally, people are curious about the new things, and in research and innovation activities it must be avoided to say 'no', instead it should be said 'possibly'.

Inspiring network environment

Inspiring atmosphere in the meetings and other network events is highly important. It is important to consider organizing physical meetings, including ideally an informal dinner.

This allows meeting the other members in an informal atmosphere, learning to know also their personal background and opinions. It cannot be overestimated what personal contacts mean for the future common collaboration.

Action is one of the most important factors when building up and maintaining interest in the network. Network environment should be taking care and improved continuously. A constantly learning network is most likely to survive.

Clear organization and respect are a key to the bright future Defining clearly the tasks, roles and organization with sufficient supporting structures, like coordination and management, is essential. It has to be noticed that in every country the processes are little bit different, e.g. about how to receive approvals and how to deal with funding.

Therefore, openness to understand others' processes and learning from each other about these differences is vital for smooth collaboration and the key for success. Often, when the network gains success, but it does not have clear governance with common rules, people start arguing. Therefore, the rules are important in avoiding conflicts and unclear situations.

Framework for professional competence building in public sector, industry and research

The professional competence building in public sector, industry and research for all stakeholders forming Innovation Focus Area (IFA) meets human capital development challenges.

Europe faces uncertainty about how mobility and infrastructure will develop in the next ten to twenty years. The European Green Deal, and ever increasing digitalisation, automation and aging of population are important drivers for future trends. It is very likely that the actual development will eventually be a mix of expected, possible scenarios (Green Recovery, Business As Usual, Rapid Technological Development, and Big Private Freedom).

A coherent view on the developments of the future demand for competences of professionals that coincide with the upcoming innovations related to future infrastructure capabilities has been developed:

- **Professional competences matching future infrastructure capabilities:** The aim of this is to determine the required professional competences for national transport infrastructure authorities (NTIA) matching the future infrastructure capabilities. It is needed to develop an understanding about the future trends in societal and technological domains, drawing different future scenarios from respectable sources. Knowing these trends, one shall be able to predict the demand for transport and respective mono and cross modal infrastructure and enabling sectors (environment, digitalisation and energy).
- **Future framework for training and education:** This develops a proposition for the future framework of training and education respective of the required professional competences for the modernization of infrastructure.

Recommendations for professional competence building

Recommendations on human capital development are drawn to advise all participating stakeholders of IFAs.

Include HCD as an important topic: People are the single most important drivers of change, and one must not forget to make them a crucial part of the innovation process. Therefore, we recommend to include a mandatory HCD component in all IFAs. This HCD component should focus on the following topics:

- Spreading of the developed knowledge
- Analysis of the required future professional
- Action plan to achieve the required tasks

Human capital development support: Support the IFAs with experts in the field of HCD, to ensure it gets the proper attention.

Connect to existing activities and experiences: There are already a lot of excellent organizations and platforms surrounding the IFAs and knowledge development on a European stage. It is recommended not to organize new platforms, but to connect to the activities and platforms that already proved their right to existence on EU level. It is also recommended to further investigate the connection with the existing funding support programs like 'Marie Skłodowska Curie' and 'Erasmus' because of the overlapping goals, and to figure out how to reinforce one another by funding opportunities for knowledge exchange.

Monitor HCD over time: Create a mechanism to continually monitor and analyse the needed competences (created within and outside the IFAs and Capabilities). With this input training and education tools can be updated accordingly.

Encouraging innovation and implementation through communication, exploitation and dissemination

Within the framework of the infra4Dfuture project, a number of events and activities have taken place, aimed at bringing together diverse background audiences, including National Transport Infrastructure Authorities (NTIA), Innovation Programme Owners (IPO), Industrial Lead Suppliers (ILS), Research Providers (RP) along with the general public. All these activities intended to build stakeholders' awareness, trust, understanding and endorsement through knowledge sharing sessions and productive discussions. For building the content for the innovation focus areas have been organized:

- **1st Expert Workshop in Bergisch Gladbach** (25th-26th February 2019)

- **Four Regional Outreach Events** (Sept-Nov 2019)

  North event: Latvia, Jūrmala,11th September 2019

  West event: France, Paris, 30th September 2019

  East event: Poland, Warsaw,15th October 2019

  South event: Greece, Thessaloniki, 5th – 6th November 2019

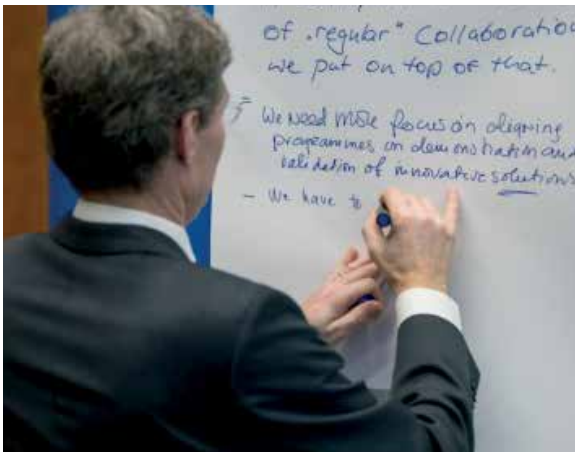
- **2nd Expert Workshop**, (cancelled due to COVID-19 and replaced by) a series of 6 IFA dedicated workshops (23rd-25th June, webinars)

IFA	Coordinator	Organisation	Country
1.1/1.2	Mats Karlsson Arjan Hijdra	Trafikverket Rijkswaterstaat	Sweden The Netherlands
2.1	Markus Auerbach	BASt	Germany
2.2	Patricia Bellucci	Stradeanas	Italy
2.3	Anastasios Mouratidis	CERTH/HIT	Greece
3.1	Andreas Blust	bmk	Austria
3.2	Janis Barbars	LVC	Latvia

- **Three high level stakeholder conferences**
  1st Stakeholder Conference (11/12/18, Brussels, RWS)

2nd Stakeholder Conference (21/05/19, Brussels, RWS)

3rd Stakeholder Conference (12/12/19, Bonn, BMK)



Key outcomes and achievements of infra4Dfuture initiative

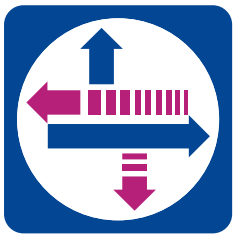
Within the framework of infra4Dfuture initiative, a ready to implement cross-modal coordination mechanism supported by the relevant stakeholders has been developed, aimed to guide the deployment of the activities within the respective concerted portfolio of programmes with the aim to drive the effective delivery of demand driven, ready to implement, cost effective innovative solutions.

A collective effort of the partners of the infra4Dfuture initiative has allowed to elaborate on a vision towards 2040, by outlining the 3 main capabilities and the respective Innovation Focus Areas.

A framework for professional competence building in order to support the implementation and deployment of the innovative solutions up to larger network scales has been created. On the basis of this framework the stakeholders from education and training can be engaged.

The infra4Dfuture initiative key outcomes are:

- Ready to implement cross-modal coordination mechanism
- Common product of and support from all NTIAs involved and wide support from stakeholders
- Strategic joint vision on future transport infrastructure capabilities and related Innovation Focus Areas (until 2040)
- Supporting toolbox
  - Joint innovation pathways until 2040
  - Human Capital Development, professional competence building for future capabilities and cross-modal approaches
  - Collaborative structures for cross-modal, transnational information transfer between innovation programmes
  - Staged-gate-reviewing process
  - Communication and dissemination tools



CERTH/HIT
Hellenic Institute of Transport

This synthesis report has been created by the Hellenic Institute of Transport of the Centre for Research and Technolgy Hellas (CERTH/HIT)
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consortium

1. Rijkswaterstaat (Ministerie van Infrastructuur en Waterstaat) - NL
2. Väylä - FI
3. Agentschap Wegen en Verkeer - BE
4. Latvijas Valsts Ceļi - LV
5. Vejdirektoratet - DK
6. Trafikverket - SE
7. Statens Vegvesen - NO
8. BMVI (Bundesministerium für Verkehr und digitale Infrastruktur) - DE
9. BASt (Bundesanstalt für Straßenwesen) - DE
10. ANAS S.p.A. - IT
11. BMK (Bundesministerium Klimaschutz, Umwelt, Enegie, Mobilität, Innovation und Technologie) - AT
12. Ministerio de Fomento - ES
13. Infraestruturas de Portugal - PT
14. Ministerstwo Infrastruktury - PL
15. Ministerstwo Gospodarki Morskiej i Żeglugi Śródlądowej - PL
16. CERTH / HIT (Centre for Research and Technology Hellas / Hellenic institute of Transport) - GR
17. Ministère de la Transition écologique et solidaire - FR
18. Netivei Israel - IL
19. Karayollari Genel Müdürlügü - TR
20. TÜV Rheinland Consulting - DE

infra 4D future

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