

# ROADMAP FOR CROSS-MODAL TRANSPORT INFRASTRUCTURE INNOVATION

## *TOWARDS A PERFORMING INFRASTRUCTURE*

*A COORDINATED APPROACH TO ADDRESSING CROSS-MODAL INFRASTRUCTURE ISSUES  
FOR AN INTEGRATED EUROPEAN TRANSPORT SYSTEM*



ERTRAC-ERRAC-Waterborne-ACARE-ECTP Task Force

Version: Formally endorsed by the ETPs involved

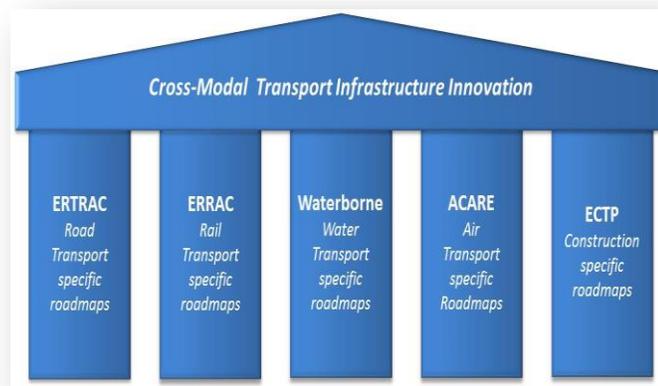
30 June 2013

## PREFACE

Transport innovation is ultimately driven by the needs of the users. Whether it is passenger or freight the needs are defined in terms of faster, cheaper or more comfortable, reliable and secure transport from origin to destination (or in more popular terms ‘from door-to-door’). These needs are independent of the modes used. In practice however, the resulting innovation is determined by an optimisation between producer capability (including technology), affordability, performance and risk. There is no case for innovation at any cost or without reference to societal constraints such as those set by policy. In their individual research and innovation agenda’s, strategies and roadmaps each of the five European Technology Platforms underpin this principle.

Bearing in mind that most if not all journeys by the transport user involve multiple modes, the Platforms also share the vision that *in addition to their respective mode-specific orientation*, there is added value to be gained by broadening them into a cross-modal perspective (see also figure). This shared vision is reinforced by the release of the White Paper on Transport, the Horizon 2020 framework programme priorities and the Strategic Transport Technology Plan. This cross-modal perspective considers the elements of transport infrastructure and the transport services and operations.

As a consequence the European Technology Platforms for road, rail, water and air transport as well as for construction (ERTRAC, ERRAC, Waterborne, ACARE, and ECTP ) in June 2012 agreed to create a joint task force in order to develop a roadmap on cross-modal transport infrastructure innovation based on, and linking, their respective agenda’s, strategies and roadmaps.



The joint task force set out on a process of extracting from the available material the research and innovation priorities in transport infrastructure research and innovation that span the modes, its scope being ‘the performing infrastructure’. This scope demonstrates that alongside the construction and maintenance of the physical structures, the supporting systems and services as well as governance, management and finance are also included.

During the process experts from the ETPs involved were fully engaged. This was done continuously through engagement of core task force experts from each of the Platforms. In addition, through two major workshops a wider range of experts from across all sectors were engaged. Furthermore, several meetings were held with the European Commission services of DG MOVE and DG RTD in order to inform them and to match expectations.

This roadmap on cross-modal transport infrastructure innovation results from the unprecedented cooperation between four acknowledged transport Platforms together with the construction Platform. It marks a major step in enabling the White Paper’s vision for a Single European Transport Area.

Brussels, Summer 2013,

The Joint ETP Task Force on Transport Infrastructure Innovation.

## CONTENTS

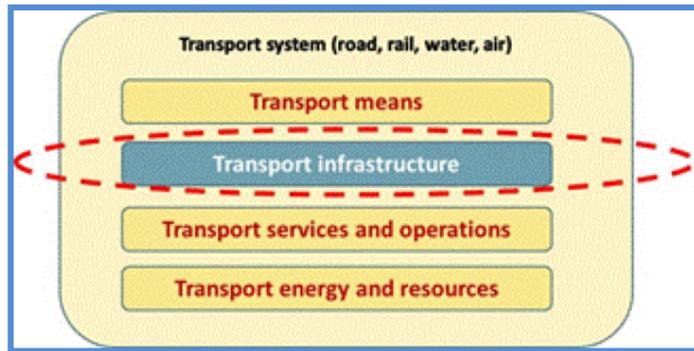
<b>INTRODUCTION</b> .....	<b>3</b>
<b>R&amp;I DOMAIN: CONSTRUCTION AND MAINTENANCE</b> .....	<b>8</b>
<b>NON-INTRUSIVE CONSTRUCTION, MAINTENANCE, ENHANCEMENT AND RENEWAL</b> .....	<b>8</b>
<i>ADVANCED SURVEY, INSPECTION AND TESTING</i> .....	9
<i>ADVANCED CONSTRUCTION CONCEPTS AND PROCESSES</i> .....	9
<i>ADVANCED MAINTENANCE AND REHABILITATION</i> .....	10
<b>TOWARDS ZERO CARBON FOOTPRINT</b> .....	<b>10</b>
<i>ENERGY HARVESTING</i> .....	11
<i>LOW CARBON CONSTRUCTION</i> .....	11
<i>INFRASTRUCTURE FOR LOW AND ALTERNATIVE ENERGY TRANSPORT</i> .....	11
<b>MULTI-MODAL TRANSPORT NODES AND CORRIDORS</b> .....	<b>12</b>
<i>OPTIMAL LOCATION, OPERATION AND ACCESSIBILITY TO AND WITHIN TERMINALS, HUBS AND GATEWAYS</i> .....	12
<i>SEAMLESS INTERCHANGE OF FREIGHT AND PASSENGERS</i> .....	13
<i>SYNCHRO-MODALITY OVER KEY TRANSPORT CORRIDORS</i> .....	13
<b>R&amp;I DOMAIN: SUPPORTING SYSTEMS AND SERVICES</b> .....	<b>15</b>
<b>INTEGRATED TRANSPORT INFRASTRUCTURE DATA/INFORMATION SYSTEMS</b> .....	<b>15</b>
<i>ACTIVE INFRASTRUCTURE</i> .....	15
<i>META (COMMON DATA) INFORMATION ARCHITECTURE</i> .....	16
<i>DATA/INFORMATION SHARING – REALISING THE META-INFORMATION LAYER</i> .....	16
<i>DATA/INFORMATION SECURITY</i> .....	16
<b>USER INFORMATION MANAGEMENT</b> .....	<b>17</b>
<i>TRANSPORT USER EXPECTATIONS AND ACCEPTANCE FACTORS</i> .....	17
<i>MARKET OPPORTUNITIES AND ACCEPTANCE FACTORS</i> .....	18
<i>COORDINATED TRAVEL PROCESS MANAGEMENT</i> .....	18
<i>DISRUPTION AND RECOVERY MANAGEMENT</i> .....	18
<b>SAFE AND SECURE TRANSPORT INFRASTRUCTURES AND OPERATIONS</b> .....	<b>18</b>
<i>ADVANCED SAFETY TECHNOLOGY</i> .....	19
<i>ADVANCED SAFETY MANAGEMENT SYSTEMS</i> .....	19
<i>ADVANCED SECURITY SYSTEMS</i> .....	19
<b>R&amp;I DOMAIN: GOVERNANCE, MANAGEMENT AND FINANCE</b> .....	<b>21</b>
<b>RESILIENT TRANSPORT INFRASTRUCTURE OPERATIONS ACROSS EUROPE</b> .....	<b>21</b>
<i>INTELLIGENT TRAFFIC MANAGEMENT STRATEGIES</i> .....	22
<i>ADVANCED CAPACITY PLANNING</i> .....	22
<i>CLIMATE RESILIENT INFRASTRUCTURE NETWORK</i> .....	23
<b>DECISION MAKING IN EUROPEAN TRANSPORT INFRASTRUCTURE INVESTMENT</b> .....	<b>24</b>
<i>ADVANCED ASSET MANAGEMENT SYSTEM</i> .....	25
<i>INFRASTRUCTURE-DRIVEN SPATIAL QUALITY</i> .....	26
<i>ADVANCED INVESTMENT STRATEGIES</i> .....	26
<i>INNOVATION GOVERNANCE</i> .....	26
<b>BRINGING RESEARCH TO DEPLOYMENT</b> .....	<b>28</b>
<b>GLOSSARY</b> .....	<b>29</b>
<b>REFERENCES</b> .....	<b>29</b>
<b>COLOPHON</b> .....	<b>32</b>

## INTRODUCTION

### History of the Joint ETP Task Force

At the Transport Research Arena 2012 in Athens, the call was made from the Member States and European Commission for a coherent roadmap for infrastructure research and innovation (R&I) across the modes. This stressed the growing recognition of the importance of infrastructure within the transport system for Europe’s goals on inclusive economic growth.

With the aim to reinforce their individual strategic interests in transport infrastructure innovation, the European Technology Platforms (ETP) for road, rail, water and air transport (ERTRAC, ERRAC, Waterborne and ACARE) as well as for construction (ECTP) initiated a joint task force for infrastructure innovation.



The ETPs examined their contributions towards enabling the integrated transport system for the 21<sup>st</sup> century. On that basis, the joint task force was mandated to map key cross-modal infrastructure research and innovation (R&I) on basis of the respective mode-specific agendas and roadmaps. The approach recognised the door-to-door mobility and transport needs of people and freight which often involves multiple modes. This roadmap on cross-modal infrastructure innovation therefore focuses on research and innovation topics that span two or more modes. As such it adds value to the mode-specific R&I strategies, agenda’s and roadmaps of the ETPs involved in the Joint Task Force; adding value to their specific strategic interests. The objective of topics considered in this roadmap is to create an ‘invest once, exploit many times’ approach to R&I in infrastructure. In that respect, the roadmap also recognises that some issues required stronger connections between stakeholders within a mode than between the modes.

### Scope of the roadmap

The scope of R&I in this roadmap is *transport infrastructure*, which comprises of the basic physical elements as well as the associated organisational structures, systems, processes and services needed for enabling the flow of passengers and freight from origin to destination, by road, rail, water and air<sup>1</sup>.

In the context of this roadmap it consists of *fixed facilities*, such as roadway segments, railway tracks, public transportation terminals, harbours, and airports; the infrastructure facing *control and information systems* that support its proper operation and permit people and goods to traverse geographical space in a timely, efficient manner for an intended purpose; the *governance and management* systems, structures and processes that link the functioning of the infrastructure with the framework of policies, regulations and legislations. As shown in the figure, infrastructure is a component of the wider transport system, supporting and interacting with transport means, transport services and operations and transport energy and resources supply.

Transport infrastructure is fundamental for the smooth operation of the internal market, for the mobility of persons and goods and for the economic, social and territorial cohesion of the European Union. The EU 27 comprises 5.000.000 km of paved roads, out of which 65.100 km are motorways, 212.800 km of rail lines, out of which 110.458 km electrified, and 42.709 km of navigable inland waterways. The total investment on surface transport infrastructure during the period 2000-2006 was € 859 billion. User operation of infrastructure generates both jobs and significant contribution to European GDP which equates to 9 million skilled jobs and 600 billion Euros.

<sup>1</sup> Although not specifically addressed within this roadmap, pipelines are also an important cross-modal element; in particular from the perspective of the sea ports.

The contents of this roadmap focus on the R&I needs developed by the ETPs involved in the Joint Task Force where relevant to two or more modes. As such this represents only part of the transport infrastructure R&I requirements since the mode-specific elements are already identified by the appropriate ETP roadmaps and agendas.

Following the scope of infrastructure, this roadmap structures the cross-modal R&I needs according to three inter-related domains:

- **Construction and maintenance of the infrastructure;** The key to improving capacity and the availability of the existing transport infrastructure network is to include solutions that support a move towards zero transport disruption caused by intrusion from inspection, upgrading and maintenance (i.e. less, faster and better planned interventions which respect the safety for the workers and users alike) as well as an understanding of how future changes in the environment (e.g. weather) and usage (changes in traffic loading and incidents) will affect it. To achieve this it is necessary to understand both the future impact on the infrastructure, the current condition of the infrastructure and predict future performance. The solutions will support seamless integrated transport through optimal inter-connectivity between the modes. This would allow improved choice for transport user's door-to-door journeys as well as yielding increased flexibility in transport flow patterns. Likewise, new build elements of the transport infrastructure must adopt an approach of minimal disruption to the existing infrastructure and other third parties and include elements of smart technology to monitor the "health" of the infrastructure to allow timely maintenance in order to maximise life and minimise maintenance interventions. Improved and innovative construction techniques need to be developed to reduce the cost and disruption of new build, renovation and maintenance. This includes the works 'in situ' as well as the off-site manufacturing chain. Finally this domain also addresses finding solutions that would reduce the carbon footprint of infrastructure. This includes direct actions such as low carbon construction and energy harvesting, as well indirect actions such as reducing the energy used by the various transport means, enabling the use of alternative fuels and energy or enhanced operational safety through use of high friction surfaces, for example.
- **Infrastructure based supporting systems and service;** Achieving an integrated transport infrastructure requires a high level of embedded intelligence in the infrastructure and systems to support the decision making process for the operators, managers and owners of transport infrastructure. This depends on the organisation of complete, consistent and dependable cross-modal data and information. Such systems will also facilitate the appropriate deployment and utilisation of the infrastructure by enabling advanced end-user applications in transport services and operations. Such applications will provide the transport infrastructure users with optimal decision making across the modes. Alongside the mode-specific (IT) systems, the challenge will be developing the cross-modal meta-layer of common architectures and systems for sharing and securing the data/information for the coordinated management of travel processes and recovery from disruptions.
- **Governance, management and finance of the infrastructure;** In order for the infrastructure owners, managers and operators to get the most out of the increasingly limited funding for transport infrastructure and to do so in a manner that is compatible across the modes and across Europe, the development of a common framework and associated methods and models is required. Its objective is to enable the transparent, risk-based optimisation of investments within and across the modes. This would include methods through which the external costs of transport infrastructure are internalised in a harmonized way in order to support the transition towards a true system of "user pays, polluter pays". The framework should also ensure that the value created by the enhanced multi-modal accessibility of transport infrastructure is captured. This framework also includes issues such as resilience against disturbances from climate change and other effects by virtue of the intrinsic quality of the infrastructure.

### **Vision 2050 and guiding goal for 2030**

The objective of the key cross-modal transport infrastructure R&I was derived with a reference to the White Paper on Transport, and the Connecting Europe Facility/TEN-T framework:

This integrated transport infrastructure system for the 21<sup>st</sup> century would be advanced, affordable and acceptable to Europe's citizens. It will be optimised between its performance, cost and (remaining) risk. It would adequately enable and support the (advancements in ) other systems and processes involved with the seamless movement of people and freight through the modes.

***BY 2050 EUROPE HAS AN INTEGRATED TRANSPORT INFRASTRUCTURE  
ENABLING A SINGLE EUROPEAN TRANSPORT AREA.***

- optimal availability and capacity of transport infrastructures
- optimal inter-connectivity between the modes
- optimal cross-modal investment decisions
- enhanced safety and security
- reduced impact on environment, spatial quality and society
- fully shared data/information base across the modes
- interoperable interface, open to the infrastructure user
- affordable in terms of Total Cost of Ownership

The objective is that it will be perceived by the user as a single network across which people and goods are able to freely flow, and within which travel information and guidance, safety and security are enhanced. Most importantly in this respect is that it will be developed as an upgrade – rather than replacement - of the existing infrastructure; making better use of available capacity, being capable of adopting new power systems and vehicle types, and being adaptable to changes in demand, technology and climate.

The 2050 vision will be enabled through the programming of the next two decades of infrastructure research and innovation priorities with a guiding goal set for the year 2030:

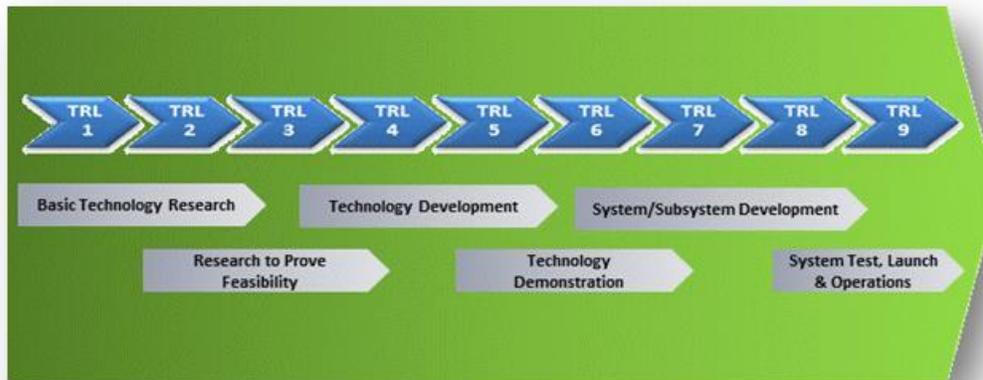
***BY 2030 RESEARCH AND INNOVATION SHOULD ENABLE AN IMPROVEMENT OF 50% IN  
INFRASTRUCTURE PERFORMANCE, RISK AND COST VERSUS A 2010 BASELINE AS WELL AS  
ENABLE SEAMLESS DOOR-TO-DOOR SERVICES FOR PASSENGERS AND FREIGHT.***

This guiding goal is decomposed into enabling a reduction in Total Cost of Ownership of 20-30% versus a 2010 baseline. This considers that taking into account all the aspects of cost and the value associated with performance, functionality and risk, an improvement of 20-30% should be enabled. This determination of total cost/value includes well-known (but often not applied) infrastructure performance indicators, such as for reliability, availability, maintainability, safety, and security, as well as new (to be developed) societal indicators such as for seamlessness, accessibility and interoperability.

### **Technology Readiness Levels in 2020, 2030 and 2050**

This roadmap aims to bring research and innovation to deployment enabling their implementation over the 40 years to 2050. Considering the long cycle times in infrastructure this time span represents 2 or three investment cycles. Starting from a 2010 baseline the R&I activities presented in this roadmap start from various Technology Readiness Levels (TRL).

This concept is shown in the figure below and ranges from exploring the basic principles of technology (TRL = 1) up to system/subsystem model or full-scale prototype demonstration and further to the completion and qualification of the actual system through test and demonstration; rendering it ready for market uptake (TRL = 9). As the guiding goal for 2030 is about enabling solutions, this implies an objective to achieve TRL = 9. However it is recognised that part of the relevant R&I activities will have longer lead times and therefore will have lower TRLs in 2030. Hence, at the start of the R&I activities a mandatory state-of-the-art assessment (SOTA) will be made for the themes and topics, taking into account the relevant past and present landmark projects and programmes.



### Programming Instruments

It is important to consider that in infrastructure R&I, the early stages of technology development will be driven by a technology push. Later stages of technology readiness (TRL = 5 onwards) will be driven by the regulation pull and to a much lesser extent the market pull associated with mass market consumer products. Therefore, it is important to consider from the start, what critical actions are needed on developing and establishing regulations, standards. These will be developed to match the needs from the R&I solution as it moves through the successive technology readiness levels.

In addition, it is important to match the appropriate funding instruments to the different stages in the development. Hence the need for a portfolio of instruments that allow for a tailoring to the specific needs of the development stage under concern (e.g. the deployment of integrated solutions on a systems level). For example the EIB and EUREKA instruments would typically be applied in the highest TRLs, whereas COST actions would apply to the lowest. Furthermore, bringing infrastructure research to deployment will be dependent on forging long term cooperation between the partners from policy, industry and research. Hence, adequate provision of the instruments needed for the 'capacities and people' aspects in the programming will be needed. This will include an objective on managed continuity and the establishment/contribution of strategic partnerships as a part of an overall approach to achieving Infrastructure innovation.

The instruments at a European level must be complemented at the regional, national or even local level. Industry participation will be important as they will typically cover the development cost to invest in future IPR and competitiveness advantages. Their co-financing of testing and evaluation should match the national and European contributions.

It is important that the solutions in the domain of 'Governance, Management and Finance' are demonstrated at the highest system level possible. This will entail a substantive link with TEN-T network which services the strategic flows of passengers and freight across Europe and thus forms the backbone of the European economy.

### Match with strategic interests of the ETPs involved

Referring to the goals in the EU White Paper on Transport, The Innovation Union (for 2020) and the Research and Innovation fields in the Strategic Transport Technology Plan (STTP) of DG MOVE, the Joint Task Force started combining the relevant research topics from the available R&I agendas and roadmaps of the ETPs involved. They then clustered them into coherent research areas and topics for each of the three domains.

The following overview table shows the level of interest of the ETPs to be involved in the cross-modal research areas identified. This interest and expected impact is characterised as either strong, moderate or none). From the table it can be seen that the research areas and themes strike a good match to the strategic interests of all five ETP's involved in the task force.

Table: Correspondence between Joint Roadmap priorities and individual priorities of the five ETPs beyond the individual commitments made in each sector		ERTRAC	ERRAC	Waterborne	ACARE	ECTP
Key; Strong (●), moderate (○) and no correspondence (-)						
CONSTRUCTION AND MAINTENANCE	<b>NON-INTRUSIVE CONSTRUCTION, MAINTENANCE, ENHANCEMENT AND RENEWAL</b> <ul style="list-style-type: none"> <li>ADVANCED SURVEY, INSPECTION AND TESTING</li> <li>ADVANCED CONSTRUCTION CONCEPTS AND PROCESSES</li> <li>ADVANCED MAINTENANCE AND REHABILITATION</li> </ul>	●	●	●	○	●
	<b>TOWARDS ZERO CARBON FOOTPRINT</b> <ul style="list-style-type: none"> <li>ENERGY HARVESTING</li> <li>LOW CARBON CONSTRUCTION</li> <li>INFRASTRUCTURE FOR LOW AND ALTERNATIVE ENERGY TRANSPORT</li> </ul>	●	●	○	○	●
	<b>MULTI-MODAL TRANSPORT NODES AND CORRIDORS</b> <ul style="list-style-type: none"> <li>OPTIMAL LOCATION, OPERATION AND ACCESSIBILITY TO AND WITHIN TERMINALS, HUBS AND GATEWAYS</li> <li>SEAMLESS INTERCHANGE OF FREIGHT AND PASSENGERS</li> <li>SYNCHRO-MODALITY OVER KEY TRANSPORT CORRIDORS</li> </ul>	●	●	●	●	●
SUPPORTING SYSTEMS AND SERVICES	<b>INTEGRATED TRANSPORT INFRASTRUCTURE DATA/INFORMATION SYSTEMS</b> <ul style="list-style-type: none"> <li>ACTIVE INFRASTRUCTURE</li> <li>META (COMMON DATA) INFORMATION ARCHITECTURE</li> <li>DATA/INFORMATION SHARING – REALISING THE META-INFORMATION LAYER</li> <li>DATA/INFORMATION SECURITY</li> </ul>	●	●	●	●	●
	<b>USER INFORMATION MANAGEMENT</b> <ul style="list-style-type: none"> <li>TRANSPORT USER EXPECTATIONS AND ACCEPTANCE FACTORS</li> <li>MARKET OPPORTUNITIES AND ACCEPTANCE FACTORS</li> <li>COORDINATED TRAVEL PROCESS MANAGEMENT</li> <li>DISRUPTION AND RECOVERY MANAGEMENT</li> </ul>	●	●	●	●	○
	<b>SAFE AND SECURE TRANSPORT INFRASTRUCTURES AND OPERATIONS</b> <ul style="list-style-type: none"> <li>ADVANCED SAFETY TECHNOLOGY</li> <li>ADVANCED SAFETY MANAGEMENT SYSTEMS</li> <li>ADVANCED SECURITY SYSTEMS</li> </ul>	●	●	●	○	●
GOVERNANCE, MANAGEMENT AND FINANCE	<b>RESILIENT TRANSPORT INFRASTRUCTURE OPERATIONS ACROSS EUROPE</b> <ul style="list-style-type: none"> <li>INTELLIGENT TRAFFIC MANAGEMENT STRATEGIES</li> <li>ADVANCED CAPACITY PLANNING</li> <li>CLIMATE RESILIENT INFRASTRUCTURE NETWORK</li> </ul>	●	●	●	●	●
	<b>DECISION MAKING IN EUROPEAN TRANSPORT INFRASTRUCTURE INVESTMENT</b> <ul style="list-style-type: none"> <li>ADVANCED ASSET MANAGEMENT SYSTEM</li> <li>INFRASTRUCTURE-DRIVEN SPATIAL QUALITY</li> <li>ADVANCED INVESTMENT STRATEGIES</li> <li>INNOVATION GOVERNANCE</li> </ul>	●	●	●	○	○

As can be seen, there is considerable strategic interest from across and outside of each transport platform. The following sections, organised by domain and R&I topic, describe in more detail the content of the cross-modal interest in each of the topics.

## R&I DOMAIN: CONSTRUCTION AND MAINTENANCE

Key to improving the capacity and availability of the existing transport infrastructure network are solutions that enable a shift towards zero intrusion from inspection and monitoring, maintenance and renewal and upgrading. This requires fewer, faster and better planned interventions. This needs to be achieved at the same time as improving levels of safety for the workers and users. Such solutions should enable a more seamless and consistent integrated transport network by delivering optimal inter-connectivity between the modes, which would allow improved choice for the transport user. This should consider the entire origin to destination aspects as well as providing more flexibility in transport flow patterns. The infrastructure system must enable response to changes in conditions within the network (e.g. weather, works, and incidents).

The domain does not only consider the in-situ aspects of construction and maintenance but also includes the upstream aspects of the manufacturing chain such as material and component production and fabrication. Finally this domain also addresses the need to find solutions that would reduce the infrastructure carbon footprint. This will include not only low carbon construction and energy harvesting from the infrastructure, but also reducing transport energy consumption and enabling the use of alternative energies by means of smart infrastructure design, new materials and methods of construction.

### NON-INTRUSIVE CONSTRUCTION, MAINTENANCE, ENHANCEMENT AND RENEWAL

#### Scope

Research is needed on systems, materials and methods for inspecting and monitoring, constructing, upgrading, renewing and maintaining the infrastructure in order to reduce the adverse impacts of such interventions. This should support a move towards much less (towards 'zero') intrusion on transport flow and on the disturbance to society. The solutions are to enable better planning for the required interventions, provide faster execution and maximise safety for users and workers during their respective activities. This in turn would improve the availability and acceptance of transport infrastructure.

The focus is on:

- Advanced and Automated Survey, Inspection and Testing:** The more efficient planning of interventions is highly dependant on the proper assessment of the remaining life span and performance degradation of the infrastructure asset. Research is needed to better understand, measure and predict the physical phenomena behind infrastructure degradation processes and their effect on the remaining functional life span. In the future all infrastructure could be constructed with sensors built-in to allow remote monitoring of performance (major bridges for example already are). The data derived from the sensors should be complemented with data from remote sensing and in-car data. Combined these data would inform operators regarding the behaviour of the infrastructure as well as they would inform designers how to improve the next generation of infrastructure.

Where suitable non-destructive testing techniques should be developed and improved to increase the rate of infrastructure assessment and thereby reduce disruption.
- Advanced Manufacturing and Construction Concepts:** The manufacturing supply chain, to a large extent, determines the speed with which the interventions are executed as well as the end-quality of the result (the 'spread') and hence the frequency of interventions. Research on new construction processes is needed in order to decrease the on-site construction time, improve the installed quality, and considerably reduce the total cost of ownership (TCO).

Research into new materials and installation techniques is needed to reduce both the carbon footprint and cost of construction as well as to minimise land take and impact on third parties (the latter of which is particularly important in the urban environment where the control and minimisation of ground movements is a very major concern during design and construction).
- Advanced and Automated Maintenance:** Maintenance (and rehabilitation) activities increasingly conflict with traffic demand. Advanced and automated concepts need to be delivered to enable faster and better execution of maintenance at any time. This would enable the infrastructure manager/operator to better plan around user requirements and reduce the exposure of workers to risk as well as the requirement for, and the impact of, the necessary safety features for workers and users.

For this challenge much is expected to be achieved by technology capture across the transport modes and from other sectors such as space and offshore exploration, nuclear energy and aviation (e.g. advanced corrosion protection (coatings), autonomous inspection, survey and repair).

### Advanced Survey, Inspection and Testing

Solutions are needed to enable high quality, fast and non-destructive surveying, inspection and testing. This enables the capture of physical phenomena into a useable number of fundamental input parameters that can be fed into the next generation of multi-scale, predictive models and network management simulation tools.

The application of the solution should be seamless across the assets and modes. The key enabling technologies (KET) include nano-electronics and sensors, electro-optics and advanced image processing, the downstream services of the Global Monitoring for Environment and Security (GMES), and operation of Unmanned Aerial Vehicles (UAV) etc. The applications areas include mobile systems (e.g. survey vehicles, UAVs as well as the utilisation of on-board intelligence) as well as stationary systems (e.g. embedded in the structures) and next-gen Computer Aided Design (CAD).

Particular attention is on self-monitoring capabilities of the infrastructure and the potential for self-reporting of infrastructure condition through the increasing use of ICT that is standard within transport means. The major challenges for self-monitoring are the compatibility and multi-scalar aggregation, wireless capabilities, multipurpose functionality (e.g. winter operations, WIM, repair monitoring etc.) as well as the delivery of performance indicators in asset management systems. These issues should include sensor choice and placement, generic and customizable ICT architecture for easy deployment, environmental (thermal, moisture, etc. and electromagnetic compatibility (EMC), nuisance rejection and on-board processing.

In the early stages of this research, critical regulation/legislation issues should be addressed, such as on communication and data/cyber security protocols.

### Advanced Construction Concepts and Processes

The manufacturing supply chain largely determines the speed with which new interventions are executed as well as the end-quality of the product and its variability. Concepts such as mobile production plants will allow shorter transport of large-volume infrastructure components. At the same time, modularity will allow greater use of standard elements such as common communications, monitoring and power systems (including new inductive systems) and will also provide the opportunity for introducing advanced and automated survey, inspection and testing. Solutions are needed in the following fields:

- **Design for optimal flexibility through advanced construction methods and modular concepts:** A new design philosophy needs to be developed (including calculation methods and procedures) that improves the (re-)use of standard/modular construction components. In addition to improved quality and lower cost, this would save on construction times. Current experiences across the transport sectors with advanced construction concepts need to be evaluated. The evaluation should include technology capture from other industrial sectors.  
Particular attention is on automated/robotic processes for manufacturing and construction, 'in-situ' and 'ex-situ' fabrications, as well as to re-use of the components. The greater use of light-weight components should be considered in order to reduce assembly and construction time including (where possible) re-use. This needs to include developing methods and tools for the planning and optimization of the construction processes taking into account construction time, complexity and logistics including temporary impacts on the network and the environment.
- **Advanced Features in Materials:** Advanced features in materials need to be captured for use in infrastructure maintenance, enhancement, renewal and construction. Particular aspects of research are self-healing and self-cleaning materials (e.g. coatings with nanotechnology) that would reduce the need for maintenance intervention.  
Other factors to be considered include operator controlled luminescence, high strength-light weight, low-carbon materials as well as extreme durability with UV resistant, corrosion free materials and components. Composite materials and bio-based products need to be assessed as well as the possibility for self-sensing materials.

- **Advanced, predictive models:** Interfacing with the previous fields of R&I development is the development of next generation of simulation methods and models that can accurately predict the infrastructure performance and life-cycle under load, extreme weather and the environment. Such systems should consider both the planning and construction phases as well as the service life of the respective infrastructures. These advanced models would link technologies, asset management and economics.  
The viable solutions should be accompanied by the appropriate (common) standards, specifications and guidelines.

### Advanced Maintenance and Rehabilitation

New ways are needed to perform maintenance and rehabilitation. The challenge is to have it non-intrusive on the flow of people and goods, cost-effective in terms of TCO and requiring minimal or even no safety provisions for the workers involved. Particular focus is on non-intrusive, remote/autonomous operation and on integrating maintenance considerations from the planning and design stage.

The research activities should start with a state-of-the-art evaluation that includes industrial sectors that already practice such techniques, such as through remote operation, robotics etc.

- **Service Life Extension:** Extending the service life of elderly infrastructure and its components will reduce the need for radical interventions. Research is needed into the development and application of more durable materials and components as well as of concepts that extend the capability of materials 'in-situ' by novel rejuvenation techniques.  
This should be supported by the development of improved tools for determining infrastructure condition and longevity.
- **Durable materials:** Focus on the development of materials and their applications for longer life performance. This area strongly correlates with the 'Advanced Features in Materials' section of 'Advanced Construction Concepts and Processes'. It also includes composite materials with integrated Structural Health Monitoring (SHM) as well as passive or semi-active control systems.
- **Reduced impact and nuisance during maintenance and rehabilitation:** The focus is on specific concepts to reduce the adverse impact to third parties and nuisance caused during operations. Issues to address include the reduction of the direct noise and vibration, dust, water and other emissions as well as the indirect effects of associated traffic.

### Expected impacts:

- Increased availability of the infrastructures, and consequently improved transport productivity.
- Reduced TCO through improved end-quality, less maintenance requirement and optimal planning of interventions.
- Towards zero fatalities and severe injuries of workers and infrastructure users on account of the respective activities.
- Improved user appreciation through better information, less intrusion and consequent congestion, brought on by optimal planning of necessary interventions.
- Better European and global market opportunities for the construction sector.
- Considerable improvement of resource efficiency through increased re-use and capability enhancement of components and materials.
- Less environmental impact through reduced intervention invoked congestion.

## TOWARDS ZERO CARBON FOOTPRINT

### Scope

Although the building and operation of infrastructure itself accounts for about 1% of the total energy consumption (i.e. carbon footprint) of transport as a whole, there are many opportunities to reduce it. This includes the reduction of the net energy embodied in the physical structures through re-use and recycling, implementing low energy systems and harvesting energy from infrastructure to the extent of net production. Although infrastructure itself may only have a modest carbon footprint, the design, maintenance and operation of the infrastructure can have a substantial influence on the vehicles, vessels and aircraft operating on and in it.

The focus is on:

- **Energy Harvesting:** Transport infrastructure has a high potential for harvesting energy, in particular geothermal, solar or wind energy. In more confined settings e.g. rail and road, considerable amounts of energy can be harvested from vehicles passing over the rail or pavement, particularly during downhill and/or braking operations.
- **Low Carbon Construction:** Embedded carbon in existing infrastructure and new build should be evaluated on a whole-system whole-life basis. This includes bio sourcing of the raw materials utilised in construction, maintenance, and renewal as well as re-using structural components after end-of-life and recycling of wastes from the sector itself or from other sectors (to be evaluated against appropriate policies). Systems that require lower energy use (such as lower temperature construction) should also be promoted. At the basis is a comprehensive and advanced Life Cycle Analysis framework, which includes all relevant externalities.
- **Infrastructure for Low and Alternative Energy Transport:** Infrastructure can be designed in ways that reduce the amount of energy for the transport using it. For example, the vertical alignment of infrastructure (e.g. heavy vehicles climbing hills) may be optimised to reduce the operation energy usage but with higher construction costs. Alongside this, infrastructure can support new-forms of low-energy and alternative fuelled systems as well as the soft modes of transport (e.g. walking and cycling) with the cross-modal system.

### Energy Harvesting

Research is needed for cost-effective solutions that generate (from MW to kW) at least an equivalent amount of energy to that consumed in the building and operating of the infrastructure systems. This includes opportunities to feed the harvested energy into smart grids and as a power source for sensor and communications systems in remote locations. The cost-effectiveness has to be evaluated on a systems level to ensure a net benefit (e.g. any additional maintenance requirements etc. need to be taken into account as well).

The focus is on electricity in road and rail; but the topic includes all new energy fuels; two-way charging opportunities in road and rail; evaluation on common technologies and implementation concepts such as geothermal heat systems and the business case for alternative energy (geothermal/solar/wind; alternative transport energy pool)

### Low Carbon Construction

Research is needed into the opportunities for innovative materials, technologies and logistics for reuse, recycling, life extension and waste reduction. This includes prefabrication concepts in view of reuse and recycling of components and structural elements.

### Infrastructure for low and alternative energy transport

Infrastructure concepts and standards should be developed with the aim to help reduce the energy consumption of its utilisation by transport. This should include basic issues such as reducing inclines, rolling losses and taking into account prevailing wind conditions. In addition, this area is strongly connected with concepts for quicker and cheaper tunnelling and ground engineering. These concepts can deliver the energy savings for transport without compromising the carbon footprint of the construction. At the same time, energy losses due to the standards of maintenance need to be reduced. Alongside this, infrastructure can support new forms of low-energy and alternative fuelled systems as well as the soft modes of transport (e.g. walking and cycling) with the cross-modal system. Hydrogen and natural gases are possible alternative fuels that may require a distribution infrastructure. In addition solutions are needed for contactless charging such as through induction. Here the issue of vehicle-infrastructure compatibility should be addressed such as mechanical compatibility and effects on infrastructure durability as well as regulation issues (such as EMC). Research is needed into the new energy distribution infrastructures that accompany the transitions from conventional energy carriers in to alternative energy carriers.

### Expected impacts:

- Reduction of energy consumption and subsequent CO<sub>2</sub> emissions from infrastructure construction and the transport operations.

- Effective distribution of alternative energies for transport means, along the European transport infrastructure network.
- Net energy production to benefit the immediate surroundings of the transport infrastructure (on local scale).

## MULTI-MODAL TRANSPORT NODES AND CORRIDORS

### Scope

Seamless integrated transport of freight and passengers over the European transport infrastructure network requires optimal inter-connectivity between the modes. This would provide transport users with better choice for their journeys taking into account the optimum options from origin to destination, in turn enabling more flexibility in transport flow patterns. In addition, multi-modal transport interchanges would contribute significantly to the objective of moving towards minimal impact on environment and society and enhance the potential for spatial development from an economic, societal and environmental perspective.

In order to enable trans-European cross-modal network management and operations, the current effectiveness and efficiency of such inter-connections (or 'nodes') needs to be taken to the next level. This requires optimized layout of, and vastly improved processes and systems, at hubs and gateways as points of interchange (within the same mode) or transfer (between the modes) for the movement of freight and passengers over the European transport (infrastructure) network. In case of freight this would also include transfer of mediums to pipelines.

The focus is on:

- **Optimal location, operation and accessibility to and within terminals, hubs and gateways:** A next generation of transport interchanges should be enabled that ensures the smooth and flexible throughput of passengers and freight over the key routes (urban) and corridors (long-distance), enhancing the journey experience for passengers and improving the reliability both for passengers and freight. This should include:
  - New concepts, processes and systems for passenger and freight activities.
  - Focus on design and operations of terminals (Large scale inter-connections, Last mile in distribution)
  - Consideration of LCA tools for environmental effects (emissions, noise pollution, biodiversity, soil and water system, etc.) of hubs and associated networks throughout their operational lifetime.
- **Seamless interchange of freight and passengers:** The transfer of freight and passengers within and between the modes needs to be improved on duration, hassle and predictability. Research should focus on the processes and supporting systems.
  - Transshipment processes & Supporting systems and technology (Full automation of handling, Extension of E-freight). Provision for automated concepts in ports, airports, rail yards and urban transshipment facilities to facilitate very rapid container/pallet swapping as well as Ro-Ro operations.
  - Concepts for smooth interchange between sub-urban high-speed passenger rail and airports and urban rail/road transport system (e.g. moving platform concept).
- **Synchro-modality over key transport corridors:** The vision for 2050 presented in the White Paper on Transport implies a dynamic alignment of volume and available capacity over the corridors (TRL = 8 in 2020), the core network (TRL = 9 in 2030) and the comprehensive TEN-T network (in 2050). In order to achieve this level of transport management, research is needed into the opportunities and conditions for the short term introduction of such synchro-modality on key routes (urban) and corridors (long-distance).

### Optimal location, operation and accessibility to and within terminals, hubs and gateways

New concepts, processes and systems are needed for improving passenger and freight transport within and between the different modes (road, rail, water, air)<sup>2</sup>. Next to the socio-geographic attributes of location and accessibility, attention is to be paid to the design and operation (including integrated maintenance processes) of terminals, hubs and gateways. Opportunities for flexible response to incentives or constraints from policy and

---

<sup>2</sup> In the case of sea and inland ports this includes the interchange to pipelines.

economy or to changes in conditions on the infrastructure network, such as from extreme weather and other incidents must be addressed as well. Accessibility in a congested environment such as urban areas is more frequently being achieved by underground construction, although this is becoming more difficult as congestion migrates to the underground environment itself.

Particular attention is on opportunities to improve large scale nodal inter-connections for passengers and freight (e.g. key sea and inland ports; airports, key commuting terminals; 'last mile' distribution) taking into account harmonized processes and services for passengers, baggage and freight (including dangerous loads). Being the consequence of the market's preferences for the concentration of passenger and freight transport their economies of scale would also offer a cost-effective pivot to achieving modal shift in the key hinterland corridors that connect the European entry-points with the hubs in the core European transport network. Also their scale would offer opportunities of optimising construction and management costs as well as for optimising the environmental performance, such as through eco-innovations and energy consumption, production and storage.

### **Seamless interchange of freight and passengers**

As journey times reduce due to higher speeds and the removal of bottlenecks, the rapid transfer of passengers and freight becomes increasingly significant. Research is needed into ways to achieve seamless processes for the transfer of passengers (e.g. security, baggage handling etc.) and freight that offer time-efficient, hassle-free and predictable connections between or within modes. This includes the required supporting systems and technologies such as fully automated freight handling and extending E-freight into the cross-modal, urban environment (truly achieving door-to-door freight transport).

### **Synchro-modality over key transport corridors**

The next generation of terminals, hubs and gateways is an important precondition for optimising the utilisation of the available capacity across the transport infrastructures. The next step is to develop a common synchro-modal transport framework and tools (data, methods and models) that enable dynamic management of the alignment between transport volumes and the available modal capacity over key routes (urban) and corridors (long-distance). Such a 'synchro-modal transport' concept would allow logistical and mobility service provider to switch quickly from one mode to another, for instance in response to economic incentives or in the event of a disruption in the supply chain. Recent pilot projects show major potential for synergy between policy objectives and industry interests in achieving modal shift up to 25%, in return bringing relief to congested road network. In order to achieve such efficiency improvement across the European transport network, the various elements of the international supply chains and networks (such as hinterland terminals, sea terminals and hinterland transport) need to become further integrated into one coherent (self-) organised system such as through the application of artificial intelligence. The information flows between all parties involved in the chain need to be organized in the best possible way for this purpose.

Research is needed to deliver an implementation strategy for synchro-modal transport on the TEN-T corridors (and the relevant sections of the secondary transport networks i.e. in the urban and economical areas linked by the corridors), taking into account the specific availability and condition of the corridors involved. The goal for 2030 is expanding this implementation strategy to the TEN-T core network, in effect enabling the objective of the integrated, coherent and coordinated system in which all key shareholders in the chain are organised in the best possible way for this purpose. This strategy is to be incorporated in the later research theme of 'decision making in European transport infrastructure investment'.

### **Expected impacts:**

- Improved mobility performance over the network by reducing time and effort required for the freight and passenger transfer in the nodes as well as by increased common use of infrastructure and capacity sharing.
- Enables further harmonisation and choice of transport products, processes and services for passengers, baggage and freight, leading to improved choice for the transport user and supporting a level playing field between transport modes. This will result in optimal utilisation of the available transport network's capacity and increased competition between modes.
- Opportunities for integrated, trans-European transport management

- Increased competition between modes by enabling flexible customer response and increasing transportation options.
- Contributes to optimal transport infrastructure investment decisions in view of the fact that modern terminal infrastructure requires massive investments and is among the largest structures ever built.
- Contributes to optimising transport energy use across the modes
- Improvement of accessibility, spatial development potential of regions and social inclusiveness

## R&I DOMAIN: SUPPORTING SYSTEMS AND SERVICES

Achieving an integrated transport infrastructure requires an adequate level of intrinsic intelligence in all the modes. This would enable appropriate decision making for the operators, managers and owners of the transport infrastructure on the basis of complete, consistent and dependable cross-modal data and information. It also would facilitate the appropriate utilisation of the infrastructure by enabling the development of advanced end-user applications in transport services and operations that provide the transport infrastructure user with personalised and appropriate choices across the modes. Alongside the mode-specific (IT) systems, the challenge is in developing the cross-modal meta-layer of common architectures and systems for sharing and securing the data/information, safety and security as well as coordinated management of travel processes and disruption recovery.

### INTEGRATED TRANSPORT INFRASTRUCTURE DATA/INFORMATION SYSTEMS

#### Scope

The data/information systems involved need to support strategic decisions about the development of the network against the backdrop of policy goals (performance, cost, risk) as well as the management and operations of maintenance, traffic management and construction.

The R&I activities in this theme should be addressed in conjunction with the R&I activities in the previous R&I topic on 'advanced survey, inspection and testing'. In addition, they are to be addressed in conjunction with the following R&I area of 'User Information Management' as the integrated data/information systems to serve the owner/manager/operator and also provide the basis for the data and information interface to the user of the transport infrastructure, for example allowing single ticketing, smart routing or tracking and tracing.

Providing this data and information on a cross-modal level requires robust interoperability over a vast array of ICT and data/information protocols.

The focus is on:

- **Active Infrastructure:** The cycle times in ICT are much shorter (1-2 years) than in infrastructure (10-30 years). Also the rapid developments in on-board intelligence and personal mobile devices are potential game-changers. Research is needed to ensure that future investments in infrastructure ICT will not turn obsolete prematurely and that on-going upgrading is possible.
- **Meta (Common data) information architectures:** Currently there is a lack of uniform or harmonised standards. This hampers interoperability across the modes. Research is needed to establish an adequate framework of common data/information architectures.
- **Data/Information sharing** Seamless door-to-door mobility options require additional integration of transport service provider data. Research is needed to identify data/information requirements as well as interoperability standards based on service requirements.
- **Data/information security:** A security breach in the data/information system could have grave consequences. Research is needed to ensure the data/information base is protected.

In order to enhance interoperability and achieve harmonised, open standards for the respective systems, it is envisaged that deployment starts on the selected TEN-T corridors, before further roll-out would be considered over the TEN-T core and comprehensive network. Beneficial deployment should include the key sections of the secondary infra network required to enable 'door to door' transport. These secondary aspects would, for example, consider the major hubs and nodes along the corridors and routes. This 'top down' approach would provide the best way to address the extreme complexities of the challenge.

#### Active Infrastructure

- Future proofing of ICT, using standards for information exchange to reduce obsolescence
- Interoperability through open standards for sensory etc. systems and components
- Driver/passenger/controller information systems using personal mobile device technologies
- Advanced Automatic real-time infrastructure condition monitoring, detection and communication capabilities; e.g. of flooding/icing/landslip and enabling intelligent and automated operations e.g. through improved prediction of remaining life span and better planning of maintenance and repair activities

- Low energy systems, reducing the energy consumption of infrastructure operations.
- Substantially reduced need for reactive intervention enables planning for continued operations and investment by embedded telematics and associated capabilities
- Current best practices will be inventoried and evaluated for eventual technology gaps that need subsequent research and innovation on telemetric systems.

### **Meta (Common Data) Information Architecture**

A framework of common data/information architectures is needed in order to provide real time, cross-modal support to both the infrastructure user and the infrastructure operator. This framework needs to be developed in the context of clearly defined service value chains, taking due account of the respective roles of the relevant shareholders and stakeholders. Using interoperability standards and an information architecture approach to develop an agreed Meta-Information layer across transport modes will enable sustained benefits across the value-chains.

The first priority is to demarcate the demand for data/information by aligning infrastructure managers/operators and bring them to a definition of a common (i.e. interoperable) base information level across the modes. This would include requirements such as for monitoring the condition of infrastructure and traffic, for monitoring of freight and passenger flows, for real time and dependable travel schemes and for intelligent transport flow management in order to optimize utilization of the available infrastructure networks. The common framework should be demonstrated in full, life practice, starting on the TEN-T corridors.

### **Data/Information sharing – realising the Meta-Information layer**

In order to enable seamless door-to-door travel and transport options for passenger and freight the data information architecture for the transport infrastructure stakeholders has to be extended to include transport operator data as well. Again, the data/information requirements have to be defined based on service needs, and open system architecture has to be developed as well as interoperability standards agreed.

This will form the basis of communication and information systems for intermodal mobility choices, sourcing, integration, distribution and storage of real-time traffic and passenger status data, multi-channel (in-journey) notification systems. The goal is to have a transport system wide information management capability.

### **Data/Information Security**

Data security and protection are essential prerequisites for the willingness of infrastructure and service providers to share data in their competitive operating environment. As such new and efficient data protection and security procedures have to be developed that allow the integration of services and infrastructure without compromising confidentiality issues.

When it comes to personal location and travel data, new procedures, systems and regulation have to be developed that enable seamless door-to-door services (please refer also to the next chapter) while still maintaining appropriate personal privacy and commercial confidentiality. This is likely to require a common European legal framework to ensure consistency across all states and the effectiveness of the system.

Another area of research and innovation is to ensure data integrity and security for communication links, e.g. in case of up- and downloads of information to and from vehicles, vessels, or craft. Data theft issues need be considered as well as ensuring ongoing data integrity from intended corruption or other threats (accidental or pre-meditated) to ensure trust, safety and security for all users across the interoperable infrastructure.

### **Expected impacts:**

- Enables interoperability of data and information across the modes. This is a basic requirement for strategic, tactical and operational decision making across the modes, such as on management on congestion, incidents, maintenance, environment etc.
- Provides the basis for advanced, real time, dependable and interoperable information services to the transportation infrastructure user, such as advanced, flexible single ticketing/pricing/tolling schemes and real time early warning services; both in the urban setting as in the long distance setting

- The advanced systems industry is enabled to build new (global) markets (for which the definition of common – open- standards, specifications and guidelines are essential).

## USER INFORMATION MANAGEMENT

### Scope

In order to enable advanced end-user applications in transport services and operations that provide the transport infrastructure user with unbiased choices across the modes, a framework of common system infrastructures, tools and interfaces needs to be developed. This will build on the data/information base that supports the owner/manager/operator of the infrastructure (see previous R&I theme of ‘integrated transport infrastructure data/information systems’).

The objective is to enable truly user-centric transport services to be realised that offer integrated door-to-door journeys according to individual user preferences with full transparency of its cost, performance and risk.

The focus is on:

- **Transport User Expectations and Acceptance Factors:** If the full benefit of an integrated transport system for passengers and freight is to be exploited, a good understanding of the variety of sources and causes for the movement of passengers and freight as well as of the incentives that influence the user’s modal choice/preference is essential.  
As the trends in policy, economy, society and technology (PEST) invoke rapid evolution of these sources and causes, adequate fore-sighting is required in view of the far 2050 horizon.
- **Market Opportunities and Acceptance Factors:** The implementation of a seamless and integrated door-to-door mobility concept relies on the determination of all relevant transportation stakeholders to get involved in that co-operative effort. Individual stakeholder involvement will be greatly enhanced if sound business cases are developed in which their associated market opportunities *and risks* are transparently addressed. The enhanced knowledge that is generated as a result of this topic would directly contribute to system optimisation and consequently greater user benefits.
- **Coordinated Travel Process Management:** Seamless transport of passengers and freight requires an infrastructure based interoperable data/information interface that is open to the infrastructure user (passengers and freight). Building on the integrated data/information system that supports the owner/manager/operator of the infrastructure (see also previous R&I topic) an appropriate meta layer needs to be developed that overarches the transport modes and in itself forms the cross-modal basis on which a next generation of appropriate (commercial) end-user applications and tools can be developed, with a particular focus on interoperability in view of co-modality and synchro-modality.

### Transport User Expectations and Acceptance Factors

In order to plan and establish a user-centric transportation system the multitude of different expectations, needs and roles of passengers and freight forwarders have to be researched and understood.

This starts with a comprehensive analysis on the key socio-cultural, technological, economic, ecological, and regulatory factors that determine user expectations and acceptance (and consecutive behaviour/decision making/choice), taking into account the social stratification (What drives the ‘optimal choice’ for different users and environments?).

As these factors are not static but change over time in a non-linear way, this analysis should include fore-sighting the developments in the decisive trends in the context of the 2050 policy goals of the White Paper on Transport as well as the identification of key events and decisions that determine the future (‘back casting’). Both persistent/long-term and intermittent climate-induced changes in demand, capacity and modal choice (and their interactions with other changes in demand, capacity and modal choice) need to be fully understood. This enables the key infrastructure shareholders and stakeholders to consider what actions, policies and programs are needed today that will connect the future to the present.

## Market Opportunities and Acceptance Factors

Seamless integrated door-to-door services for passengers and freight rely on the provision of data by transportation infrastructure stakeholders and transport operators alike. While the concept of data sharing is intriguing and seamless door-to-door connectivity is very attractive to the end-users, the benefit for the individual transport stakeholder at first can be questioned, as e.g. data sharing may cause additional cost and even pose a risk in a competitive environment while not providing immediate and evident returns.

Uncertainty factors like these that may influence and impact development of the transport industry have to be captured and understood. Market based mechanisms building on sound business cases or new market opportunities highlighting the attributes and specifications necessary for a seamless traveller experience across different modes have to be developed in order to secure involvement of all relevant transport stakeholders. Potential showstoppers towards seamless door-to-door mobility concepts have to be identified and addressed pro-actively with appropriate market tools.

## Coordinated Travel Process Management

Starting from the integrated data/information system serving the needs of the infrastructure owner/manager/operator (see also previous R&I topic), research is needed to determine the match with the data/information requirements of the transport services and operations that would provide seamless transport. Solutions need to be developed for the mismatching requirements. Opportunities from intelligence in transport means need to be taken into account.

Particular attention should be paid to issues as 'real time' generation of the required data/information, continuous and ubiquitous provision (e.g. no 'gaps' in tunnels or borders), and unbiased data/information on modal reliability, availability of capacity and other relevant attributes determining the user's choice of mode.

## Disruption and Recovery Management:

- journey monitoring and disruption detection, pro-active reconfiguration of journey elements, customer notification,
- smart (re) routing; not all through the same alternative, which could lead to additional congestion induced disruption
- support to crisis management and contingency planning in case of large-scale disruptions

## Expected impacts:

- The infrastructure user (passenger, freight forwarder) is assisted in the choice of a more efficient journey through clearer offers (e.g. time vs. cost).
- Improved productivity in freight transport
- Safer environment for passengers
- The transportation infrastructure meets citizens' expectations.
- User information management is a central building block towards the single European transport area, as it provides the meta-layer under which different modes appear as a single transport system to the end-users.

## SAFE AND SECURE TRANSPORT INFRASTRUCTURES AND OPERATIONS

### Scope

Even though most of the infrastructures safety issues are related to single modes it has been recognized that a synergy in safety technologies and safety management systems would enable a quicker evolution towards the "zero fatalities" aim of the EU.

Passengers and freight forwarders alike expect the completion of travel or transport without any kind of security or safety incident and with minimal impact of security measures towards progress to the destination. So security regulation has to be harmonized and different security systems have to be integrated to create an interoperable security network. Cross-modal security aspects have to be addressed also in order to create a level playing field between modes towards security regulation and levels.

The focus is on:

- **Advanced safety technology** sharing across transport platforms
- Application of **advanced safety management systems** by sharing best-practice and lessons from across the platforms
- **Advanced security systems** that allow for clearance for travellers or freight once across the whole journey, not mode by mode

### Advanced Safety Technology

- infrastructure based systems that support safety systems in vessels, vehicles and aircraft; early warning capabilities in the infrastructure;
- development of new materials with enhanced and durable properties (e.g. long lasting high friction wearing courses);
- development of new monitoring systems;
- improved worker safety including the development of fast track solutions and new work zone technologies to limit the personnel at risk;
- Information sharing.

A suite of advanced infrastructure based safety measures will be demonstrated in selected sections in the European transportation network in particular related to infrastructure based pro-active systems such as early warning for extreme weather events, and other disturbances in the functioning of the transportation network.

### Advanced Safety Management Systems

Integrated cross-modal safety management systems are required e.g. to conduct Infrastructure Safety Impact Assessment and corridor level safety evaluations.

For this aim the following issues have to be tackled:

- Harmonization of safety indices within each mode and across the modes;
- Harmonization of cost effectiveness procedures for the evaluation of the potential safety effectiveness of a given infrastructural solution and technologies;
- Tools for the evaluation for potential safety effectiveness of ICT technologies;
- Tools for the safety assessment of multimodal corridors and hubs;
- Enhanced tools for the evaluation of road/rail interaction issues in corridors;
- Urban safety and road/rail interaction issues;
- Multimodal safety management criteria for emergency management in case of critical events.
- Integration of safety management systems within enterprise business management systems
- Multi-modal safety governance, competences, regulatory bodies, accountabilities and oversight

### Advanced Security Systems

- Critical infrastructures; preventing disruption or destruction from malicious acts (cyber-attacks, trespassing, terrorist).
- Infrastructure protection from trespass/security/terrorist threat; automatic security breach detection devices, cross modal security strategy
- Advanced cross-modal & harmonized security processes and related systems (non-intrusive detection methods, highly secure networks for data sharing, etc.) for passengers, baggage and freight
- Urban infrastructure networks as well as regional and long distance networks.
- Safety systems protected and/or resilient to malicious acts, whether physical, electrical, electronic, software, light or cyber.

### Expected impacts:

- Improved safety and security across the modes.
- Better management of safety issues. Integrated system

- The direct impact is less fatalities and severely injured, and the associated societal cost, as well as reduced hassle for passengers and freight during travel. This inherently brings improvements in the utilization rate of existing infrastructures and hence better accessibility for social-economic functions. Improvement of economic attractiveness.
- Standardisation and harmonisation of measures for assessing infrastructure safety characteristics.
- Improved market take-up of better performing road safety solutions and systems
- Better market uptake of innovations, such as advanced safety and security measures
- Better response to user needs and increased customer satisfaction
- Significant reduction of societal cost (loss of productiveness, concern or distress)
- Improved match with societal demands for mobility, comfort, expectations, ageing, ...

## **R&I DOMAIN: GOVERNANCE, MANAGEMENT AND FINANCE**

In order to ensure that infrastructure owners, managers and operators get the most out of the increasingly limited transport infrastructure investment funds ('sweating the assets') and to do so in a manner that is compatible across the modes and across Europe, the development of a common framework and associated methods and models is required. Its objective is to enable transparent, risk-based optimisation of the investments within and across the modes, in which external costs of transport infrastructure are internalised in a harmonized way in order to support the transition towards a true system of "user pays, polluter pays", and in which the value created by enhanced multi-modal accessibility of transport infrastructure is captured. This includes issues such as resilience against climate change and other disturbances from infrastructures' intrinsic quality.

The R&I activities under this area should be taken on in conjunction with those in both other R&I domains: 'Construction and Maintenance' and 'Supporting Systems and Services', in order to deliver effective solutions.

For this R&I domain, the time to 2020 should be used to establish the basic elements of the framework. For reasons of manageability, their viability will be demonstrated on (significant segments of) selected TEN-T corridors, with the objective to establish first cooperation agreements between the key shareholders involved. Of key importance is the inclusion of the main secondary transport networks that link these selected TEN-T corridors to the key economic and urban areas. This includes pipelines for mediums.

Working towards the 2030 milestone, this basic framework needs to be finalised and the proven solutions fully implemented on all TEN-T corridors (solutions will be rolled out for the other TEN-T corridors, and tailored to their specific needs when and where required).

Having established the full framework for governance, management and finance of the European transport infrastructure around 2030, the final stage towards 2050 is concerned with implementation on the TEN-T comprehensive network, including the secondary transport network for all key economic and urban areas of Europe.

## **RESILIENT TRANSPORT INFRASTRUCTURE OPERATIONS ACROSS EUROPE**

### **Scope**

The issue of infrastructure resilience is essential in order to ensure that flows of people and freight move smoothly across the wider European transport network, regardless of the mode involved, and regardless of the weather conditions (e.g. cold winters, low water) and other natural or man-made disturbances. Although events affect modes differently, their complementarity allows for effective coordination across the modes. For example, bulk freight can be transhipped though rail or water, and even through pipelines in the case of media.

Solutions are needed that improve the ability of the transport infrastructure network to accommodate disturbances from its intrinsic quality. This spans from the local scale to the European scale as local or regional incidents can have an impact on the overall system. This is particularly important for the TEN-T network that services the strategic flows of passengers and freight across Europe. However, this should include the underlying transport networks of the key European economic/urban areas as well as taking into account the pipelines for mediums.

This improvement should be risk driven, based on a transparent cross-modal evaluation that enables the aggregation from mode-specific applications (e.g. at the local level) to coordination across the modes at the European level. At the core is the common understanding of the impact of events on the transport modes and of optimal level of resilience in terms of performance, cost and (remaining) risk. Sub-issues are to deal with the complementarities between the modes and required contingency in their capacity in order to accommodate modal shifts in response to events.

The R&I activities under this area should be taken on in conjunction with those in both other R&I domains: 'Construction and Maintenance' and 'Supporting Systems and Services'. In particular the enabling of intelligent infrastructure is an important precondition for delivering effective solutions.

The focus is on:

- **Intelligent Traffic Management Strategies:** Traffic management needs to be brought on the next level in order to accommodate growth in demand for transport capacity and performance, in particular where this is concerned with the trend towards 'self-management'.  
Transition strategies need to be developed that match day-to-day operations to long term developments in transport demand within the context of key external factors such as from policy, economy, society, technology, environment and legislation. The strategy should enable mode-specific application as well as cross-modal coordination in order to optimise utilisation of the infrastructure.  
Of particular importance is the ability to predict dynamic traffic flows (1h-24h) as the basis for adequate day-to-day response strategies e.g. through pricing and personalised traffic information. In addition attention should be paid to 'smart' and (where appropriate) cross-modal response to major incidents.
- **Advanced Capacity Planning:** The long term capacity needs for passenger and freight transport dependent on many factors (policy, economy, social; technology, environmental and legislation). Their prediction is essential in order to determine future investment requirements in baseline capacity as well as appropriate redundancy levels in view of contingency planning. Current models provide insufficient basis for governance, management and finance of the transport networks on a strategic, European scale. A next generation of sophisticated (cross-modal) infrastructure planning and mobility demand forecasting models and tools is required that enable advanced long term capacity planning and incident management over the TEN-T network, including the secondary networks in the key economic and urban areas. The models and tools should facilitate the determination of the appropriate levels of redundancy in the network as well as the accommodation of planned and unplanned intrusions (e.g. by major maintenance and rehabilitation or by natural causes), with the objective to provide optimal flexibility of travel between modes in the short term future as well as in the long term future.
- **Climate Resilient Infrastructure Network:** The need for improved resilience against extreme weather events is one of the key cost drivers in infrastructure management and has major implications at the Transport level if not designed into the overall system. In view of the long investment cycles in infrastructure the TEN-T network needs to be evaluated on risks and appropriate measures in order to ensure timely decision making on the consecutive investments.

### Intelligent Traffic Management Strategies

The aim is to develop a consistent and cohesive strategy that, by 2030, enables an adequate level of 'self-management' by the user for his day-to-day transport movements across the modes and across Europe. The strategy is set within a framework of collective measures in order to ensure appropriate management in view of local, regional, national and European level objectives (e.g. environmental impact, disruptive events).

The strategy is to focus on the transition of the current 'directive' practices a cohesive cooperation oriented traffic management framework that spans the strategic, tactical and operational levels. The strategy has to be 'open' in order to incorporate cost-effective opportunities from on-going technology developments, such as use of cooperative systems, (forms of) automated transport and other technological developments such as from the R&I domain of 'Supporting Systems and Services'. Particular attention is on the development of short term traffic prediction (1 hour to 48 hours) and the effects of potentially disruptive local weather conditions based on forecasts, which enables dynamic response to major incidents tools should be developed to enhance the interfaces between infrastructure and the localization and safety of goods and passengers (e.g. GNSS-based tools).

### Advanced Capacity Planning

The aim is to develop the next generation of models and tools for long term capacity planning. This includes the means of responding to incident management over the TEN-T network, with the objective to provide optimal connectivity and long term flexibility of travel between modes. In addition to the TEN-T network, the secondary networks in the key economic and urban areas should be included. The development should be based on the current models available with the respective owners, managers and operators of the networks.

With the next generation of sophisticated (cross-modal) infrastructure planning and mobility demand forecasting models and tools, dependable assessment should be made for long term capacity need and optimal flow patterns across the modes (passengers and freight) for the TEN-T corridors and comprehensive network (by 2020) including

the secondary networks in the key economic and urban areas they connect. These prognoses should include (local/regional) environmental impact from the utilisation of the transport network and assessment of contribution to European mobility goals.

This will serve as the basis for sophisticated contingency planning through the identification of capacity bottlenecks in the network as well as for determining appropriate levels of (local) redundancy in order to accommodate major intrusions to the steady state such as from major maintenance and rehabilitation actions, large events or by natural causes such as from climate change. For a selection of such major disturbances, vulnerability maps need to be developed as the basis for development of adaptation strategies (and mitigation when applicable).

Part of the research requirement is to define the need for new planning legislation to enable cross-modal infrastructure to be managed and maintained by appropriate parties, e.g. for rail, road, tram and bus.

### **Climate Resilient Infrastructure Network**

Research is needed to identify the climate risk 'hot spots' in the European transport network, identify the appropriate adaptation measures, and to develop cross-modal implementation strategies that optimise over cost-performance-risk, and that build up from the investment base lines of the respective infrastructure authorities and relevant private market players, including through efficient PPP schemes (see also the later topic of Advanced Investment strategies' under 'the R&I area of 'Decision making in European Transport Infrastructure Investment').

The research is to start off with developing common methods for risk assessment on basis of state-of-the-art. This will define the data/information base level required for building a comprehensive risk map for the core TEN-T network.

Particular focus for 2020 is on mainstreaming of climate adaptation measures into cross-modal infrastructure development and management implementation strategies. The basis for this is a European risk map for the core TEN-T network, which needs to be developed in close cooperation with the network's operators on basis of a harmonised risk assessment method for the impact of climate phenomena on the management and functioning of the core network. These maps should identify the vulnerable locations in the network and the impact of eventual disturbance from weather extremes against the backdrop of uniform climate scenarios and harmonised methods for down scaling the scenario outcomes to appropriate local and regional application requirements. The cost-effectiveness of the adaptation measures is to be based on Life Cycle Cost. Within the network, the specific issues related to gateways, hubs and urban areas need to be addressed.

Particular focus is on the assessment of the impact of climate change and extreme weather conditions on the transport infrastructure. The work should start with the assessment of climate change scenarios and its determination of the effects on the transport infrastructure. This includes the integration of terrestrial and satellite systems for the structural health monitoring of key infrastructures located in a natural risk (earthquakes, landslides, floods) prone area.

Adaptation measures and strategies need to be developed that enable minimizing the impact on seamless transport operation as well as provide optimal information to the users of the transport infrastructure. Their validation should be in full life practice demonstration projects. These measures could include the strategic application of new materials, techniques and systems for construction, operations and maintenance in order to ensure reliable network availability during unfavourable weather conditions. Such measures also should address the benefits and vulnerabilities of the use of infrastructure for climate adaptation, such as the use of roads/railways as flood defences.

There may be benefit in developing resilience KPIs in order to: quantify base-levels of network resilience and the corresponding impact of disruptive events in order to facilitate development of mitigation actions; measure the progress of implementation of resilience measures; facilitate more proactive reactions to disruptive events by identifying event-specific performance goals which are aligned with network capacity and safety requirements.

This topic contains particular links with the topic of 'Infrastructure-driven Spatial Quality' under the next R&I area of 'Decision making in European Transport Infrastructure Investment'.

### Expected impacts:

- Enhances the sustained available capacity on the TEN-T network.
- Enables incident management on a European level.
- Enables smart interaction between infrastructure management/operations and transport services and operations (e.g. smart rerouting in circumstances of extreme climate events or other unplanned incidents).
- Better appreciation of cost-effectiveness of spare capacity/appropriate redundancy (Capacity/ resource optimisation).

## DECISION MAKING IN EUROPEAN TRANSPORT INFRASTRUCTURE INVESTMENT

### Scope

The challenge is concerned with delivering a common European framework and corresponding toolbox that enables decision making by infrastructure owners, managers and operators on the basis of service levels, transparently building up from application on the local and mode-specific level all the way to the level of the cross-modal TEN-T network. This enables them to get the most out of the increasingly limited transport infrastructure investment funds ('sweating the assets') and to do so in a manner that is based on compatible service level agreements that enable objective comparison across the modes and across Europe ('level playing field').

In the optimisation of performance, risk and cost, the cost component should be upgraded to 'Total Cost of Ownership' (TCO) by internalising the external cost of transport infrastructure in a harmonized way. This in turn supports the transition towards a true system of "user pays, polluter pays" and captures the value created by the development of the local and regional areas that transport infrastructure connects.

The R&I activities under this area should be taken on in conjunction with those in both other R&I domains: 'Construction and Maintenance' and 'Supporting Systems and Services'. In particular the enabling of intelligent infrastructure is an important precondition for delivering effective solutions.

The focus is on:

- **Advanced Asset Management System:** The effort should be on developing a cross-modal asset management system (framework/toolbox), starting from the recent innovations in managing mode-specific infrastructure networks as assets. The system should be based on a common approach across the infrastructure owners, managers and operators for measuring asset performance with a focus on the major infrastructure cost drivers in each of the modes. The system should be demonstrated on selected TEN-T corridors. This should be the basis for building up a long term investment planning from the investment baselines of the local, regional and national infrastructures involved.
- **Infrastructure-driven Spatial Quality:** Transport infrastructure is a key factor in structuring spatial quality of regions. It determines the economic and societal development potential of regions and has significant impact on the liveability of regions and therefore is confronted with the issue of societal acceptance. Driving the European transport infrastructure to its optimal configuration meets with major challenges in the availability of adequate land for infrastructure development. In particular where transport infrastructure needs to be developed close to major conurbations, land is scarce in view of the many other claims on the same location. Long lead times and expensive measures are the consequence.
  - Cross-border and Cross-modal integration increases the complexity of the share and stake holder field exponentially. Governance processes should include/feature: Corridor platforms, Shareholder agreements, Stakeholder management, Coordinated investment strategies
  - The challenge is to scale up the current governance practice from the regional, mostly mode-specific level to the European wide transport infrastructure system.
- **Advanced Investment Strategies:** Novel approaches to generating successful investment portfolios for the TEN-T network need to be put in place that encourage investment in capacity to encourage growth and consequently an increased return against investment. Key in these sophisticated investment strategies and plans is the reconciliation of the European added value with the added value at the subsidiary national, regional and local scales. This needs to be founded in a common life cycle approach for the infrastructures as well as on a common definition for total cost of ownership. As such the investment portfolios should take into account the opportunities for enhancement and de-

bottlenecking the available infrastructures from an overall transport and mobility plan, as well as include their life cycle requirements for maintenance, and renewal (in view of the prominent issue of aging of the structure). This would include the provision of optimal redundancy in their capacity and measures to improve their resilience against disruptive events, such as from extreme weather.

- **Innovation Governance:** Large synergies can be achieved in the R&I portfolio of the key (institutional) stakeholders involved in transport infrastructure innovation. By establishing a common European framework of data, methods, models and schemes, the various projects and programmes of these stakeholders can be associated and even aligned with the objective of achieving optimal return on innovation investment (ROI). This requires a common understanding and appreciation of each other's objectives and targets, strategies and resourcing instruments (i.e. innovation procurement schemes). Key issues in the framework are how to reward and facilitate innovation by industry and how to effectively coordinate across the stakeholders (see next chapter on 'Bringing Research to Deployment').

### Advanced Asset Management System

In order to enable strategic, cross-modal and risk-driven management of the European core transport network, a coherent, trans-national asset management system annex toolbox needs to be developed and demonstrated. At the basis lies a holistic governance concept that -through clear service agreement levels- defines the required efficiency and resilience, taking into account the interests of key elements in the transport service value chain. This system, and corresponding toolbox, should ensure cross-modal consistency on the European network level whilst enabling (public and private) national, regional and local infrastructure authorities/managers/operators to tailor it to their specific needs.

At the basis of this system and corresponding toolbox lies:

- **a shared definition of the stakeholders' objectives, and their expression in basic asset performance levels.** Key research topics are the inventory and quantification of the needs, risks in view of the strategic policy goals of the stakeholders along the TEN-T corridors and their relation to asset performance levels in terms of reliability, availability, maintainability, safety and security, health, environment, etc. This forms the basis for cost-benefit assessments across the chain ('back-to-back') in which the focus is on harvesting synergies between investments in construction, maintenance, enhancement and renewal.
- **a common whole life and risk-based approach,** that allows for effective and efficient allocation of resources. This approach should incorporate the master planning, design, construct, operation and renewal of infrastructures and should be able to deal with evolving stakeholders demands, such as invoked by climate change effects, new transportation concepts and policies to achieve modal shift. Key topics are: achieving a balance between performance, risk and cost in a context of changing demands; cross network planning and cross asset optimisation, based on stakeholders' needs; risk-based operation, maintenance and renewal strategies (e.g. in view of the remaining functionality/life span); asset value strategies.
- **a coherent information backbone,** that is based on valid, accurate and complete data, and that is interoperable across assets, across networks, across modes, and across borders. A prerequisite is that the information backbone is linked in an interoperable way to adjacent information systems such as for traffic management. Key topics are: an adequate inventory of information needs and cycles for asset owners, asset managers and service providers; the translation of these information needs into data requirements; the definition of the respective European information management model; a gap analysis with existing information models and systems. Consequently a standard architecture and language is needed across the modes is needed to ensure effective information exchange at an overall transport level thus realising significant EU added value and customer/citizen/user benefit.

By 2020 a generic **Building Information Model for transport infrastructure purpose** (BIM-INFRA) needs to be developed and demonstrated for selected TEN-T corridors. The key issue is to capture best available technology from other sectors and develop the key standards. In view of the shifts in role and responsibility (such as under DBFM contracts), a key requirement of this BIM would be that it should enable the infrastructure authorities/managers/operators a consistent steer on the manufacturing & construction supply chains ('manu-services'). Particular attention should be paid to effective and efficient acquisition and handling of the 'big' data involved. In association with this BIM-INFRA appropriate decision support system should be developed.

## Infrastructure-driven Spatial Quality

Research is needed to match economic, environmental, societal benefits and costs; in a coordinated integrated approach for planning, development and management of infrastructure assets to the extent that societal acceptance of infrastructure is improved. In recent years practice has shown, that through an integrated approach in which (re)development of infrastructure and land-uses results in much faster lead times and considerable savings can be achieved while improving the societal acceptance in the immediate surroundings of the infrastructure (relating to e.g. Transport Oriented Development, multi-modal spatial corridor development, multi-modal nodal urban development).

The objective is to enable (transport) authorities – from the vision of e.g. ‘seamless mobility’ – to develop a coherent, and practical toolbox to plan and execute infrastructure (re)construction works with significant increased efficiency in investment, planning cost and output quality. Among the targeted users are infrastructure authorities, infrastructure providers/managers and commercial organisations. The method results in coordinated synergy with land use and mobility planning stakeholders and their interests in the respective works. An innovative methodology and approach needs to be developed and demonstrated in selected life practice situations on the urban scale as well as on the European regional scale (corridors).

Key in this approach is the adequate and transparent capture of the economic, societal and environmental values (including accessibility of services / activities and climate change issues) and investments included in the spatial envelope of the respective works as well as an adequate approach for multi-stakeholder engagement (e.g. by addressing the various stakeholder interests in monetary terms).

An innovative, strategy-driven methodology and approach for a multi-stakeholder coordination and engagement should be developed and demonstrated in selected real practice situations on the urban scale as well as on the European regional scale. Key in this integrated planning of Land Use, Mobility and Infrastructure is the adequate and transparent capture of the economic, societal and environmental values and investments (including accessibility of services and activities and the effects of climate change), to serve as a common reference for expressing the various stakeholder interests in monetary terms.

The aim for 2020 is to develop and demonstrate a common framework/toolbox to simultaneously address and evaluate the requirements from the perspectives of (multi modal) network development (issues of scale, agglomeration of spatial functions and life cycle), the institutional framework (issues of governance, finance and organisation), and the supporting data methods and models. This demonstration should focus on selected works/locations along three key European transport corridors. A roll-out strategy is to be delivered for the framework/toolbox focusing on the core TEN-T network for implementation in 2030. The aim is to implement coordinated planning, development and management of transport infrastructure and land-uses at the main corridors of the TEN-T network in 2050.

## Advanced Investment Strategies

In a first stage of development, harmonized investment strategies and plans should be demonstrated for selected TEN-T corridors. The focus in the corresponding research activities is on the establishment of a common framework for data (fully shared database for the respective corridors), methods, and models. Key issues to be included are the concept of Total Cost of Ownership and the reconciliation of added value over the subsidiary scales (local – regional – national - European). Building on this basis sophisticated decision support systems and financing business models (e.g. tolling, single ticketing on basis of objective comparison) should be developed. Particular attention is on establishing common risk-based (pre-commercial) innovation procurement schemes.

## Innovation governance

Research is needed in order to establish a common framework of data, methods, models and schemes for harvesting synergy from coordinated R&I portfolios, on a European level. By 2020 the R&I portfolios for selected TEN-T corridors should be evaluated on opportunities for optimising the return on innovation investment (ROI) across the shareholders involved through associating or even aligning their individual current and planned projects and programmes. The basis for this is the understanding and appreciation of their objectives and targets, strategies and resourcing instruments (e.g. innovation procurement schemes). Particular attention is on the facilitation of industry –spanning from SME to large corporations- in order to stimulate their innovation

development and participation in the coordination, together with stakeholders from policy and research. Next to effective sharing (for learning) of knowledge such as through easy-to-access information services (advanced search engines), this includes a sound strategy on testing approach and facilities, enabling testing across the range of technology readiness levels (TRLs) as well as across the scales (from single technologies to systems level) as well as effective cooperation on standards, specifications and guidelines.

### Expected impacts:

- Enables optimal management of the core TEN-T network with respect to its shared service levels in terms of reliability, availability, maintainability, safety, security, health, environment, economy and policy (RAMSSHEEP criteria).
- Enhances the development of TEN-T corridors, core network and comprehensive network, in conjunction with the secondary networks were appropriate through enabling optimal transport infrastructure investment decision making on a European level, balancing performance (e.g. reliability, availability, maintainability, safety) with the cost (in terms of TCO) and (remaining) risk.
- Optimises mobility effectiveness and efficiency on the available European Transport infrastructure network, by enabling cross border congestion abatement, in particular for the urban/economic areas (multi-stakeholder approaches, including first responders, infrastructure authorities, businesses, transport operators etc.).
- Enables European coordination on the challenge of renewal of ageing infrastructure.
- Enables transparency in the optimisation between performance, ('true') cost and (remaining) risk for the TEN-T network through introduction of a common European framework of asset performance levels in terms of reliability, availability, maintainability, safety, security, health, environment, etc.
- Enables the internalisation of externalities in the 'true cost' (and value) of the transport infrastructure networks, through the introduction of Total Cost of Ownership (TCO)
- Deployment of pan-European procurement schemes and plans over the TEN-T networks
- Enables integrated supply chain oversight and management for both infrastructure authorities, (private and public) managers and contractors, in turn enabling the emergence of new business models and market services from EU-contractors and manufacturers reinforcing the trend to operate networks under DBFM contracts.
- Optimal resilience against weather events and other incidents as well as to changing land-uses and life-styles influencing transport infrastructure
- Coordinated mobility planning and land use planning at the urban scale as well as at the EU regional scale, leading towards improved availability, reliability, resilience of the transport system and towards improved accessibility of infrastructure services and activities.
- Better understanding of the drivers for location choice of businesses and people, such as access to transport modes and services. From this understanding: improved efficiencies in decision making, leading to an effective reduction of travelling distance and time in commuter patterns; of the environmental impact on the (immediate) surroundings of the infrastructure (quality of life, liveability, reduction of CO2 emissions) as well as improved consolidation of urban areas
- Significant cost savings in the operational planning and execution of renewal and (re) construction works: up to 10 % less investment (by finding smarter and more specific solutions), up to 50% less planning costs (by shortening the planning duration), and a leverage on investments up to 1:6.

## BRINGING RESEARCH TO DEPLOYMENT

Europe needs its 21<sup>st</sup> century transport infrastructure today rather than tomorrow. Hence the need for short lead times for bringing research to deployment, in particular considering that the infrastructure vision for 2050 and guiding goals for 2030 are only two or three cycle times away, urging Europe to act NOW.

Both can only be achieved when infrastructure innovation, supported by targeted research activities and adequate competence building in the sector, is enabled through the partnership between the relevant stakeholders. This main streaming of innovation will require the creation of new forms of cooperation that integrate, alongside the research and development activities, issues such as procurement, business models, standardisation and legislation, knowledge transfer, training and capacity building.

### *Building the business cases for research and innovation deployment*



Such a partnership should include the key institutional stakeholders with a holistic approach to organising the contributions from all relevant organisations. This should support coordinated activities in all the relevant areas needed to accelerate the development of relevant innovations and their implementation and should include the nurturing of the skills needed across the EU. This should also support the creation of a lasting culture of innovation through capacity/competence building and institutional strengthening.

The testing and deployment of the solutions on a systems level will be a challenge due to the number of technological and organisational parameters (and their interdependencies), the scale of investment for shareholders and impact on stakeholders. Therefore, a well-managed process is required in order to focus and fast track efforts to bring research to deployment. In fact, the EC ambitions for the TEN-T corridors in 2020, the TEN-T core network in 2030 and the TEN-T comprehensive network in 2050 provide an excellent opportunity to do so: the TEN-T networks are well defined and segmented and establishing their specific need for research and innovation deployment can be readily done. The same is true for identifying key shareholders and stakeholders to the research and innovation challenge. A strong consensus between EU and the Member States is the only ground on which such opportunity can be built, the common investment can be optimized and results can be shared adequately throughout European regions, according to local needs.

The next step could be defining appropriately sized (cross-border) segments of the TEN-T corridors as to reflect a proper systems level for deployment whilst holding specific research and innovation challenges. For example, the innovation needs of intricately webbed network segments in highly urbanized regions such as the Randstad or the Ruhr, differ from those of long-distance linear segments in the Nordic and Eastern member states, and from those in environmentally sensitive settings such as the passages through the Alps.

The characteristics of the segments determine the structures and partnerships that would drive the research and deployment over these segments. Their development involves issues such as subsidiarity, intellectual property rights, legislator/regulatory framework (e.g. innovation procurement schemes) and of course co-funding rates of the shareholders.

Finally, the issue of competence building in the sector should be addressed. The new technologies need to be absorbed by the working force in order for their adequate implementation. This includes actions from the educational sector (academic as well as vocational) e.g. on updating their curricula and providing challenging training schemes and apprenticeships.

## GLOSSARY

ACARE:	Advisory Council for Aeronautics Research in Europe
DBFM	Design, Build, Finance and Manage
ECTP:	European Construction Technology Platform
ERRAC:	European Rail Research Advisory Council
ERTRAC:	European Road Transport Research Advisory Council
WATERBORNE TP:	Waterborne Technology Platform
TCO:	Total Cost of Ownership
R&I:	Research and Innovation
ROI/ROII:	Return on (innovation) investment
RPAS:	Remotely Piloted Air Vehicle
TRL:	Technology Readiness Level
GMES:	Global Monitoring for Environment and Security
UAV:	Unmanned Aerial Vehicles – now replaced by RPAS

## REFERENCES

Following overview includes references to the various research agenda's, roadmaps and implementation plans of the European Technology Platforms involved in the Joint ETP Task Force, as well as references to various current and planned land mark projects and programmes (not limitative), and related references from other sources.

### ACARE References:

- Flightpath 2050, Europe's Vision for Aviation; Report of the High Level Group on Aviation Research; ACARE; [http://www.acare4europe.org/sites/acare4europe.org/files/document/Flightpath2050\\_Final.pdf](http://www.acare4europe.org/sites/acare4europe.org/files/document/Flightpath2050_Final.pdf)
- ACARE Strategic Research & Innovation Agenda, Volume 1; <http://www.acare4europe.org/sites/acare4europe.org/files/attachment/SRIA%20Volume%201.pdf>
- ACARE Strategic Research & Innovation Agenda, Volume 2; <http://www.acare4europe.org/sites/acare4europe.org/files/attachment/SRIA%20Volume%202.pdf>

### ERRAC References:

- The ERRAC Roadmap Project; ERRAC; <http://www.errac.org/spip.php?article4>
- RailRoute2050; [http://www.errac.org/IMG/pdf/railroute2050\\_errac\\_final\\_v2.pdf](http://www.errac.org/IMG/pdf/railroute2050_errac_final_v2.pdf)
- Strategic Rail Research Agenda; <http://www.errac.org/IMG/pdf/SRRA-2007.pdf>

### ERTRAC References:

- ERTRAC Multi-Annual Implementation Plan for Horizon 2020; ERTRAC
- ERTRAC Research and Innovation Roadmaps - Implementation of the SRA 2010; Joint document, September 2011; ERTRAC
- Straße des 21. Jahrhundert - Innovativer Straßenbau in Deutschland; Bundesministeriums für Verkehr, Bau und Stadtentwicklung; [www.bmvbs.de/.../220-strasse-im-21-jahrhundert.pdf](http://www.bmvbs.de/.../220-strasse-im-21-jahrhundert.pdf)
- Routes de 5ème generation; IFSTTAR; <http://www.ifsttar.fr/en/recherche-expertise/colonne-1/nos-grands-projets/r5g-5th-generation-road>
- Forever Open Road programme; FEHRL; <http://www.foreveropenroad.eu/>

- Ferry Free E39; NPRA; <http://www.vegvesen.no/Vegprosjekter/ferjefriE39/Nyhetsarkiv/Ferry-free+coastal+route+E39,+Project+launch+conference.205923.cms>
- Exploratory Advanced Research Programme; FHWA; <https://www.fhwa.dot.gov/advancedresearch/>
- BIM project; Rijkswaterstaat; [http://www.rijkswaterstaat.nl/zakelijk/slimmer\\_werken/bouwwerk\\_informatie\\_model/](http://www.rijkswaterstaat.nl/zakelijk/slimmer_werken/bouwwerk_informatie_model/)
- Field Operational Test on Traffic Management on the A10 Amsterdam City Ring (PPA); Rijkswaterstaat; [http://www.rws.nl/zakelijk/innovatie/doorstroming\\_door\\_innovatie/lopende\\_projecten/projecten/praktijkproef\\_amsterdam/index.aspx](http://www.rws.nl/zakelijk/innovatie/doorstroming_door_innovatie/lopende_projecten/projecten/praktijkproef_amsterdam/index.aspx)

### Waterborne References:

- strategic research agenda; OVER VIEW - ISSUE II - May 2011; Waterborne
- Port Vision 2030/Port Compass; Port of Rotterdam Authority...
- “Strategic Research and Innovation Agenda of Inland Waterway Transport, PLATINA (March 2013)”
- ESPO Green Guide: Towards excellence in port environmental management and sustainability: European Seaports Organisation, June 2012
- Port Performance Indicators; Project ‘halftime’; coatings test
- Quay wall modelling system; that allows (port) managers to predict, simulate, analyse, prioritize, budget and plan maintenance of quay walls. (<http://www.portofrotterdam.com/nl/Over-de-haven/havenontwikkeling/Pages/kademuur-modellering-systeem.aspx>);
- Multi-core Rotterdam: underground pipeline distribution system for oil, chemicals and gases (capacity sharing); <http://www.portofrotterdam.com/en/Business/liquid-bulk/Pages/pipelines.aspx>
- Code24 Corridor Development Rotterdam-Genoa (<http://www.code-24.eu>): Corridor Information System
- IDVV : Stimulus Programme Dynamic Traffic Management for Inland Navigation; Rijkswaterstaat

### ECTP References:

- Research for Future Infrastructure Networks in Europe; Building up infrastructure networks of a sustainable Europe, ECTP-reFINE, January 2012
- reFINE Strategic Research Agenda Draft, ECTP-reFINE, November 2011
- reFINE Strategic Targets and Expected Impacts, ECTP-reFINE, October 2012
- reFINE Roadmap, ECTP-reFINE, v2 - May 2013
- Grand Paris Project
- IUK/ERG Cost & Efficiency Programme SEA project (Tours-Bordeaux high speed railway)Stuttgart 21: Connecting Europe - more than just a new train hub in the heart of a city Renewal of the A12 highway in the centre of The Netherlands
- HATCONS Project; High Workability Concrete for Underground Infrastructure
- OLIN Project
- SKRIBT; Schutz KRitischer Brücken und Tunnel im Zuge von Straßen
- REHABCAR; REHABILITATION OF ROAD AND MOTORWAY NETWORKS
- EXPLOTUN’Ground Exploration and Improvement Techniques Ahead of an Excavation Front
- CLEAM Project
- T2A TERMINAL HEATHROW AIRPORT
- Design and construction of the new runway on the Júcar riverin Cuenca
- THE WILD BRIDGE; Pilot sustainable bridge solutions using UHPFRC
- NBT Project; New Ballastless Track

### General references:

- WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system; COM/2011/0144 final
- COMMUNICATION FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT; Research and innovation for Europe’s future mobility; Developing a European transport-technology strategy; COM(2012) 501 final/SWD(2012) 260 final

- COMMISSION STAFF WORKING DOCUMENT; Preliminary Descriptions of Research and Innovation Areas and Fields; Accompanying the document Communication Research and Innovation for Europe's Future Mobility; COM(2012) 501 final/SWD(2012) 260 final
- Proposal for a COUNCIL DECISION establishing the Specific Programme Implementing Horizon 2020 - The Framework Programme for Research and Innovation (2014-2020); (Text with EEA relevance) COM(2011) 811 final/2011/0402 (CNS)/SEC(2011) 1427-Volume 1/{SEC(2011) 1428-Volume 1
- COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN COURT OF JUSTICE, THE COURT OF AUDITORS, THE EUROPEAN INVESTMENT BANK, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND TO THE COMMITTEE OF THE REGIONS A growth package for integrated European infrastructures
- The Geography of Transport Systems, 2nd edition; Jean-Paul Rodrigue, Claude Comtois and Brian Slack (2009); ISBN 978-0-415-48324-7
- Investment in Air Transport Infrastructure, The World Bank, Public-Private Infrastructure Advisory Facility (PPIAF), 2010, The International Bank for Reconstruction and Development
- Transportation Performance Index: Complete Technical Report, Let's Rebuild America; U. S. Chamber of Commerce; 2010
- First Intermediate Report "Evaluation of cohesion policy programme 2000-2006, work package transport", August 2009

**COLOPHON**

The Joint ETP Task Force on TRANSPORT Infrastructure Innovation consisted of following Members:

Chair:	Ruud Smit (Rijkswaterstaat)
ACARE	Peter Hotham (SESAR Joint Undertaking) & Christoph Schneider (Munich Airport)
ERTRAC:	Kallistratos Dionelis (ASECAP), Francesca La Torre (University of Florence)
ERRAC:	Dennis Schut (UIC), John Amooore (Network Rail)
Waterborne:	Victor Schoenmakers (Port of Rotterdam), Andreas Baeck (Via-Donau)
ECTP:	Luc Bourdeau (Centre Scientifique et Technique du Bâtiment)