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D1.3 – Joint innovation pathways until 2040

Version 1.0

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Contents

1 Executive summary

This document builds on deliverable D1.2 "*Joint vision on transport infrastructure innovation until 2040*", and presents a synopsis of the consolidated descriptions for each of the innovation focus areas (IFAs) defined under the i4Df initiative. For each of the IFAs, the specific challenge and context are presented as well as expected impacts, and priority topics for collaboration towards 2030. In addition, this document presents an overview of links with relevant national, transnational and European programmes and initiatives for innovation and implementation (a more detailed analysis is provided in D2.3 '*Effective collaborative structures and schemes for cross-modal, transnational information transfer and cross-fertilisation between innovation programmes and initiatives*') as well as indicative timelines for developing the priority topics up to first deployment actions. Finally the document presents measures that are seen as necessary for enabling implementation and deployment of innovations.

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.

IFA 1.1/1.2:	Integrated Network Performance Management
IFA 1.3:	Responsible and innovative procurement and finance

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.

IFA 2.1:	Decarbonisation of infrastructure management
IFA 2.2:	Preserving the environment
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.

IFA 3.1:	Smart data and information ecosystem for accommodating automated and connected transport
IFA 3.2:	Information provision for process optimisation in infrastructure management

Innovation descriptions. The IFA descriptions have been consolidated after close consultation with experts from the consortium members (and associated experts) through a series of webinars 23-25 June 2020. Starting out with eight IFAs in deliverable D1.2, after consolidation, the number was reduced to seven as IFA 1.1 '*Network Performance*' and IFA 1.2 '*Integrated infrastructure network management*' were merged in to one:

Link to relevant European and national programmes and initiatives. A first snapshot of national, transnational and European programmes and initiatives were identified and linked to the innovation focus areas of interest. The overviews are by no means exhaustive but nevertheless provide a sound first basis for effective coordination and collaboration in Europe. Deliverable D2.3 '*Effective collaborative structures and schemes for cross-modal, transnational information transfer and cross-fertilisation between innovation programmes and initiatives*' presents these programmes and initiatives in more detail.

Timelines for innovation delivery. For each of the priority topic an indicative timeline is presented in which three successive stages are distinguished in time: research and

development (stage I, spanning TRL 4 to 7), demonstration and validation (stage II, spanning TRL 8 and 9), and market uptake (stage III, spanning deployment up to larger network scales). These indicative timelines assume collaboration on the priority topics is taken on within the next years.

Necessary measures for implementation and deployment. The NTIAs are pressed for innovative solutions that support their strategic goals, and that they can deploy in their infrastructure management processes[1] 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 in their power to remove barriers for innovation and deployment and where opportune accommodate industry and research in their activities to deliver validated innovative solutions.

In this context the following measures are considered necessary:

- *Broaden NTIA endorsement for the i4Df results*
- *Emphasise 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 (i.e. CEF/TEN-T days and TRA conference) for high level NTIA and stakeholder support and commitment*
- *Build a NTIA coordinated, common information base of proven innovations*

[1] The i4Df initiative focuses on (commonalities in) the management of tangible infrastructure networks for surface transport in which 'infrastructure' is defined as the physical ('hard') and organisational ('soft') structures and facilities 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.

2 Introduction

2.1 Purpose of the document

The purpose of this document is to provide further direction on opportunities for collaboration on the innovation focus areas originally described in deliverable D1.2.

2.2 Deviations

Task 1.3 is described as follows in i4Df's 'Description of Action' (DoA):

> *The aim of this task is to consolidate pathways for innovation and implementation for each set of infrastructure capabilities/focus areas, including the link to relevant European and national programmes and initiatives (from WP2).*
>
> *Following task 1.2, a series of EU-regional outreach events will be organised in M12-13 (under WP 4) to capture the input from the individual stakeholders from the public sector and industry from the respective EU regions for deliverable D1.3 Joint Innovation Pathways until 2040. These events reach out to the individual stakeholders that ultimately are decisive for the implementation and deployment of the innovative solutions that the coordination mechanism aims to drive. The input will be used to sharpen the Joint vision on Transport infrastructure innovation until 2040 (D1.2).*
>
> *The third stakeholder conference (M15) will be built on this (sharpened) joint vision by discussing and concluding on implementation pathways until 2040 for each of the infrastructure capabilities. These pathways hold the description of innovation actions for each of the corresponding innovation focus areas and indicate their link to the relevant European and national innovation programmes and initiatives. The pathways include timelines for the delivery of ready-to-implement innovative solutions and necessary actions for their implementation and deployment.*

D1.3: Joint innovation pathways until 2040 [17]

> *Document providing clear descriptions and timelines for development and implementation and deployment for innovative solutions for each of the infrastructure capabilities defined by the NTIA.*

Noting the above presented excerpt from the DoA, following deviations have occurred, resulting in marginal loss of quality:

Delayed delivery due to COVID-19

COVID-19 has proven to be a game changer to the anticipated process for delivery of this document. Next to an inevitable delay on the due date, also several physical events that were planned for spring 2020 with the objective to capture final input from the stakeholder groups, had to be cancelled and replaced by digital solutions. Nevertheless the quality loss is assessed as marginal.

This document was originally planned for M17 (Feb 2020). However, this was rescheduled to maximise input from the second i4Df expert meeting (the so-called 'prelaunch event', planned for 16-17 March 2020).

As this event –as well as the launching event at TRA 2020- was cancelled due to COVID-19 restrictions, the delivery date was re-scheduled to June 2020 anticipating a more elaborate written interaction with the consortium members on achieving the described scope.

However, in order to improve quality of the outcomes from this process the decision was made to include a series of webinars with experts from –and associated to- the consortium members at the end of June. As a result the delivery date was extended to mid-July 2020.

2.3 Delivery process

The following activities have contributed to the preparation of this deliverable:

- **EU-regional outreach events.** From September to early November, four EU-regional outreach events were organised in which stakeholders from the corresponding groups of countries were invited to learn in more detail about the i4Df initiative, and to express their early interest in joining the coordination groups of infrastructure authorities and experts:
  - Northern event: 11 September in Jürmala, Latvia.
  - Western event: 30 September- 1 October in Paris, France.
  - Eastern event: 15 October in Warsaw, Poland.
  - Southern event: 5-6 November in Thessaloniki, Greece.
- **Third i4Df Stakeholder conference.** On 12 December 2020, this conference was hosted by the German Ministry for transport and information (BMVI) in Bonn.
- **Second Expert Workshop**/Consultation of the consortium members. Series of 6 IFA dedicated workshops, 23-25 June 2020. This series of webinars has replaced the original expert and stakeholder consultation planned in March (expert workshop in Copenhagen-Malmö), April (TRA 2020) and May (TEN-T days) that were cancelled because of COVID-19.

IFA	coordinator	organisation	country
1.1/1.2	Mats Karlsson Arjan Hijdra	Trafikverket Rijkswaterstaat	Sweden The Netherlands
1.3	--	--	--
2.1	Markus Auerbach	BASt	Germany
2.2	Patrizia Bellucci	Stradeanas	Italy
2.3	Anastasios Mouratidis Sjaak van der Werf	CERTH/HIT Rijkswaterstaat	Greece The Netherlands
3.1	Andreas Blust	bmk	Austria
3.2	Janis Barbars	LVC	Latvia

Note: For IFA 1.3, there was no coordinator available from the consortium prohibiting an expert consultation in the webinar series from 23-25 June 2020. Lacking updates, the innovation description presented here has been copied from the deliverable D1.2 '*Joint vision on transport infrastructure innovation until 2040*'

3 Implementation pathways until 2040

3.1 Description of innovation actions.

In the i4Df initiative, the focus is put on transport infrastructure[2] innovation and implementation for road, rail, waterborne and airborne transport of passengers and goods from origin to destination.

The innovation focus area (IFA) descriptions have been consolidated after close consultation with experts from the consortium members (and associated experts) through a series of webinars 23-25 June 2020. Starting out with eight IFAs in deliverable D1.2, after consolidation, the number was reduced to seven as IFA 1.1 '*Network Performance*' and IFA 1.2 '*Integrated infrastructure network management*' were merged in to one:

Following paragraphs present an aggregated description for each of the seven IFAs.

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.

IFA 1.1/1.2: Integrated Network Performance Management

IFA 1.3: Responsible and innovative procurement and finance

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.

IFA 2.1: Decarbonisation of infrastructure management

IFA 2.2: Preserving the environment

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.

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

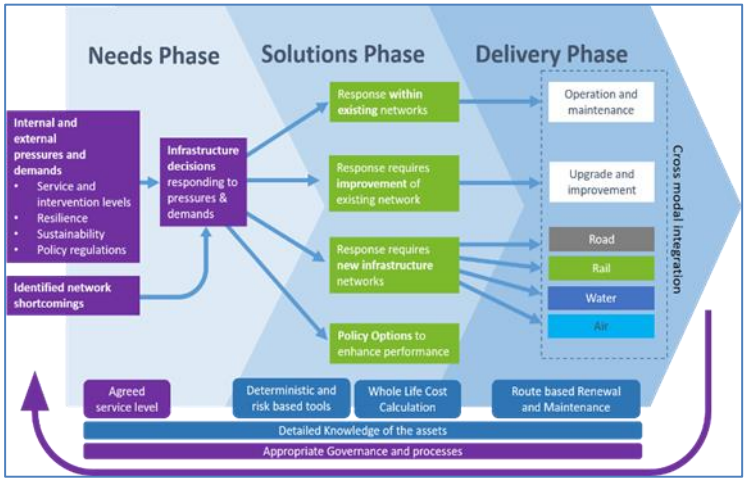
IFA 3.2: Information provision for process optimisation in infrastructure management

3.1.1 IFA 1.1/1.2: Integrated Network Performance Management

Challenge/context

[2] The i4Df initiative focuses on (commonalities in) the management of tangible infrastructure networks for surface transport in which 'infrastructure' is defined as the physical ('hard') and organisational ('soft') structures and facilities 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'.

In the dynamic multi-stakeholder context of the rapidly evolving mobility and transport sector, the NTIAs are held to their social licence to operate, ensuring their networks meet the current expectations on a day-to-day basis (safe, reliable and cost-efficient). Therefore, NTIAs need to be effective coordinators in a myriad of public-public and public-private coalitions to address the wide variety of connected issues (environment, finance, synchro-modality, urban/regional transport, digitalization, climate, circularity).



In order to appropriately address the national and European ambitions and needs for sustainability and digitalisation within boundaries of available resources and finance, they need to collaborate on common governance frameworks that span the TEN-T and relevant supporting networks. This can build on the current situation that most infrastructure agencies have adopted a form of Asset Management, which is defined as 'coordinated activities to provide value through the assets under their responsibility'. Common to these frameworks is a so called 'Line of Sight' (LoS), through which they translate performance goals reflecting high level policy driven ambitions and needs through the various organisational layers all the way into practical activities that need to be delivered from the markets (see figure). Typically this is governed through a cascade of key performance indicators (KPIs).

Expected impacts

The aim is to deliver by 2030 a demonstrated and validated framework for performance management across the TEN-T core network, in support of a single European transport area. This will build up from collaborative demonstration and validation activities on cross-border segments of the TEN-T core network managed by regional cooperatives (Nordic countries, Benelux, Iberian etc).

Through implementation of this common framework, national infrastructure authorities can achieve:

- 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 man-made events, such as extreme weather incidents and unavailable/blocked assets etc.

Priorities towards 2030

- *TEN-T demonstration and validation tracks.* The first action is for groups of willing NTIAs to demarcate several demonstration and validation track on connecting sections across the TEN-T. These serve as a concrete geographical setting in which NTIAs can exchange and share their infrastructure governance frameworks and practices in search of common denominators that enable compatibility between the nationally defined service levels and associated KPIs.

- *Common 'line of sight' for the TEN-T core.* Once the commonalities are established, the effort can be aimed at delivering a common language and 'line of sight' to manage the translation of policy needs to delivery from the market across the EU-regional TEN-T testbed. This in turn enables several opportunities for common development and implementation

- *Alignment in sustainability targets in infrastructure management.* Across Europe infrastructure managers are evaluating the impact of the Green Deal package on their primary processes, and their subsequent actionable management perspectives. A coordination action is in order to share these exercises among peers and to identify commonalities. The objective is to deliver a common correlated portfolio of service levels and KPIs as well as practical steps across the 'line of sight' from needs to market in order deliver on these.

- *Building digital twins on the EU-regional scale.* Following the alignment of network management frameworks and practices across larger EU-regional sections of the TEN-T, the implementation of integrated network performance management can be further consolidated through building digital twins of the respective TEN-T sections. By building the digital twins from a generic generator, compatibility with the developments on the other EU-regional testbeds can be assured in turn providing a longer term option for digital twinning of the entire TEN-T network (and relevant supporting networks).

- *Integrated mobility management systems.* As the EU-regional testbeds would typically encompass populated economic areas in Europe, these digital twins can subsequently be used to deliver optimised, integrated mobility management systems for these areas.

- *Future proofing of infrastructure planning.* With models for entire sections of the TEN-T reflecting population and economic ecosystems, cross-border investment planning for the mid-term (5-10 years) can be achieved. This enables high level discussions on future proofing of infrastructure planning; responding to significant trends in policy, economy, society, technology, legal and environment (PESTLE).

3.1.2 IFA 1.3: Responsible and innovative procurement and finance

Strategic context and challenges

Transport infrastructure owners and managers are facing a number of challenges in the implementation of innovations in the process of modernising the European transport infrastructure. Procurement is at the heart of this process as it manages the interaction and the risk sharing model between the public sector (i.e. usually the owner of the infrastructure) and the private sector (i.e. the contractors) when innovations are being deployed during the modernisation of the transport infrastructure. Additional pressure is put onto infrastructure owners and managers to use their purchasing power to support wider societal (e.g. support of SMEs, social return clauses to support apprenticeships) and environmental (e.g. use of recycled material) goals. Current procurement procedures are often seen as a barrier for the application of innovative approaches, transnational cooperation and the achievement of targets for wider societal goals such as sustainability.

Procurement procedures and instruments need to evolve with the innovations that will be delivered on the transport infrastructure network to speed up the uptake and implementation of innovations.

Expected impacts 2030

Innovations in this area will strengthen the role of procurement in the early phases of the transport infrastructure projects when decisions are made about the scope, the goals on innovation in the project, and collaboration with (transnational) public partners and the private sector. This will be achieved through novel collaboration structures and procurement parameters, developed and tested in a multi-modal and transnational context. The expected impact is a quicker and easier implementation of innovations during the modernisation of the European transport infrastructure.

Priorities towards 2030

- *Life-cycle costs analysis in innovative contracting:* Innovative contracting for construction and maintenance could play a key role in providing greener and more cost efficient transport infrastructure. The role of life-cycle costs analysis (LCCA) could be strengthened as a selection criterion during tendering procedures, considering aspects such as carbon footprint, material durability and other environmental impacts. Further, innovative contracting could support shared and unified procurement platforms in Europe for generic systems, components and subsystems (e.g. as already used in the automotive and aviation industries) in order to move away from customised locked-in systems.

- *Risk sharing approaches:* Building on recent (national) work, common innovative risk sharing and management approaches could be established to provide suitable models to share risk between infrastructure owners, end users, designers (e.g. design-build tenders) and contractors.

- *Simulation models in procurement:* In order to encourage innovative practices in contracts, innovations need to be assessed to optimise procurement processes e.g. by the application

of simulation models. The use of proof of concept demonstrators for innovations will also facilitate and speed up procurement and deployment procedures.

– *Innovative financing schemes:* Linked to procurement processes are also innovative financing approaches to raise funds for new infrastructure investments through direct payment of the infrastructure by e.g. the user including the relations between users, mobility providers, and contractors.

3.1.3 IFA 2.1: Decarbonisation of infrastructure management

Challenge/context

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 decarbonised 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 (e.g. through facilitating and stimulating the uptake of electrification, renewable energy); on transport operations for passengers and freight (e.g. through intelligent traffic management strategies and operations), and on the relevant manufacturing construction industry (e.g. through green procurement). Furthermore, the surface area and adjacent areas of transport infrastructure offer opportunities for (synergies in) harvesting energy.

Of the challenges in the decarbonisation of infrastructure management mentioned, the energy transition in infrastructure is considered as the aspect that requires most collaboration between NTIAs across countries and modes. Infrastructure authorities across Europe and beyond have already invested significantly in building up knowledge and expertise in facilitating the energy transition. However, this mostly concerned limited projects and programmes in limited settings, often aiming at proof of concept or demonstration. The activities of this IFA specifically focus on preparing NTIAs for the energy transition through collaboration in the identified priorities topics. Topics such as “circular economy” can be considered as future priority topics.

Expected impacts 2030

– 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.

Priorities towards 2030

- *Electric road systems: cross-border demonstrators including pre-standardisation:* Further development of Electric Road Systems need cross-border demonstrators involving relevant stakeholders from other sectors, such as from energy, which would provide the knowledge and financial capacities to build and operate such systems at deployment.
- *Energy Harvesting: Development of a European portfolio of demonstrated/proven technologies:* An assessment of the impact and cost-effectiveness building on the current abundance of separate projects. The study will provide the NTIAs with an overview on a European scale. This overview can facilitate an analysis of the reasons why most of the technologies haven't entered the market yet.
- *Development of new legal and governance models for the emerging new cross-sectoral (e.g. energy and transport) and cross-modal technologies and collaborations:* Legislation often lags behind fast technologic evolution and therefore new concepts and models for the (legal) implementation, governance models or more specifically business cases have to be developed. This is especially important for the cross-modal and cross-sectoral context these emerging technologies will have to be built and operated in.

3.1.4 IFA 2.2: Preserving the environment

Challenge and context

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 (e.g. through green procurement). Furthermore, their responsibility for the surface area and adjacent areas of transport infrastructure offer opportunities for mitigation and adaptation.

Infrastructure authorities across Europe and beyond have already invested significantly in these developments.

Expected impacts

- 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.

Priorities towards 2030

Taking into account the main environmental stressors, four main research subjects have been identified focused on the related impacts reduction: noise, air pollution, water, habitat and biodiversity.

Advanced, cost-effective noise mapping, assessment and abatement. The Environmental Noise Directive (END) of 2002 requires to Member States to produce strategic noise maps on a 5-years basis for all major roads, railways, airports and urban agglomerations, and to adopt Action Plans based on noise mapping results in order to prevent and reduce the harmful effects on human health. To date, still more than 30% of data required is not available. The cost and quality requirements for noise mapping activities seem to limit further progress. This topic includes:

- *Automation of noise mapping,* considering the possibility of using mobile phones, to improve the accuracy of noise maps and reduce the cost of the process;
- *Next generation impact assessment tools,* assessment/simulation of design, implementation, operation and maintenance, and simulating noise perception (e.g. immersive virtual reality);
- *EU-regional scale monitoring network,* interconnecting public databases and further information systems (noise, air quality, traffic and meteorological data), enabling a comprehensive overarching insight of the environmental impact of combined national infrastructure networks, including relevant regional sections.
- *Improved understanding of dose-response relationships* to better understand the impact of noise on human health.
- *Source measures for noise abatement*. Innovative solutions to abate noise at the source (roads, railways, vessels);
- *Next generation noise abatement techniques,* including advanced traffic control and management strategies (transport planning);
- *Introduction of drones in monitoring, inspection.* Drones are becoming more and more essential equipment on construction sites and during regular maintenance and asset inventory activities, as they can be faster and more cost-effective than traditional methods. However, some drawbacks from the environmental perspective have not be considered yet. Noise, emissions and safety are the main issues that should be further investigated in order to assess their overall impact.

Cost-effective abatement of NOx, PM10, PM2.5 emissions. Many cities and other urban areas are failing in meeting EU legislation for air quality pollutants. The common vision is that reducing emissions at the source is the most effective and efficient solution to mitigate air pollution. Efforts need to scale up in order to boost their wider adoption.

One of the main challenges is determining the emissions under real driving conditions, and related, certified values for type-approval limits. Building on a future basis of commonly agreed monitoring systems for actual vehicles emissions, following topics have priority:

– *Common pricing techniques:* The eventuality of common pricing of pollutant emissions as a source measure needs to be assessed on effectiveness and manageability perspective.

Water Treatment. The current widespread runoff treatment systems on road and rail infrastructures across Europe are mostly designed from a 'precautionary principle' rather than on basis of scientific and technical evidences. This can frequently result in an over-design of the (combined) measures with corresponding overspenditure. Therefore, it is important to know how and when to implement treatment systems and keep treatment options as natural as possible. Following topics are prioritized:

– *Assessment of natural water treatment solutions:* Study on the state of the art and cost-effectiveness of (prospect) natural water treatment solutions, including relevant deployment parameters, such as related space consumption and impact on biodiversity.

Preservation of habitats and biodiversity. Transportation infrastructure contributes significantly to the fragmentation of landscapes and habitats which is a major cause of receding biodiversity across Europe. The challenge is to reduce its impact on habitats and infrastructure by minimizing adverse effects and seizing on the various opportunities the networks offer as well.

– *Habitat reconnection measures.* 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 taken into account reflecting the various aspects related to environmental impacts. Opportunities of the existing space belonging to the infrastructure have to be investigated to preserve and improve biodiversity.

3.1.5 IFA 2.3 Integrating multi-layer networks and nodes

Challenges and context

The European Union has one of the most advanced, complex and densely webbed transport networks in the world. Its further development towards a European single transport area will require significant upgrading of the current ageing infrastructure networks both in quantitative and qualitative terms.

Increasingly -and in particular in Europe's urbanized regions- the associated national and local investment plans need to consider optimization across a multitude of economic, societal and environmental boundary conditions and stakeholders. This optimization is often limited to the very specific spatial setting of the plan, disregarding eventual impacts on the functionality of other (adjacent) sections of the transport network. This in turn can lead to sub optimization on the overall network scale.

Therefore, the need is for the implementation of a common multi-parametric approach that enables optimization of the performance of transport links and nodes, with care for the preservation of the environment and the liveability of urban centres. Such approach should include performance indicators on the spatial, network, social and institutional dimensions of transport activities to be considered simultaneously on three scales: the local (intra-urban)

scale, the scale of the functional urban area (or the Daily Urban System) and the trans-national scale of the TEN-T Network.

Expected impacts

The aim is to deliver by 2030 an implementation of the multi-parametric approach in several EU-regional clusters in the TEN-T. The deliverable will be in the form of digital twins that can support the involved infrastructure authorities in their effort to optimise their investment planning in close engagement with relevant stakeholders from economy, society and environment.

Through implementation of this common approach, national infrastructure authorities can achieve:

- 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).

Priorities towards 2030

Specific priority topics with view to integration are identified as follows:

- *Data warehouses at the Functional Urban Area (FUA) scale.* Optimal transport system collaboration at the Functional Urban Area scale needs dedicated data warehousing, including models for sustainable cooperation and collaboration between public and private sector. A first step in this process is establishing common data architectures and standards that enable exchange of historical as well as real-time data between relevant stakeholders, such as public authorities, freight operators, infrastructure and traffic managers. From this foundation, cooperation models can be developed to enable effective and secure mobility data and capacity sharing. The approach would be from the TEN-T scale down into the relevant supporting networks with a particular focus on the peri-urban settings in the FUA. In case of larger, cross-border scale FUAs, the respective national access should ensure appropriate harmonisation and standardisation.

Additional research development should focus on the transport/mobility interfaces, such as of freight/persons, intra-/inter-urban, last-mile/long-distance transport as well as on generic spatial-economic assessment approaches that enable integrated public-private business casing in Functional Urban Areas .

– *Mobility labs at the Functional Urban Area (FUA) scale.* The FUA scales concern intricate webbed mobility and transport subsystems to the overall TEN-T system. Examples of such scales are Rotterdam/Antwerp-NRW, Vienna Bratislava, Lisbon-Madrid-Barcelona, the Po riverbasin, and Malmö-Gothenburg.

  In these subsystems a plethora of local and regional stakeholders interact and collaborate to dispatch freight and passengers between the multitude of origins and destinations within the FUA as well as in the wider European and global Hinterlands (continental and sea). Noticing that demonstration and validation activities need appropriate scales to reduce marginal additional cost of the respective activities, FUA scale mobility laboratories across Europe are needed that foster learning by doing. Combined the FUA mobility labs can build a network for exchange of lessons learned and sound practices from a 'bring your own lab' philosophy.

– *Multi-scalar infrastructure planning*. A common approach is needed that enables multilevel planning and coordinated (spatial) asset management, spanning the local scale (intra city), FUA scale and the TEN-T corridor scale. In the urban nodes, these three network scales strongly interact when it comes to traffic flows. Hence measures to optimise the combined mobility system of the urban node –such as through replacement and renovation of the respective infrastructure networks- need collaborative appraisal economic, societal and environmental parameters across all three network scales with the FUA scale is pivotal to both other scales.

– *Integration of transport energy distribution.* The hubs and terminals in the FUA setting are interfacing 'last-mile' and long-distance transport. Therefore they are particularly suited for reinforcing the energy transition by introducing energy distribution infrastructures for alternative fuels and electricity at low marginal additional cost. This requires careful planning and development through strategic public-private alliances. Key is to facilitate the development and dissemination of good practices and standards that enable the required technical and organisational compatibility between the involved energy, mobility, and transport infrastructure sector.

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

Challenge and context

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 increasingly blurred, 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, e.g. for trip planning and information provision. The role of infrastructure managers and owners in a multimodal and transnational data sharing eco-system needs to be defined and developed to enable infrastructure owners and managers to benefit more from digitalisation and big data in their internal processes, whilst securing a high level data security and privacy.

Expected impacts

Innovations 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 multimodal and transnational digital layer that interlinks various transport activities to support EU-wide services for infrastructure owners.

Priorities towards 2030

– *Large-scale demonstrations focusing on the needs of the infrastructure owners/managers.* The role of infrastructure owners and managers is essential in large-scale demonstrations of CCAM solutions. Demonstrations of the interaction between CCAM solutions for passenger and freight and the infrastructure can create infrastructure focused knowledge that enables the development of business cases for infrastructure owners and managers to move along the ISAD levels. The necessity for cross-border elements is the strong need to harmonisation and interoperability of technologies and methodologies also for infrastructure owners and managers.

– *Physical and digital infrastructure.* Infrastructure owners and managers are faced with the challenge of managing the transition of their physical infrastructure (markings, road signs,

layout, etc.) and digital infrastructure (connected road side units, digitised spatial network, etc) towards higher levels of automated, cooperative and connected mobility solutions. Further collaborative research is required on the Infrastructure Support Levels for Automated Driving (ISAD) to enable the most efficient and cost-effective approaches (incl. business models) to ensure that infrastructure owners and managers invest in the most suitable physical and digital infrastructure.

– *Governance models for infrastructure owners and managers to accommodate CCAM.* Data and connectivity is an essential resource for the deployment of CCAM. 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. This includes the development of new governance models that enable cooperation initiatives across institutional, modal and national boundaries. The integration of legacy systems for data management into the evolving multimodal and transnational data ecosystem requires also consideration.

3.1.7 IFA 3.2: Information provision for process optimisation in infrastructure management

Strategic context and challenges

For many years there has been an ongoing evolution in infrastructure management towards automated design, construction control and inspections etc., 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. Ideally, all data involved in all life phases of the infrastructure should be accommodated and processed by an integrated digital twin, of which the BIM-system is the fundamental backbone.

New (big) data from external data providers will offer new potential to benefit from digitalisation, which, if used rightly, can contribute to significant cost savings and optimisation in work processes. Artificial Intelligence (AI) can assist in this development by processing and interpreting all the already existing data that is currently not being used to any satisfactory extent, and AI 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 robotised equipment and get decision-making support from artificial intelligence. A transition phase, where old and new techniques are co-existent, is unavoidable.

Expected impacts

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.

Priorities towards 2030

- *Dynamic Asset Management Systems.* Conventional Asset Management Systems (AMS) depend on data that usually is gathered by the NTIAs on a regular basis, but rarely the frequency of data gathering is sufficient to allow for dynamic analysis with a short detection-to-action period. Recent availability of mobile crowd sensing data (mobile phones and their sensors) and access to car manufacturers data (car sensors) has led to opportunities for development of dynamic AMS.

- *Synthetic digital twin.* AI assisted measuring system that would combine data from high speed and remote sensing (satellite systems, UAVs, LiDAR, georeferenced photographs) to synthesise reliable data for creation of digital twin (both in linear and point applications).

- *Dynamic and Automated AMS for network maintenance decisions.* Development of novel Dynamic (semi)Automated Asset Management System (DA AMS) that is built on the experiences gained from conventional AMS with ability to introduce maintenance action ordering (MAO). MAO needs a set of proofing tools – either visual or sensor based that shall be developed alongside the DA AMS.

- *Legal and Technical issues around Artificial Intelligence.* Development of legal and organisational frameworks for use of AI in infrastructure management. Common systems and procedures for data acquisition, validation, calibration and exchange.

- *Robotisation: avoiding barriers.* An assessment of the barriers for the use of robotisation (and its enabling activities – digital twins, modular construction, mobile factories, 3-D printing, gaming, and Augmented Reality and Virtual Reality) in the construction processes.

3.2 Link to relevant European and national programmes and initiatives

The following overviews presents a snapshot overview of research and innovations programmes and initiatives identified during the runtime of the i4Df initiative.

National Programmes and Initiatives	Country	IFA 1.1/1.2	IFA 1.3	IFA 2.1	IFA 2.2	IFA 2.3	IFA 3.1	IFA 3.2
FoPS Research Programm Urban Transport	DE	X	X					
CoT - City of Things - smart cities and municipalities	BE-VL	X		X	X			X
TakeOff (bmk)	AT		X	X	X	X	X	X
Future Mobility	AT	X	X	X	X	X	X	X
FFI - Strategic Vehicle Research and Innovation	SE			X	X		X	X
Sustainable transportation	CH	X	X			X	X	X
FEREC	FR	X		X	X		X	X
IDRRIM	FR	X		X	X		X	X
BMVI Network of Experts	DE	X		X	X		X	X
PON Research and Innovation	IT	X	X	X	X	X	X	X
DuLo Programme	NL			X	X	X		
V&R Programme	NL	X	X					
NGInfra - Next Generation Infrastructures	NL	X	X	X	X	X	X	X
Platform WOW – Dutch infrastructure managers	NL	X	X	X	X	X	X	X
Action plan automated mobility	AT						X	
Framework for BIM implementation	LV							X

Transnational and European Programmes and Initiatives	Country	IFA 1.1/1.2	IFA 1.3	IFA 2.1	IFA 2.2	IFA 2.3	IFA 3.1	IFA 3.2
CEDR Research Calls	Europe	X	X	X	X	X	X	X
Shift2Rail	Europe	X	X	X	X	X	X	X
NordFoU	Nordic Council	X	X	X	X	X	X	X
BRA - Baltic Road Association	EE, LT, LV	X	X	X	X	X	X	X
D-A-CH	AT, CH, DE	X	X	X	X	X	X	X
Horizon Europe	EU			X	X		X	X
Connecting Europe Facility	EU	X	X	X	X	X	X	X
LIFE	EU			X	X			
CHARM	BE-VL, NL, UK						X	X
Benelux Union	BE, LU, NL	X	X	X			X	X

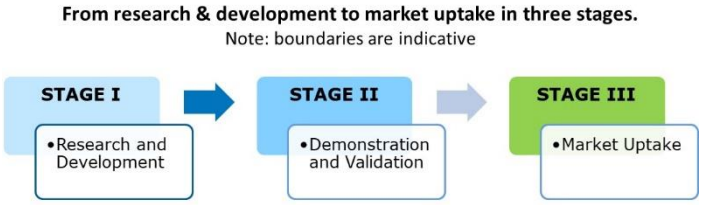
The overviews are by no means exhaustive but nevertheless provide a sound first basis for effective coordination and collaboration in Europe. Individual research and innovation projects are excluded from this overview, due to the large scale of European and national projects. It is clear that list of relevant programmes and initiatives needs to be updated regularly.

Deliverable D2.3 '*Effective collaborative structures and schemes for cross-modal, transnational information transfer and cross-fertilisation between innovation programmes and initiatives*' presents these programmes and initiatives in more detail.

3.3 Timelines for innovation delivery

The timelines for innovation and implementation distinguish between three stages that are related to ranges in the technology readiness level ladder (see figure)

Following overview presents the indicative timelines for the NTIA priorities for innovation and implementation (topic titles only).



IFA	Priority towards 2025	Until 2025	Until 2030	Until 2035	Until 2040	Until 2050
1.1/ 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
1.3	*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			

The overview indicates that most of the NTIA priorities are directed at either research and development (Stage I) or demonstration and validation (Stage II). Notwithstanding the relevance of research and development, the current strategic ambitions, objectives and impacts that EC and member states are envisaging for the next multi-annual financial framework (MFF) for 2021-2027, indicates that the focus in the timelines should be 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).

3.4 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[3] 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 in their power to remove barriers for innovation and deployment and where opportune accommodate industry and research in their activities to deliver validated innovative solutions.

[3] The i4Df initiative focuses on (commonalities in) the management of tangible infrastructure networks for surface transport in which 'infrastructure' is defined as the physical ('hard') and organisational ('soft') structures and facilities 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.

In this context the following measures are considered necessary:

- **Broaden NTIA endorsement for the i4Df results:** In the i4Df initiative, infrastructure authorities from 17 member and associated countries collaborated to deliver a common description of innovation needs over the next decade. Though this is a significant setting by itself, the number of NTIAs in Europe is far bigger. It is essential that this wider setting of NTIAs also endorses the delivery of the coordination mechanism and find it an inspiration to build from, thus providing the continuity and gravitas beyond the runtime of the i4Df initiative (until 30 September 2020). Their endorsement will reinforce necessary confidence from the industry and supporting research to invest in a structured demand and supply side dialogue with the NTIAs as procuring clients for innovation.

- **Emphasise demonstration and validation activities (TRL 8-9):** In their common and concerted innovation agendas and programmes, the NTIAs should emphasise demonstration and validation of innovations picking up from advanced prototyping and preliminary business casing (i.e. TRL 6 to 7) noticing these activities have a timeframe of 3 to 7 years, depending on the complexity and risk at hand. Picking up from lower TRL levels should not be excluded, but NTIAs should be aware that bringing these to TRL 9 will take many more years.

- **Identify large scale TEN-T testbeds:** A key enabler for demonstration and validation actions up to pre-standardisation (i.e. TRL 9) is providing adequate economy of scales for both the NTIAs as the procuring client, and industry as the lead supplier of innovation.

  In order to build these (European) scales, groups of NTIAs should to commit and identify to providing appropriate sections on their combined (TEN-T) networks that industry and research can use for demonstration and validation.

  Such collaborative testbeds can build on the various existing EU-regional cooperation frameworks and initiatives, such as Nordic Council, Benelux Union, etc. Combined TEN-T testbeds should offer a representative image of the possible issues from policy, economy, society, technology, legal and environment in European infrastructure management.

- **Converge towards collaborative programme governance and management:** Over time, the IFA collaboration ecosystems will build up a significant portfolio of innovation and implementation activities. Along with their enduring collaboration, mutual understanding and trust will build which in turn enables a further collaboration, such as on twinning and co-programming as well as for collaborative knowledge exchange, sharing, and transfer through various events. This transition can only be effective if the NTIAs converge towards collaborative programme governance and management that is open, transparent, and agile.

- **(Co-) fund NTIA collaboration from EC framework programmes.** In order to foster the emerging IFA collaboration ecosystems it is important that the Horizon Europe and CEF/TEN-T framework programmes envisage (co-) funding trans-European sharing and transfer of results from demonstration and validation activities (e.g. common frameworks, guidelines, specifications, pooled expertise). For example, this could concern translations into the national language which is key for effective dissemination of the knowledge into the operational processes of infrastructure management across the TEN-T network.

Other examples include (co-) funding of travel and lodging of relevant stakeholder experts (in particular from EU-13) in order to ensure the corresponding expenditures are not a barrier for their participation.

Furthermore, (co-) funding may be considered for setting up dedicated scientific and business boards to advise the collaborating NTIAs in their decision making about ensuing stages in the concerted innovation delivery process (e.g. assessing state of the art).

- **Provide European anchor points for high level NTIA and stakeholder support and commitment**. It is imperative that the interlacing CEF/TEN-T days and TRA events serve as tier 1 level anchor points in time for the combined innovation collaboration activities. Together with the previous measure on the required synergies between respectively CEF (implementation) and Horizon Europe (innovation development) on the agenda, this will provide strong incentive for high level management from NTIAs and their relevant stakeholders to attend.

  Such set-up would also enable improving synergies and coherence with relevant tier 2 European events (such as on ITS conference), and with relevant tier 3 events on the national and regional level.

- **Build a NTIA coordinated, common information base of proven innovations**. As the NTIAs across Europe show a relative spread in organisational maturity levels, it is key to foster a common information base with relevant results from the rolling portfolio of innovation activities. Such reference should not only foster the paradigm of “learning from each other’s strengths” in effect narrowing the spread between the NTIAs. In addition it can offer broad support for various dissemination, direction and decision making on all levels of activities; from strategic to operational. In line with the demand driven nature of the i4Df coordination mechanism, this reference basis should be coordinated/governed by the collaborating NTIAs.