Transport infrastructure capabilities for 2040

A common innovation ambition of transport infrastructure managers in view of their investment challenge

Version: Draft for i4Df GB members

Date: 29 April 2019

Executive summary

A well performing transport infrastructure network is essential for achieving the European ambitions and goals on competitiveness, growth and jobs, achieve alignment with the UN Agenda 2030 and related sustainability goals, which the EU has played an important role in shaping. Infrastructure is essential for the prosperity of Europe, especially in the peripheral areas. Its sustained provision in reference to the demands and requirements from the economy, society and environment poses a major investment challenge to the public infrastructure owners and managers. This investment challenge is the key driver for the infrastructure managers' ambition to cooperate on infrastructure innovation and implementation actions, starting with the next multi-annual financial framework of the European Commission (2021-2027).

This document presents the reference base for further elaborating on this cooperation ambition: a common, systemic vision on surface transport infrastructure capabilities for 2040 and the main innovation areas that need to be evolved in order to reach the capabilities. The infrastructure capabilities and the innovation focus areas (IFAs) will serve as a guiding framework for structured, demand driven cooperation and collaboration between infrastructure managers, innovation programme owners, relevant industry and supporting research on infrastructure development, innovation needs and their implementation actions.

The document starts out by providing a demarcation of infrastructure, followed by a presentation of the three infrastructure capabilities for 2040 and their respective guiding objectives. The main part of the document presents 14 IFAs for the period until 2030. It concludes with a summary of requirements for professional competence development.

This document will be developed in steps. The current version reflects the outcomes of a consultation with infrastructure managers and the European Commission on 11 December 2018 (1st i4Df high-level Stakeholder Conference) and European experts from 16 countries during the 1st i4Df Expert Workshop (25-26 February 2019). The current version of this document is a preparatory document for the 2nd i4Df GB meeting that will take place 2-3 May 2019 in Thessaloniki, Greece.

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

Introduction

The coordination and concertation of infrastructure innovation and implementation across the portfolio of EU and transnational programmes and initiatives will be done from a reference to future 'capabilities' that infrastructure managers expect to provide to the end user and society as a whole. Although presented here as independent entities, the following set of three capabilities work interdependently:

Infrastructure optimally meeting end user needs. The ability to provide the optimal transport infrastructure network capacity in order to accommodate ever 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 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).

In the following sections of this document, first a demarcation of infrastructure management is presented, followed by a description of each of the three capabilities in terms of guiding objectives for 2040, the corresponding innovation focus areas (IFAs) that are key to achieving these objectives, and a first indication of professional competences that need to be developed alongside the innovation development and implementation.

The description in this document is aggregated at a strategic level as to support awareness, understanding and support at decision making levels. Further elaboration of the IFAs (in terms of specific challenges the infrastructure managers need to address, the expected impacts and the corresponding topics) will be achieved by engaging with a wide community of experts, starting with the discussions at the 1st Expert Workshop.

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Demarcation of Infrastructure Management

In the i4Df initiative, the focus is put on transport infrastructure innovation and implementation for road, rail, waterborne and airborne transport of passengers and goods. As one of three components of the transport system, the trend for infrastructure management is towards rapidly growing interdependencies with vehicles, logistic and mobility services. As a consequence, the boundaries within the system become increasingly blurred. From this perspective, any demarcation of infrastructure management should be considered with appropriate flexibility. From this, a priority is on understanding these interdependencies and corresponding cross-cooperation and collaboration with the other stakeholders.

Demarcation and geographical setting

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, railways, waterways, or less tangible such as is the case with air and sea corridors. The initiative focuses on 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 terms of geographical setting and functionality, the initiative focuses on the TEN-T comprehensive networks (links and nodes), including relevant supporting sections of the non-TEN-T networks that carry most of the traffic and are strategically most important (e.g. also in the context 'military mobility'). Airports and waterborne ports are regarded as singular nodes in the network with focus on accessibility, availability and reliability of the (inter) links.

These urban and economical nodes have an essential role in enabling effective and efficient distribution of passenger and freight flows across the multimodal European transport area. They can be of different scale and organisation but are typically set in the densely populated areas and economic centres of Europe. The utilisation of these nodes is usually to the maximum service capacity, i.e. highly congested.

The **end user** of the infrastructure network includes the **direct user** of the network and **stakeholders** who provide services and data for information to the direct users.

Key trends, drivers and enablers for 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 well informed movement of passengers and freight from origin to destination across different modes. Key challenges to this service provision are: the requirements of **replacement** and **renewal** ; the intense competition for **space** and fiscal **budget**; demands and opportunities from **digitalisation** for economy and society; the sensitivity to economic and social pressures from **disruption** (e.g. end of life cycle, natural and manmade events); **liveability** and **sustainability**; adaptation to **climate change;** and the opportunities to **synergise** with **data** and **energy** network management (e.g. with TEN-E, the Trans-European Networks for Energy, in greening the transport energy pool).

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 organisational structures. For example, the impact of digitalisation 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, digitalisation will drive new, currently unknown business models which subsequently will drive profound changes in societal attitudes and behaviour, in turn affecting the current role and position of infrastructure managers.

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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.

Guiding objectives for 2040

- Full accommodation of the anticipated development in transport demand across the network, achieving effective alignment between the surface infrastructure networks through interoperability and seamless integration between modes at every stage.
- Effective ownership throughout the whole infrastructure lifecycle, from planning and design to end of life.
- Effective, adaptive integration and implementation of innovations across the delivery process chain.
- Significant reduction of total cost of ownership (TCO), e.g. reduction of TCO by 30% for infrastructure managers.
- Achievement of zero fatalities and severe injuries of infrastructure workers and end users.
- Resilience to natural and man-made hazards, including adaptation to climate change.
- A low-cost, affordable high capacity infrastructure that supports end users' service combinations of mobility and logistics

Innovation Focus Areas

1-1 Guaranteed asset health and availability

Specific challenge:

Transport infrastructure must become more reliable with higher service quality at lower costs. This can be achieved by using new technologies to improve maintenance operations with minimum intrusion on traffic flow and exploiting "more value from data" to effectively manage the entire transport value chain through a continuous flow of information. A high level of safety for all users is key to ensuring the continuous availability of all modes. The improved interconnection of different transport sub-systems (e.g. "hard" and "soft") through "top-down" (e.g. integrated mobility management) and "bottom-up" (e.g. smart data for end users) approaches has a high potential in contributing to the guaranteed availability of transport infrastructure.

Expected impacts:

The infrastructure owners require a better toolbox to assess and balance the conflicting requirements of saving costs, improving safety and increasing the service quality for end users. There is also a potential of better testing, evaluation and management systems to give the infrastructure owners a better basis for informed decision-making. This innovation focus area strongly builds on the principle of "more value from data" to effectively manage the entire transport value chain through a continuous flow of information. Coordination on European and regional level is a prerequisite for further improvements in this area.

Potential topics:

- New technologies (e.g. new construction materials and methods) as well as testing methods and testing infrastructure to improve maintenance operations with minimum intrusion to transport flows at a low cost. Among others, this can include automated maintenance and construction, remote manufacturing of spare parts, self-healing materials and cold bituminous techniques.

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- Quality orientated process control during the whole infrastructure life cycle based on existing technical standards for sensors and data processing. Among others, this can include full remote condition monitoring, robotics and BIM using automatically self-generated data from construction processes.
- Cost efficient, safety-orientated and intelligent maintenance planning systems, including digital twins and the network categorisation to determine optimal availability levels.
- Integrated mobility management systems to ensure minimal impact on accessibility during infrastructure construction projects.

1-2 Integrated infrastructure life-cycle management

Specific challenge:

The benefits of an integrated infrastructure life-cycle management 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.

Expected impacts:

It is expected that innovations in this IFA will significantly increase the uptake and mainstreaming of life-cycle management across all transport infrastructure, especially for transnational and multimodal infrastructure.

Potential topics:

- Further social, economic, technical and environmental optimisation studies for sustainability of life cycle management are necessary which take into account all transport modes.
- The optimisation of Life-cycle costing (LCC) will allow justified investments and maintenance costs and lead to cost efficient and effective operations and the development of long-lasting structures.
- Infrastructure adapted to future needs and technologies. The development of long lasting infrastructure for future needs and to accommodate upcoming technologies, materials and construction methods will minimise future maintenance measures. From the beginning, the infrastructure has to be planned in a multi-functional manner considering cables, water pipes and further infrastructure to be installed within the infrastructure. Focus should be on the use of circular economy, i.e. recycling of materials and structures.
- Asset management system development: A self-sustaining asset management system including the focus on intermodal infrastructure needs to be designed, created and maintained. Life cycle analysis (LCA) and condition based management (CBM) are tools for the creation of predictive maintenance measures that should also include societal business cases. In this context, a performance-based approach has to be considered, i.e. actions on structures based on the introduction of a performance based standard (PBS) approach and a smart infrastructure access programme (SIAP).
- For each of these disciplines, a planning of the development in relation to the technological process needs to be created.
- For international operators, the use of national databases will become necessary and ways how to use this data have to be figured out.
- Decision making & costs: An assessment of the impact of the LCA, taking into account all different single transport modes from planning to operation and maintenance. This will allow the optimum allocation of the available budget. Ideally, this LCA needs to consider justified investments / maintenance costs of the whole life cycle as well as cost efficient and effective operations.

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Links to other IFAs:

There are links to IFA 1-1 "Guaranteed health and availability", IFA 1-4 "Responsible procurement fostering strong innovation delivery mechanisms" and IFA 3-4 "Data-driven and digitalized asset management".

1-3 Service timed to the second

Specific challenge:

Transport infrastructure has to offer the necessary service for the end user in a reliable and safe way. The predicted increase of traffic volume results in a higher urgency to plan and organise construction and maintenance work with minimum interruptions regarding duration and impact. For the 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. It is necessary to distinguish between services offered to private users and industrial use in order to define priorities.

Aim is to minimise or even prevent the end user from being affected by both any planned or unforeseen interruptions of the transport network and to ensure reliability, maintainability and safety of an integrated network.

Expected impacts:

Real time service approaches with risk-based scenarios and strategies will meet the expectations of the end users in regard to faster reaction times of the overall operation and maintenance of transport infrastructure. These approaches will help to significantly reduce and limit interruptions on the transport network. A high flexibility and a close cooperation between road and rail will allow syncro-modality through the multi-modal infrastructure by the combination of the potential of the single modes resulting in an optimal use of the whole infrastructure network.

Potential topics:

- Intelligent prediction of maintenance: Models for a systematic cross modal and cross border infrastructure management have to be developed to achieve a proactive network maintenance planning, avoiding unplanned maintenance measures and developing sound alternatives for the overall traffic volume. BIM modelling (potentially also including moving objects) is a strong instrument to support the forecast and planning of construction as well as an instrument for the conduction of maintenance measures during the operational phase. For these different requirements, the best-fitting options need to be considered for the development of this tool.
- Accident/incident management: Predicting the probability of accidents/incidents as basis for the development of models and the application of technologies to forecast and/or to assess the impact of these events. New technologies for the early detection of damages and deterioration and emergency plans for timely interventions have to be developed from both a cross-border and cross modal perspective.
- The concepts of "forgiving infrastructure" and "self exploring infrastructure" are principles to be further developed to minimise the impact and the duration of disturbances on the traffic infrastructure network. The use of artificial intelligence (AI) and related methods and processes will support to achieving the intended goals.
- Use of big data: The use of big data is a tool helping to develop practical solutions for the management of mobility. The use of data from end-users and their evaluation has to be taken into account for the further development of predicting real time specific detouring navigation advices to calculate and suggest user specific routing. Inter alia swarm intelligence can be used to reach these goals. Investigation of vehicle data supports the detection of damages that occur spontaneously. Data openness need to be considered.
- The approaches of the Shift2Rail initiative (aspect: "Service operation timed to the second") and the systemic approach of the railway network used for its operation, construction and maintenance should be investigated on their potential transfer and application in the road network. The rail mode is based on the principle that railways are a system of systems.

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- Sound coordination of all phases of planning activities of the various stakeholders by means of precise simulation including an outlook on operation (principle of digital twins).

Links to other IFAs:

There is a link to IFA 1-1 “Guaranteed health and availability” that includes infrastructure asset management from a construction perspective taking into account the concept of digital twins.

1-4 Responsible procurement fostering strong innovation delivery mechanisms

Specific challenge:

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:

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, 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.

Potential topics:

- 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.
- Innovative risk sharing and management approaches could provide suitable models to share risk between infrastructure owners, end-users, designers (e.g. design-build tenders) and contractors.
- In order to encourage innovative practices in contracts, innovations need to be assessed (e.g. simulation models) to optimise procurement processes. The use of proof of concept demonstrators for innovations will also facilitate and speed up procurement and deployment procedures.
- Linked to procurement processes are also innovative financing approaches to raise funds for new infrastructure investments.

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1-5 Key Performance Indicators to meet the end user's mobility and logistics needs

Specific challenge:

Transport infrastructure owners and their end users are currently facing a rapid change in the mobility and the transport infrastructure sector. Digitalisation 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 that enable more informed decisions about the services infrastructure owners provide or journeys end users take. Further, end users are also becoming more conscious about the use of the transport infrastructure and they put more value on aspects such as sustainability or access to digital services whilst using the infrastructure. Hence, it is clear that infrastructure owners need to broaden their understanding of end user needs (i.e. mobility and logistics) in order to provide services that are satisfactory to them. From an end user perspective the division line between modes (incl. new mobility services like MaaS) will become more blurred as the smart phone will become the main tool to influence daily mobility decisions.

Current key performance indicators (KPIs) and assessment techniques that are being used by infrastructure owners to measure end user needs do not reflect accurately the described changes. New KPIs are required that reflect the changing relationship between infrastructure owners and their end users. This puts infrastructure owners into the position to have a dynamic relationship with end users that results in better services and shapes the needs of end users.

Expected impacts:

Innovations in this area will facilitate infrastructure owners to become institutionally prepared to meet emerging end users' mobility and logistics needs. Among others, this will result in the development of new multimodal KPIs, data collection approaches, and analysis techniques and assessment tools.

Potential topics:

- Infrastructure owners need to develop updated definitions of their end users and their changing needs until 2040. These need to recognise 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.
- Current KPIs need to be thoroughly reviewed and updated. This includes the actual definition of the KPIs, their measurement techniques and the threshold values. The KPIs should reflect a wide set of end user needs, also including needs from the logistics sector. Market observations and big data (i.e. more value from data) could also be used to anticipate user needs.
- Implementation of services to provide synchro-mobility solutions, e.g. synchro-modal journey planning, tools for users including travel costs and reliable traffic info, and logistics related topics. This requires a clearer understanding of the data formats required and the use of new data sources (e.g. in-vehicle data provision).
- Solutions for interoperability with logistics planning and electronic transactions (e.g. block chain) along the logistics chain.
- Dynamic management of KPI's to regularly adjust to changes in user needs.

Links to other IFAs:

There are links to IFA 1-2 "Integrated infrastructure life-cycle management", IFA 1-3 "Service timed to the second" and IFA 3-4 "Data-driven and digitalized asset management".

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1-6 Strategies and approaches for ensuring optimal safety, security and resilience of the infrastructure network

Specific challenge:

Serious events such as disasters and terrorist attacks illustrate the importance of improving the safety, security and resilience of transport infrastructure. It is therefore necessary to engage in a holistic examination and appraisal of the transport infrastructure to establish the degree to which mechanisms are in place for preparing and planning for, as well as coping with and adapting to unexpected and adverse events, and making the infrastructure operational again as quickly as possible.

In the context of transport infrastructure, operators strive to ensure that transport assets and services function continually and safely in the face of a range of existing and emerging hazards. An effective risk assessment needs to be performed in both categories of events, natural disasters and terroristic attacks, by the Transport Infrastructure Manager. This has led to a specific focus on the concept of resilience and how this can be defined, measured and improved across the transport system. Following the results of this risk analysis, proactive measures to prevent these threats may be planned and taken, but also, mechanisms 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.

Expected impacts:

Significant improvement of transport infrastructure resilience to man-made and natural disasters. Achievement of zero fatalities and severe injuries of infrastructure workers and end users due to maintenance and construction works.

Potential topics:

- Intelligent construction site planning taking into account the effects on traffic safety of workers and passengers: The Intelligent Transportation Systems can be used to improve traffic flow and safety on roads by work zones: network cameras, traffic sensors, VMS and alert flashing signs. These innovative tools are established to reduce work zone-related congestion and improve safety. They provide delay and speed information to warn motorists of slowed traffic ahead and encourage diversion. Smart lighting, changeable speed limits may also be used to improve safety. Automated construction equipment will diminish construction and road closure time.
- Holistic consideration and assessment of the resilience of the transport infrastructure using risk-based approaches: Risk assessment is indispensable in order to identify threats, assess vulnerabilities and evaluate the impact on assets, infrastructures or systems taking into account the probability and the severity of the occurrence of these threats. Proactive engineering measures need be taken after a comprehensive risk assessment for every transport infrastructure segment. Moreover, innovative technological tools, such as satellite information systems (GNSS), early warning and public awareness digital panels, radio channels and digital telephony, are some of the potential means to mitigate the impact of natural hazards. The holistic consideration includes measures taken prior to an event, mechanisms addressing an incident under real-time conditions and recovery actions.
- Vulnerability analysis for infrastructure elements. Identification of critical elements: Vulnerability may be comprehended as the susceptibility to the damaging effects of a hazard. Specific vulnerability assessment for all critical elements, especially tunnels, bridges and intersections, must be carried out with regard to natural hazards: earthquakes, floods, landslides, storm surges. Intelligent monitoring may be effective with view of planning proactive measures. The INFRARISK project identified bridges, tunnels, earthworks (embankments and cuttings), retaining walls, road pavements, railway tracks and drainage systems as decisive civil engineering assets to provide safety and availability of land transport infrastructure.
- Dynamic safety management systems for motorways, bridges and tunnels: There is a growing trend in development and application of real-time crash risk prediction models within dynamic safety management systems. These real-

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time crash risk prediction models are constructed by associating crash data with the real-time traffic surveillance data, collected by loop detectors. The objective is to develop real-time prediction models that will potentially appraise the traffic safety condition of a motorway. Application of these prediction models to bridges and tunnels, most vulnerable assets of transport infrastructure, is a challenge for road operators.

- Online security analysis and risk assessment for real-time recommendations for tunnel operators and tunnel control centers: Flexible, modular and innovative systems comprising detection sensors and risk assessment models are the core elements of new methods to prevent incident risks in tunnels. These methods help to pool the data as well as perform real-time analysis, plausibility checks and evaluation of safety-relevant data from various detection systems. Common traffic information and innovative detection data will be combined, merged and prioritized in real time. Through the integration of conventional and new detection technologies, such as infrared technology, Automatic Incident Detection (AID), or video detection, into the existing monitoring system of road tunnels, an optimization can be achieved, especially in the field of prevention.
- IT-security of tunnel and traffic control centers and strategies for improvement and protection: Industrial Control Systems (ICS's) in the Transportation Sector include supervisory control and data acquisition (SCADA) systems, distributed control systems (DCSs), programmable logic controllers (PLCs), and general-purpose controllers (GPCs). Most ICSs began as proprietary, stand-alone systems that were separated from the rest of the world and isolated from most external threats. Today, widely available software applications, Internet -enabled devices and other non-proprietary information technology (IT) offerings have been integrated into most ICSs. This connectivity has delivered many benefits, but it also has increased the vulnerability of these systems to malicious attacks, equipment failures, and other threats. As a rule, ICSs must operate continuously and reliably, often around the clock. Unlike IT systems (which process, store, and transmit digital data), ICSs typically monitor the system environment and control physical objects and devices, such as switchgears, message signs, and valves; these devices are often located in remote locations.

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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.

Guiding objectives for 2040

Optimal contribution to climate change mitigation

- Facilitate the energy transition of the surface transport system. This concerns the transition in the energy pool of the transport modes and supporting measures to improve energy-efficiency of mobility services (passengers, freight).
- Minimise carbon footprint of the whole service-life of infrastructure, including the infrastructure delivery process chain.
- Achieve energy neutrality of the infrastructure management process. This concerns overall energy balance of the daily operational processes, e.g. lighting, signalling, data collection, information provision, lifting and ventilation.

Optimal contribution to liveability

- Collaborate on the minimisation of 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.
- Compliance with COP21 and Agenda 2030/UN targets for sustainable development in the context of European objectives and targets.

Innovation Focus Areas

2-1 Resource efficient manufacturing, construction, operation and deconstruction

Specific challenge:

The transport infrastructure authorities need to contribute to the transition towards a circular and decarbonised society. This requires innovative, integrated approaches and strategies ensuring minimal reliance on non-renewable resources while securing a high degree of performance, efficiency and sustainability for the entire manufacturing and delivery chain.

Expected impacts:

Successfully addressing this challenge requires large scale transformations in which the public infrastructure authorities and industrial parties join forces to achieve the appropriate economy of scales from common objectives and perspectives. The innovation focus is on delivering a validated, next level suite of models, methods and data.

Potential topics:

- Frameworks and strategies for the distribution of costs, benefits and risks across the actors in the manufacturing and delivery chain.
    - Approaches to consider deconstruction/recycling during the planning and design phase of the lifecycle.
    - Approaches to enhance the reuse or recycling of construction materials at minimal (energy) costs while complying with technical requirements.

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- Practical common toolbox for applying circular economy principles at low carbon energy costs

  On the short term, innovation activities should focus on delivering a common toolbox of practical guidelines and specifications, building on the principle of learning from each other's strengths, utilising the various available good practices. Following the focus should be on delivering the (validated) next generation of these tools.

  - Methods for manufacturing, refurbishing or rehabilitating transport (related) infrastructures with the objective to significantly extend functional life spans of infrastructures.
  - Performance-based design models and manufacturing techniques (e.g. 3D-printing) with the objective to substantially reduce materials consumption.
  - Common ecological assessment methods and models for alternative materials.
- Assessing the sustainability of scaled-up approaches integrating circular economy principles

  Applying circular economy principles does not necessarily translate into more sustainable practices. Robust life-cycle assessments are needed to support the deployment of innovative solutions. Hence the following shall be pursued:

  - Development of common databases related to (but not limited to) hazardous substance contamination/release, carbon footprint, energy and virgin material consumption over infrastructure service-life.
  - Harmonisation of calculation protocols and tools for life-cycle analysis ensuring transparency, comparability and reliability of assessment results.
- Developing methods, models and guidelines for sustainable procurement practices
  - Public authorities' involvement is key to a successful transition of new approaches into practice. Procurement practices shall evolve to foster a strong, stable demand for low carbon, resource efficient solutions. Accelerating these changes calls for the widespread development and promotion of methods or guidelines in public procurement building upon the latest scientific/technical/organisational advances and needs to helping innovative companies to reach proper economies of scale for a wide diffusion of best technologies/practices.

2-2 Advanced strategies and approaches for accommodation of the energy transition in transport infrastructure.

Specific challenge:

The transport system is committed to deliver its share in achieving the COP 21 targets. In addition, infrastructure management operations hold significant leverage on the energy transition and efficiencies in transport means (e.g. electrification, renewable energy) and transport operations for passengers and freight (e.g. through intelligent traffic management). Further on, the surface area and adjacent areas of transport infrastructure offer opportunities for harvesting energy. As part of the energy transition, energy efficiency is an important measure to reduce greenhouse gas (GhG) emissions, especially in infrastructure construction industry and operation. Infrastructure authorities across Europe and beyond already invest in innovations concerning energy efficiency, energy harvesting and the integration of energy (transport) systems in the transport infrastructure. However, this mostly occurs on a small case by case or pilot manner.

The biggest challenge here is combining the needs for roads and mobility with the needs and business models of the energy systems and energy sector. Therefore it is crucial to include the new stakeholders as partners (TSO and DSO[1], as

[1] TSO, Transmission System Operators (in NL, TenneT) and DSO, Distribution System Operators (in NL, Alliander, Stedinetc)

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well as producers) in the process in a systematic way. But it also implies that road authorities should be prepared to participate in climate and energy initiatives as one of the stakeholders, and need to communicate the needs and characteristics of the transport sector clearly in order to come to safe and sustainable solutions.

There are links to other the IFA 1.2 Integrated infrastructure life-cycle management, IFA 2.4 Advanced approaches and strategies for the integration of (urban) nodes in the TEN-T networks – multimodal, multi-scalar, and multi-objective, IFA 3.1 Managing the transition towards the accommodation of automated transport on road, rail and waterways infrastructure and IFA 3.3 Secure and resilient data and information provision across the multimodal, transnational network (road, rail, water, air) for all users.

Expected impacts:

- The closer integration of the strategic transport networks with the strategic energy networks on European, national and regional level.
- The increased production of renewable energy on transport infrastructure‘s assets.
- The seamless legislative integration of the new processes.
- The reduction of energy consumption by more efficient technological operations, e.g. while operating tunnels (LED technique) or maintaining roads.

Potential topics:

- Preparation of transport authorities for the energy transition:
- Integration of refueling and recharging infrastructures for electric vehicles, including energy logistics at rest and parking areas.
- Adaptive lightning systems to reduce energy consumption based on traffic volumes, luminance external values and road characteristics. Use of alternative ways to reinforce luminance at the entrance of tunnels by deploying natural light through mirrors and wave guides.
- Identification and assessment of the potential of harvesting renewable energy on infrastructure and its verges and assessment of the related challenges, e.g. impacts on land use.
- Assessment of the contribution of vehicles to storage capacity (vehicle2grid).
- Strategies for eco-efficient traffic flow management across corridors and routes.
- Energy management of the transport process, including cross-modal alignment and investments of the transport network in respect to the energy network.
- Foster best practices as new standards and share a cross-modal strategic programming approach:
- Development of supporting policies, including the fostering of new or harmonisation of existing standards.
- Support of the social acceptance of the transition process.
- Examples of partnerships of road authorities and TSO/DSO to foster shared standards.
- Facilitating modal shift towards „low energy“ transportation

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2-3 Collaborative strategies and approaches to minimise environmental impact

Specific challenge:

Minimizing environmental impact of the transport system requires innovative approaches and strategies that aim on establishing effective collaboration between transport means, logistical and mobility services and Infrastructure management.

Innovation focus is on the reduction of noise and vibration, reduction of pollutants to air, soil and water, and preservation of habitat and biodiversity.

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.

Potential topics:

- Reduction of noise and vibration: Main focus has to be laid on the emissions from wheel-surface contact (source measures), but also noise abatement techniques (next generation noise barriers) and advanced traffic control and management strategies have to be considered. It is further necessary to improve the understanding of the impact of noise on human health (dose-response relationships).
- Implementation of a BIM system for noise measurements: Creation of appropriate tools to manage the design, implementation, operation and maintenance of noise mitigation measures, simulating noise perception (immersive virtual reality) to test the effectiveness of noise mitigation measures and of noise impact as a whole for environmental impact assessment.
- Reduce costs of noise mapping activities: Automation of the process of noise mapping, considering the possibility of using mobile phones could help to improve the accuracy level of noise maps.
- A large monitoring network, interconnecting public databases and further information systems (noise, air quality, traffic and meteorological data) would allow to achieving an overall view of the environmental impact.
- Reduction of emissions or transport to air, soil and water: This topic focuses on the emissions of NO_x, PM10, PM2.5 but excludes CO_2 emissions. The consideration and development of new pricing techniques unified on European level) based on pollutant emissions (noise, air, water) will lead to a re-thinking and the investigation of possibilities to mitigate air pollution directly at the source (smaller cars, gas treatment, brakes made of different materials).
- Treatment of emissions: Explore and implement the possibility to keep treatment options as natural as possible, taking into account the related space consumption and considering biodiversity. The implementation of on-site water run-off treatment using the local soil in the existing network should be facilitated for both the road and rail mode.
- 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 connecting 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.
- Use of new techniques: Drones have the potential to change the system delivery of freights. The necessity for more space for parking drones has to be investigated, taking into account their emissions (noise) and new safety questions.

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2-4 Advanced approaches and strategies for the integration of (urban) nodes in the TEN-T networks - multimodal, multi-scalar, and multi-objective.

Specific challenge:

The European transport infrastructure system holds significant prospective efficiencies in accommodating the transport demand whilst addressing the challenges from economy, society and environment. Current practices in planning and design are typically focused on one specific infrastructure layer (i.e. local, national or international). This results in a situation where each planning entity only acknowledges to a limited extend that the subject under attention is part of a larger and dynamic system. This current practice has a significant impact on multimodality for passenger and freight, and how innovations are being deployed on the network.

Expected impacts:

Innovations in this area could lead to a better integration of varying planning levels to achieve a better performance of the TEN-T network and accessibility of urban nodes. This will reduce the need to allocate additional space for transport infrastructure and enable the more efficient use of the existing space already allocated to infrastructure. End users will improve their understanding and appreciation of the net benefit of transport infrastructure across various levels for economy, society and environment.

Potential topics:

- Mutual understanding and identification of innovative synergies among priorities at local, regional, national, European and international level.
- Smart networks and green planning of infrastructure. Involvement and participants of end users in the planning processes for transport infrastructure across different layers.
- Understand the impact on planning processes of the emergence of new, more sustainable transport business models for passengers and freight.

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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.

Guiding objectives for 2040

Full accommodation of connected and automated mobility, maintenance, and construction concepts on transport infrastructure

- Facilitate the transition towards smart mobility concepts (freight and passenger) for emerging concepts for automated mobility, e.g. Connected Cooperative and Automated Mobility (CCAM) for road and Automatic Train Operation (ATO) for rail.
- Use automated, semi-automated and remote-piloted solutions for infrastructure maintenance and construction to improve safety for workers and reduce costs.
- Proactively define the capabilities of infrastructure in the accommodation of automated and connected mobility, maintenance and construction solutions.

Optimal position in evolving data-driven infrastructure management processes

- Proactive position of the infrastructure manager within the infrastructure related data-driven ecosystem, including clearly defined data flows between multimodal, -national and -sectoral stakeholders.
- 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.

Physical, digital and virtual infrastructure aligned with data networks and energy grids.

- 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.
- A clear business model and case for investment in and maintenance of digital and virtual infrastructure.

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Innovation Focus Areas

3-1 Managing the transition towards the accommodation of automated transport on road, rail and waterways infrastructure

Specific challenge:

The entire mobility system is currently in a transition phase towards higher levels of digitalisation: 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 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 are currently facing:

- The position of the infrastructure owner within the value chain and governance structure of the deployment of connected and automated vehicles is subject to cross-sector (i.e. OEMs and infrastructure owners) agreement and alignment. Potential roles range from regulator, infrastructure provider to service provider.
- Understanding the impact of connected and automated vehicles from the perspective of infrastructure owners' core business activities, such as road safety, traffic efficiency customer service, maintenance and construction.
- Understanding the role of the infrastructure owner as the contributor and manager of the ODD that different types of CAVs will operate in. A clear business case for infrastructure owners to optimise the ODD through changes to the physical and digital infrastructure is still missing
- A multitude of research and innovation activities will be required to tackle the stated challenges. Even though there are numerous CAV research projects and test sites, they are often not looking at the needs of the infrastructure owner. Current research activities on impact assessment of the deployment of connected and automated vehicles have mainly focused on the perspective of the vehicle manufactures and wider societal issues.

Expected impacts:

Innovations in this area will facilitate infrastructure managers to become institutionally prepared 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 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.

Potential topics:

- The investigation of the new and evolving role of the infrastructure owner in the context of the deployment of connected and automated vehicles. The role requirements include, among others, the supervisor of digital governance, strong stakeholder position in the value-chain of connected and automated vehicles, and an evolving of a sustainable business model for accommodating connected and automated vehicles. The new role will be based on a skilled workforce that is able to tackle the accommodation of connected and automated vehicles.
- The development of an impact assessment assessing the impact on the core business activities of infrastructure owners. The impact assessment needs to consider the evolving penetration rates of passenger and freight CAVs

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fleets. The results needs to provide clarity on the limitation of the current infrastructure (incl. tunnels and bridges) to derive approaches (e.g. limiting platooning on structurally weak infrastructure) to tackle potential side effects of the CAV deployment.

- Formulation of digital infrastructure requirements and the related business case for the deployment of connected functionalities.
- Identification of CAV functionalities that can support the core business activities of infrastructure owners, e.g. the use of CAV sensor data to collection data about infrastructure condition.
- Broaden the range of CAV testing activities to better consider the needs of the infrastructure owners. Testing the use of CAVs in infrastructure owner fleets, e.g. for safety vehicles during road construction.
- The newly developed “Infrastructure Support Levels for Automated driving” (ISAD), which strongly focuses on the needs of the infrastructure owners, is a first vital step in defining different ODD infrastructure classifications that can support the accommodation of connected and automated vehicles. The classification needs to be developed further to include wider aspects that consider the needs of infrastructure owners. This can also include aspects such as digital twins (e.g. OpenDrive) that can be used for the navigation of CAVs.
- Development of test facilities and processes that cater for the research needs of the infrastructure owners.

3-2 Advanced approaches and strategies for automated construction, maintenance, strengthening and inspection of infrastructure by artificial intelligence

Specific challenge:

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. The following three different areas, which have their own specific challenges, can be identified in this IFA:

- Robotization in infrastructure will mainly be used for equipment to do heavy operation without using man power. Before 2030 remote control of individual machines by means of “joy stick”-operation will be available and after 2030 gradually remote control of the complete work from a control room will become available. In this end situation the construction/maintenance process could potentially be completely driven by software-applications, which will also be capable to correct small deviations from the pre-programmed job execution. For bigger deviations control room operators are needed to intervene.

  Standardising, modularising and industrial prefabrication of large percentage of the infrastructure and the use of 3D-printing techniques will ease the way to automate most construction, repair and retrofitting projects. Further, the use of BIM can be seen as a precondition for the deployment of robotised equipment.

- 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. There is a challenge that sensors in the infrastructure might have a shorter lifetime than the infrastructure itself.

- Data interpretation by AI can both improve the maintenance/construction process and improve the determination of the correct maintenance moment. AI is only possible if BIM or other equivalent techniques are available and reliable. It is assumed that a data authority is required to regulate availability and reliability of

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both data and the analytical tools. The transition from quality control based on fewer measurements to AI of less accurate but continuous measurements will require induce changes in construction standards.

Expected impacts:

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, pillars etc.) and (almost) continuous and instant monitoring opens the doors to very accurate big data analysis. The governance structures of infrastructure managers will be adjusted to include AI into decision-making processes across the entire organisation.

Potential topics:

- 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 BIM, modular construction, mobile factories, 3-D printing, and Augment Reality and Virtual Reality can support wider robotization of construction 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 and data exchange procedures will enable infrastructure managers to exchange data with contractors along the value chain.
- Infrastructure managers need to review legal requirements and organisation 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.

3-3 Secure, resilient and smart data and information ecosystem across multimodal and transnational networks for all users

Specific challenge:

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. Key challenges include:

Infrastructure owners are already major producers and managers of data that use sophisticated systems that have been developed over decades. The key challenge for infrastructure owners is to connected legacy systems to the evolving multimodal and transnational data sharing eco-system. In this context the role of the National Access Points (NAPs) in enabling infrastructure managers to benefit from and provide data to a multimodal and transnational data sharing eco-system needs to be explored further.

Infrastructure owners have access to a wide range of data sources, but new data sources (e.g. crowd sourcing information about construction sites) are becoming available that enable new forms of data analysis from within the organisations, but also external actors take a more dominant role as data providers and analysts. The key challenge for infrastructure owners is to ensure a high data quality and the certification of external actors to process and analyse data for infrastructure owners and managers. This challenge also needs to be seen in the context of the evolving use of artificial intelligence for data analysis and decision support.

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Expected impacts:

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).

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

Potential topics:

- 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 cooperations across institutional, modal and national boundaries.
- Investigate the role of the NAPs in enabling infrastructure managers to benefit from better data collection and management, including the development of approached for meta-data catalogues, data quality standards, data security, data source certification and licensing.
- The integration of legacy systems for data management into the evolving multimodal and transnational data ecosystem.

3-4 Data-driven and digitalised asset management

Specific challenge:

Integrated infrastructure life-cycle management involving planning, construction, operation and eventually decommissioning is widely accepted as an ideal and sustainable approach, but the deployment needs to be facilitated further.

Traditional infrastructure management has been based on visual inspections along with random spot checks of e.g. material quality, but for many years there has been an ongoing evolution 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 BIM-system, which is also capable of handling risk management procedures.

Infrastructure data used to be generated and treated internally by the infrastructure owner, but 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.

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.

Potential topics:

- The use of AI to process and interpret infrastructure data, especially for data that has previously been labour intensive and time consuming (e.g. GPR-data, crack and damage detection from photos).
- Incorporation of data from sensors mounted in vehicles, trains and vessels along with data from external sources (e.g. from mobile phones) into Asset Management Systems.

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- Data management and processing. Smart systems to make better use of data that already exists but is not used intelligently in infrastructure Asset Management. Identification of new and yet unused data sources and new combinations of data to facilitate identification of damages and structural problems.
- Development of measuring systems and systems for data processing to facilitate the creation of BIM models (digital twins) for the existing infrastructure.
- Cross-modal data management and combined BIM models for road, rail and waterways/ports. Identification of synergies.
- Cross-border corridor considerations (TEN-T network etc.) in relation to infrastructure data and Asset Management Systems.
- Long term ambition: Automated Asset Management System incorporating data automatically loaded from sensors, automated decision tool and maintenance action ordering.

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Required professional competences

In the context of future infrastructure capabilities, the key trend to be acknowledged is that increasing emphasis will be on the 'soft' side of infrastructure management including the people behind the operations. The above capabilities describe that the new types of collaborations are required to achieve the guiding objectives in 2040. Multidisciplinary skill sets are required as professional competencies to enable the required "collaborations".

Below is an initial overview of the multidisciplinary skill sets required from the perspective of each capability:

FROM END USERS NEEDS:

- System managers with broader competencies able to understand end user needs.
- Teams with different competencies: traditional engineers, data scientist and climate experts.
- Influence universities to educate students to be able to manage complex transport networks.
- Training courses for operators on emerging technologies, such as automation, electric-mobility, resilience, climate change and safety audits.

FROM SUSTAINABILITY:

- Education for "environmental modelling" related to the field of meteorology and environment.
- Creation of life cycle energy balances and integrated impact assessment (e.g. engineers with a deep knowledge in energy economy). Development of business cases for energy transition.
- Improvement of the general skills: Communication skills, creativity, ability to handle complex issues.
- Creation of new business models for low-cost and seamless integration of the transport and energy network.
- Creation of highly qualified multidisciplinary teams consisting of people with different education (background) and skills.
- Development of models for a cross-border exchange of best practices between the different modes.

FROM DIGITALISATION:

- Building skill sets to use data as a valuable resource.
- Enabling the workforce to cooperate with automated, robotic and remotely-piloted solutions.
- Introduce AI into decision-making processes across the entire organisation for infrastructure management.
- Build multi-disciplinary skill sets to enable cooperation within broader and more complex stakeholder structures.
- Support for the creation of start-up facilities to boost the implementation of innovation.

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