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REFINET multi-modal transport infrastructure (RMMTI) model

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Project Coordinator: Alain ZARLI (CSTB)
Tel: +33 493 95 67 36
Fax: +33 493 95 67 33
E mail: alain.zarli@cstb.fr
Project website address: **www.refinet.eu**

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Abbreviations

Acronym	Full name
CSA	Coordination and Support Action
CEF	Connecting Europe Facility
EU	European Union
ERTRAC	European Road Transport Research Advisory Council
ERRAC	European Rail Research Advisory Council
ACARE	Advisory Council for Aviation Research
ECTP	European Construction Technology Platform
ALICE	Alliance for logistics Innovation through collaboration in Europe
HLSI	High Level Service Infrastructure
RMMTI	Refinet Multimodal Model for Transport Infrastructure
STA	Smart Transportation Alliance
S2R	Shift to Rail
LDT	Long distance transport
GHG	Greenhouse gas
CEDR	Conference of European Directors of Roads
FEHRL	Forum of European National Highway Research Laboratories
ERTMS	European Rail Traffic Management System
ITS	Intelligent Transport System
TIIM	Transport Infrastructure Information Modelling ()
SHM	Structural Health Monitoring
BIM	Building Information Modeling
BOT	Build-Operate-Transfer
PPP	Public Private Partnership
LOS	Level of service
KPI	Key Performance Indicator
MOT	Ministry of Transport
PM	Particulate Matter

NZTA	New Zealand Transport Agency

Definitions

Term	Full name
LOS	Level of service: *Level of Service* (also called *Quality of Service* or *Service Quality*) refers to the speed, convenience, comfort and security of transportation facilities and services as experienced by users. Level-Of-Service (LOS) ratings, typically from *A* (best) to *F* (worst), are widely used in transport Planning to evaluate problems and potential solutions. Because they are easy to understand (they are similar to the schools grades)[1]
Multimodal transport	Multimodal transport: The carriage of freight or passengers or both, using two or more modes of transports.

[1] See Ref [23]

1. INTRODUCTION

The Transport sector is one of the major drivers for economic growth and its reach into every aspect of society cannot be overstated. An **efficient and effective transport system** not only supports the economy with the movement of people and goods, but its influence is much deeper. Yet, it has a major impact on the environment and on the communities. Most activities in scientific disciplines such as chemistry, physics, computing, economics, psychology, logistics, as well as engineering, such as mechanical, civil, electrical, electronic, are directly or indirectly associated with applications in transport.[2]

The European transport infrastructure network is a shared heritage of great economic value, enabling wealth to be generated across the continent. The magnitude of Europe's transport infrastructure is indeed quite high – in terms of (1) Roads, with a total road network of approximately 5 million km in the 28 EU Member States, (2) Railways, with a total length of lines around 215,000 km, and (3) Waterways, with 41,000 km of navigable inland waterways. Europe possesses one of the densest and most developed infrastructure networks in the world, but most of these infrastructures were constructed in the period 1960-1970 and were designed for a working life of 50 years. Now these infrastructure networks are often strained far beyond their intended capacities in terms of traffic flows and loads, and with a 50-years design life at an end, a large part of the existing infrastructure reaches the end of its lifetime. Many of the existing infrastructures no longer fulfill current functional requirements and today's safety and quality standards, and require being strengthened and transformed: the ensuing reconstruction works will inevitably create an important disturbance of traffic with associated economic consequences. In addition, as result of the different socioeconomic developments in the European regions during the second half of the last century the transport infrastructure still need to be deployed in some of them. This is high priority for many European regions, as building a new regional transport infrastructure, extending and enhancing existing networks and removing transport bottlenecks therefore contributes directly to the fulfilment of the EU Cohesion policy goals. Decisions made today will have a decisive effect for mobility patterns extending beyond 2050, to the end of the 21st century. The Strategy adopted by the European Commission is built upon a *Single European Transport Area* (SETA) [SETA] supporting at European scale mobility of people and goods based on integrated and optimized services provided by Global Operators, and supported by Intelligent Transport Systems (ITS).This need at global European level is also explicated by the *Connecting Europe Facility* and its transport programme [CEF], which promotes and strengthens seamless transport chains for passenger and freight, while keeping up with future technological trends.
The cost of replacing the existing European infrastructure is considerably high, and massive coordinated investment and funding are necessary - considering that the construction and renovation activities of transport infrastructures today represent around 4,000 billions of dollars world-wide, and it is anticipated that this figure will be doubled by 2025. Without investment on research and innovation the sector will behave business as usual, which means building infrastructure the 20th century way – high carbon, wasteful, inefficient and at high cost. This means that the required business adaptation process to transform the transport sector into an integrated, inclusive, seamless, safe and sustainable mobility system as supported by the Transport "White Paper" [EC White Paper 2011] will hardly happen if innovation is not considered at the heart of the strategy. It is therefore vital to improve infrastructure delivery for people and freight, moreover becoming globally competitive.

Across Europe there is an urgent need to modernise construction delivery, and industry will not do it on its own – the risks, the structure of the industry and the implementation of EU procurement are barriers for innovation. Given the complexity of existing and future infrastructures, **there is need for a common European-**

[2] Mr Alessandro Damiani (Head of Unit, European Commission DG RTD, Hermes project workshop, 2014)

wide approach to the development and delivery of innovative concepts and solutions for infrastructure design, construction, maintenance and upgrading **to improve and extend in a customer-centric way the capacity of the existing network**.
Eventually, they face new challenges such as climate change conditions, cross-modal requirements and aging. In addition, the European Transport Infrastructure Construction Industry is the leader world-wide, keeping innovation high in the agenda in this sector will contribute to maintain the European leadership of the industry in this area.

Europe needs an interconnected multimodal transportation system that ensures a safe, efficient, accessible, affordable, convenient and comfortable move of people and goods with minimal adverse impacts to the environment. The design of a seamless integrated transportation system is required to achieve a competitive and connected EU. Drawing on the analysis of several documents produced by European Technological platforms, industry and other influential organizations, **this report outlines the most relevant characteristics of the REFINET Multi-Modal Transport Infrastructure (RMMTI) Model.**

There are several European initiatives that share this vision. A major one is the ECTP reFINE[3] initiative that advocates the need for developing High-Level Service Infrastructures (HLSI), to be considered the core elements of a future fully functional and EU-wide multimodal integrated transport by 2030 – the HLSI exposing the major following features:

- providing infrastructures for high quality mobility services for people and goods while using resources more efficiently;
- ensuring overall better service and performance, including multimodal integration and intermodal continuity for the end-user, less congestion, optimised transport time, etc.;
- higher degree of convergence and enforcement of social, safety, security and environmental rules for infrastructures, with minimum service standards (including minimum service obligations) at all time;
- interconnected solutions for the next generation of multimodal transport management, including information services and systems for all infrastructures.

The ERTRAC-ERRAC-Waterborne-ACARE-ECTP Task Force also raised high the need for research and innovation actions in order to 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 by 2030.

Why is it important investing in transport infrastructure?

The results show that deteriorating infrastructure, long known to be a public safety issue, has a cascading impact on the economy, negatively affecting business productivity, gross domestic product, employment, personal income and international competitiveness. The economic consequences of continued underinvestment in infrastructure and the economic gains that could be made if we choose to invest in infrastructure are astronomical [4].

Aged Infrastructure Networks often need to operate beyond their design lifetime or in combination with other heterogeneous systems. For the European community, the utilization of these Infrastructure Networks beyond their design life is, in many cases, essential to keep the European system of systems functional. Furthermore, there is an increasing demand for better asset management of transport infrastructure in order to meet the so-

[3] The reFINE initiative is now managed in the context of the newly formed “Infrastructures & Mobility” Committee within the ECTP – http://www.ectp.org.
[4] See Ref [65]

called "grand challenges" defined by the EU (sustainability, energy consumption, environment, employment and social cohesion) in a cost efficient way. In addition, the lack of balance between societal and political concerns and the resistance against major infrastructure development projects has to be addressed too.
New threats like climate change will directly affect the efficiency and robustness of the transport network. Roads and other highway infrastructure elements are already subject to extreme weather events, such as storms, heat waves and freezing weather that are part of natural weather variations, as well as seasonal differences where it is hotter, colder, wetter or dryer than average seasons or years. Climate projections indicate that climate change will further increase the frequency and severity of extreme weather events in the future as well as having more usually longer term effects related to change in average temperatures and rainfall.
In order to maintain competitiveness, the European transport networks need to be resilient to the impact of climate change at reasonable operating costs, ensuring safety and sustainability, achieving 100% reliability under extreme events and, especially in freight corridors, with limited congestion. Some research projects[5] have already been funded to assess the risk and the impact of the developing climate upon transport infrastructure. Some of them even attempt to define mitigation measures. However, the technology to mitigate, prevent or withstand the effect of this future climate is still to be developed.

Transport demand is strongly driven by demand growth in, to and between large cities and other urban areas. The demand for long distance journeys is already growing in many countries and is expected to increase. Elderly people will use transportation networks more frequently, particularly in urban areas and for long distance journeys. Besides, the patterns for younger people are expected to change in favour of multimodal travel patterns with fewer car owners. In any case, the current growing number of vehicles and mobility trends in the world, the challenges presented by transportation, which are global concerns, such as congestion, safety, security, energy efficiency and the environment, are likely to come high in the agenda for the near future.

As mentioned above, without investment on research and innovation the sector transformation into an integrated, inclusive, seamless, safe and sustainable mobility system as envisaged in the White paper will hardly happen. From a technological perspective, innovation is expected to produce more energy and resource efficient systems. [6]

Figure 1 High Speed 1, formerly CTRL (UK).

Regarding integration between modes, although major achievements have been obtained, the European transport networks still exhibit an insufficient level of integration, at several levels, including: infrastructure, information, regulation or servicing. In practical terms, we have the coexistence of multiple single-modal networks with some contact points. There is therefore the need to continue the efforts of integrating, so that, the long term political goal of having seamless door-to-door transport services across EU could be a reality. In this sense, the European

[5] http://ec.europa.eu/research/transport/news/items/eu_projects_say_transport_networks_vulnerable_to_climate change_en.htm
[6] See Ref [27]

Commission has put forth the ambitious Connecting Europe Facility (CEF) investment program, under which, €26.25 billion will be made available from the EU's 2014-2020 budget to co-fund TEN-T projects in the EU Member States

Physical, digital and operational interconnectivity amongst Long Distance Transport (LDT), urban areas and hubs, integrating automated transport, as well as standard interfaces and protocols, are clearly needed.
The European infrastructure and transport sector faces novel challenges in new scenarios:

- A safe, efficient, accessible, affordable and seamless integrated transportation system is required to achieve a competitive and connected EU.
- An integral and efficient asset management is demanded: time and cost effective operation, maintenance and reconstruction, especially in urban areas.
- European infrastructure reliance on carbon intensive and non sustainable materials has to be reduced.
- Infrastructure has to incorporate resilience to climate change.
- Infrastructure availability and capacity has to be maximized, reducing downtimes due to maintenance and repair.
- Both rural areas and urban areas face major challenges with regard to infrastructure. Depopulation and the social exclusion of the elderly need to be prevented, and urban planning must adapt.
- A massive increase in waterborne transport is expected[7].
- The transport system has to be sustainable in terms of GHG emissions, air quality, land use, water, waste and resource efficiency while minimising impact on biodiversity and ecosystem services;
- 4 hours door to door (ACARE)
- Synchromodality (ALICE)

These achievements will result in :

- Better performance of infrastructure and vehicles.
- Better trans-shipment facilities, minimizing time and resources in transferring freight from one transport mode to another.
- Development of reliable planning tools that optimize the use of transport networks.
- The effects of improved transportation conditions on economic productivity[8] and competitiveness will result in efficient accomodation between different transport modes, reduces congestion and contributes to a well-connected more competitive Europe.
- Resource efficient and low-energy transport.
- Faster interconnection between modes.
- High quality jobs in design, construction and maintenance.
- Higher productivity and quality of service to users: timely alerts and reduction of congestion, lower lifecycle costs and better capacity to translate production savings into procurement savings.
- A strong boost to growth and employment.

Money spent on capital investment and operations will increase:

- The flow of income supporting business activity and jobs
- The long-term productivity impacts,

[7] See Ref [61]
[8] See Ref [73]

Why do we need a new infrastructure policy for Europe?

A new infrastructure policy for Europe is required because:

- Transport is fundamental to an efficient European economy.
- Freight transport is expected to grow by 80% by 2050, and passenger transport by more than 50%[9].
- Growth needs trade. And trade needs transport. Areas of Europe without good connections are not going to prosper.

In practice there are five problematic areas which need to be tackled at EU level:

- Missing links, in particular at cross-border sections, are a major obstacle to the free movement of goods and passengers within and between the Member States and with its neighbours.
- There is a considerable disparity in quality and availability of infrastructure between and within the Member States (bottlenecks). In particular, East-West connections require improvement, through the creation of new transport infrastructure and/or maintenance, rehabilitation or upgrading of existing infrastructure.
- Transport infrastructure between the transport modes is fragmented. As regards making multi-modal connections, many of Europe's freight terminals, passenger stations, inland ports, maritime ports, airports and urban nodes are not up to the task. Since these nodes lack multi-modal capacity, the potential of multi-modal transport and its ability to remove infrastructure bottlenecks and to bridge missing links is insufficiently exploited.
- Investments in transport infrastructure will contribute to achieve the goals of reduction of greenhouse gas emissions in transport by 60% by 2050.
- Member States still maintain different operational rules and requirements, in particular in the field of interoperability, which significantly add to the transport infrastructure barriers and bottlenecks.[10]

Additionally, there is an urgent need to incorporate innovation in the market. Policy can strongly promote this change, sharing risk and shortening the path from research to market. This requires a coordinated effort between Infrastructure procurers, research agents, designers and contractors. A larger use of Public Procurement for Innovation and Green Procurement processes and a stronger collaboration of the value chain in pilot and demonstration projects assessing lifecycle impacts, followed by dissemination of findings can accelerate market uptake of innovation. [11]

This document introduces the REFINET Multi-Modal Transport Infrastructure (RMMTI) model and framework, which is a key ambition of the H2020 REFINET Coordinated and Support Action, whose overarching aim is to create a shared European vision and strategic implementation plan about how the multimodal European transport infrastructure network of the future should be specified, designed, built or renovated, upgraded and maintained. REFINET especially relies on a sustainable innovation network that integrates relevant stakeholders from all transport modes (road, railway, maritime, fluvial…) and transport infrastructure.

[9] See Ref [41]

[10] See Ref [41]

[11] Innovating for Growth through Transport Infrastructure, Jose Viegas, Secretary General International Transport Forum, OECD,EC-DGMOVE – 22 March 2013

2. Approach

Objective

This document aims to define the RMMTI. It will enable the visualization and the integration of the partial approaches elaborated by the different European Technology Platforms, transport sectorial associations, European Commission and national governments of the European transport infrastructures at medium (2030) and long term (2050). This RMTTI model focuses on key aspects as: integration of the different transport modes (cost-saving, reduction of energy intensity and subsequent CO2, pollutants and noise emissions); adoption of Green Infrastructures; increasing the infrastructure's capacity and optimising their maintenance costs; enhancing the sustainability, performance and reliability of the infrastructures; extending the life span of ageing transport infrastructure; minimising traffic disruption mainly at upgrading works… The model includes the associated KPI (Key Performance Indicators, see Chapter 6), which will allow benchmarking the current transport infrastructures against this model.

Several Strategic Research Agendas, Roadmaps, and documents addressing the way forward for transport infrastructure have been elaborated so far. This document aims to build up on these previous work (See References). However, except:

- those elaborated by the REFINE initiative,
- the FOREEVER Open Road Programme
- the Roadmap elaborated by the Cross-modal group formed by ACARE, ECTP, WATERBORNE, ERRAC, and ERTRAC[12]

none of these documents focus on the needs of the infrastructure sector. Our approach is primarily dedicated to the transport infrastructure needs.

Multilevel approach

This document has defined the following structure to house the required specifications for the RMMTI:

- Level 1: where to allocate target service level specifications.
- Level 2: to enable the integration of a systemic perspective for cross cutting specifications.
- Level 3: to place the technological improvements required.

Performance

A cross modal approach of drivers of level of service (performance) for all modes has been adopted for the REFINET Multi-Modal model for transport infrastructure (RMMTI).

- Availability: lack of disruption during maintenance, extended life time, …
- Safety and Security
- Accesibility
- Harmonisation of services in coordination between countries and regions
- Comfort
- Standardisation

[12] See Ref [42]

Specific attention will be devoted to specific challenges emerging at mode interfaces/nodes

SYSTEMIC APPROACH

A whole systemic approach along the whole life cycle of new generation of intermodal networks, driven by cost-benefit considerations, is demanded. The systems of systems nature of the transport networks[13] requires a coordinated approach to High Level Service Infrastructure (HLSI) performance aspects such as safety, security, sustainability, efficiency, reliability and challenges regarding the demand of knowledge in building more resilient networks to natural and man-made hazards.

This systemic approach in the design, construction, operation and maintenance stages of new generation of intermodal networks and infrastructure will ensure:

- smooth and efficient mobility services for people and goods.
- overall better service and performance, including multimodal integration and intermodal continuity for the end-user.
- a higher degree of convergence and enforcement of social, health, safety, security and environmental rules for infrastructure.
- Interconnected solutions for the next generation of multimodal transport management.

The analysis and decomposition of the architecture of the system of systems will enable the identification and quantification of interdependencies, thus facilitating the establishment of criticalities. This process requires the assistance of the transport infrastructure owners and operators.

A paradigm shift in the areas of safety and resilience will arise from the system of systems changing risk approach, as interconnected infrastructure networks. The holistic assessment of the transport infrastructure resilience will enable coordination and timely response throughout the interdependencies, with prevention, resistance to disturbance and failure recovery measures.

TECHNOLOGICAL GAPS

Many of the technologies that are needed to allow evolving the European transport infrastructures towards the RMMTI model are already available in the market or will be available in the next years, but the sector is not aware about their availability and potential. In order to overcome the gap between “common practices” in design, construction and maintenance of transport infrastructures and the “most sustainable practices” that could be deployed, the different technologies that are offered by the main engineering companies, contractors and maintenance services providers will be considered in the RMMTI

How have we defined the model? Methodology

The most relevant high level documents elaborated by:

- the European Commission,
- relevant Technology Platforms
- transport sectorial associations,
- industry,
- national governments,
- CEDR,
- FEHRL, etc.

[13] System of systems: dedicated systems that pool their resources and capabilities together to create a new, more complex system which offers more functionality and performance than simply the sum of the constituent systems.

have been selected and analyzed in order to identify the characteristics of the European multimodal model for transport infrastructures.
These documents were analyzed by the REFINET partners, and also by external experts from National Construction Platforms.

In parallel a bottom-up approach was undertaken, gathering information to shape a map of Research projects. For this analysis a template was facilitated, in order to standardize the process. The synthesis and conclusions of the analysis of the documents are presented below.

Moreover, some workshops were developed, in order to get the feedback from selected experts. The Workshops carried out aimed at identifying the major trends and challenges within the transport infrastructure sector, and at defining a framework for the analysis of future multi-modal transport infrastructure RMMTI model, thinking of new and existing transport infrastructures.

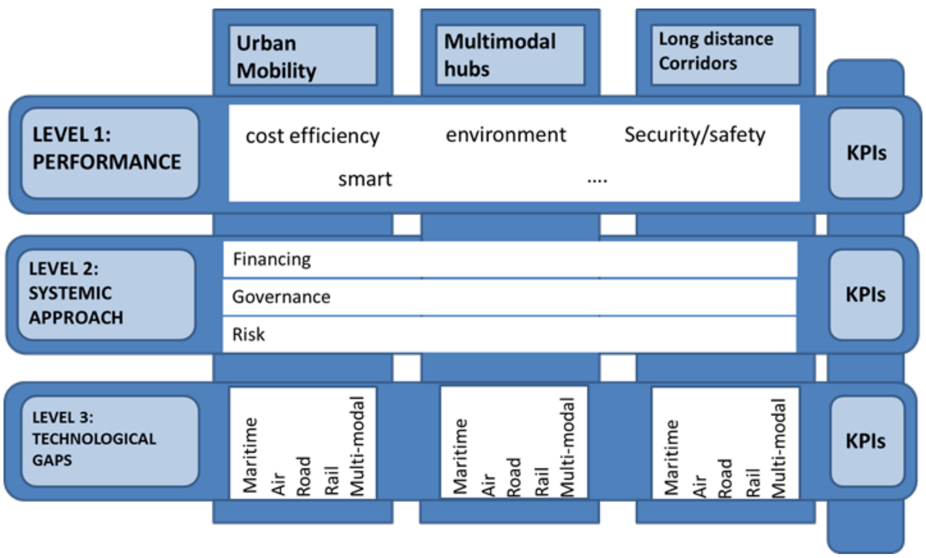


Figure 2 Framework for the analysis of future multi-modal transport infrastructure RMMTI model

Finally, synergies with other CSAs in this area of knowledge have been taken into account, exchanging information and producing common documents.

This project is an opportunity to follow up previous work carried out by:
• the coordinated initiative of reFINE in the European Transport Infrastructure field, which produced relevant documents such as the reFINE impact Assessment and Roadmap;
• ERTRAC-ERRAC-Waterborne-ACARE-ECTP, which produced the "Roadmap for cross-modal transport infrastructure innovation";
• Work carried out by infrastructure managers at regional, national and EU level.

REFINET is a joint effort of ECTP, ENCORD, FEHLR, UIC, PTEC, …, which, as mentioned above, showed a high level of commitment before REFINET, and will continue to be engaged in this initiative, sharing common

interests in the transport infrastructures field in the future (e.g. see recent creation of the Infrastructure and Mobility Committee).
REFINET is committed to engage with the whole infrastructure sector by engaging them through the expert network and through dissemination activities. The intention of REFINET is to broadly disseminate the results (model and SIP) with the support of the EC (DG Research Transport, DG Move, DG Regio, etc.) in order to be enriched in the future.In fact, there is a positive experience in collaborating among the transport research initiatives as the related ETPs and associations (ECTP, ERTRAC, ERRAC, Waterborne, ACARE, UIC, FEHRL, PTEC) have expressed their interest in research roadmapping for transport infrastructures, which will ensure the updating of the model.

In any case, the results will be opened to the research community through these organizations working groups, committees, events, websites, …; therefore the model would be used and updated in the frame of technology platforms and other initiatives.

Eventually, after REFINET completion, it is already planned that the ECTP "Infrastructures & Mobility" committee will take over the role to work and integrate the (post-REFINET) activities in coordination with others ETPs.

However, during the project, the regular information and communication activities targeting the Refinet Community and beyond enable to "coach" the transport and construction stakeholders.

In addition, the involvement of (carefully selected) stakeholders (by the consortium) within the project (via Workshops), forms a real catalyzer of the adoption of the Model and Vision by the transport and construction stakeholders.

Finally, the transport and construction stakeholders being involved in the organizations which are partners of REFINET Consortium, the post-project coaching will be ensured via the regular meetings of these platforms.

3. BACKGROUND

At European level, and in order to tackle all the challenges facing the transport network infrastructure owners, transport operators, engineering and construction companies and other stakeholders across all modes, the need of sharing knowledge and cooperating in a way that will be beneficial to all parties and that will increase the overall performance of multimodal transport infrastructures is supported by the European Commission trough three H2020 Coordinated and Support Actions that have been jointly launched:

- USE-iT: Users, Safety, Security and Energy in Transport Infrastructure [USE-iT 2015];
- FOX: Forever Open Infrastructure across (X) all Transport Modes [FOX 2015];
- REFINET: Rethinking Future Infrastructure Networks [REFINET 2015].

While REFINET particularly aims at building a large community of stakeholders from all transport modes and the construction sector too, and on which the 3 CSA projects intend to rely upon to achieve their objectives, the objective of these 3 CSAs are from a complementary perspective:

- developing a roadmap describing the research challenges and implementation steps to achieve greater cooperation and co-modal operations in the areas of users, safety, security and carbon/energy (USE-iT);

- defining a comprehensive cross modal approach in the area of construction, inspection, maintenance and recycle & reuse of transport infrastructure, that would serve primarily infrastructure owners/operators in anticipating the future (FOX).
- delivering a shared European vision of how to specify, design, build or renovate, and maintain the multimodal European transport infrastructure as well as deploy this vision to support European competitiveness (REFINET). The ultimate REFINET objective is to provide with a strategic research agenda that will integrate and prioritize short-, medium- and long-term research and innovation targets, with a focus on the entrepreneurial consideration of infrastructures that targets the architectural, engineering and contracting eco-system, including socio-economic aspects of the development and the management of infrastructures.

The 3 CSAs have been integrated into a general scheme of development for European research and innovation in transport infrastructures. In such a framework, REFINET contributes to create a European-wide consensus on where to focus by 2020 and beyond in terms of research and innovation in order to further increase the performance of multimodal transport infrastructure. REFINET, supporting the EU 2020 strategy, will kick-start a long-term ambition and initiative, paving the way to enhanced technology transfer and mass-market development for innovative materials, components, systems and processes supporting the pan-European generalisation of ***advanced multimodal HLSI***, especially considering the three following key attributes for HLSI:

- **Green**: Infrastructure networks are designed for a minimum environmental impact over their entire life cycle from design and construction stage, to service and final recycling. Continuous, efficient and reliable quality of service makes infrastructure a major contributor to reducing energy and materials resources for European economy. The environmental impacts of infrastructures during their whole life-cycle are to be dramatically reduced, optimising their energy and raw materials consumption during construction (including upgrade) and maintenance, reducing nuisances and environmental impacts (e.g. noise, vibrations, pollution of air and groundwater, affection to biodiversity…) and land occupation during service life, reducing waste generation during maintenance and demolition, etc.;
- **Smart**: Infrastructure networks provide a high quality level, continuous and safe service throughout natural and man-made hazards, and climate change. They support European quality of life in sustainable cities by a continuous and safe circulation of people and goods, providing the physical means for mobility to live and work. Quality of services is visible and recognised by all categories of users and by society. Existing and new infrastructure must be considered as key components of an inclusive society, in which everyone's life chances are maximized. Every people must have access to the services and facilities they need and the transport infrastructures is one of them. The needs of specific groups such as disabled people, minority ethnic communities, elderly people, children and young people and faith groups are met. Their voices are considered in the community planning and decision-taking, and they are able to use community resources. Associated challenges are the assurance of the Equality and Diversity, the fostering of the Citizenship Participation and the accessibility and affordability to Services and Infrastructures;
- **Low Cost**: Infrastructure networks are commonly regarded as a shared heritage of great economic value; their maintenance and upgrade costs are optimised and safely managed as a necessity to preserve and increase the quality of life for the future generations of European citizens. It is important to keep in mind that low cost does not mean "low cost quality", it indeed means affordable costs that are socially acceptable, targeting cost-benefit optimisation and coping with contradictory constraints from cost to environmental friendliness.

It is already acknowledged across Europe that there is need for a common European-wide approach to the development and delivery of innovative design, construction, maintenance and upgrading concepts and solutions to improve and extend in a customer-centric way the capacity of the existing network. Several European initiatives share this vision, among them the ECTP initiative supported by the "Infrastructure & Mobility" Committee that advocates the need for developing HLSI, to be considered the core elements of a future fully functional and EU-wide multimodal integrated transport by 2030

The ERTRAC-ERRAC-Waterborne-ACARE-ECTP Task Force [TaskForce 2013] also raised high the need for research and innovation actions in order to enable an improvement of 50% in infrastructure performance, risk and cost versus a 2010 baseline as well as enabling seamless door-to-door services for passengers and freight by 2030. Ageing, climate change and demographic changes are the most impactful drivers of the European Transport network. With the growing number of vehicles and mobility trends in the world, the challenges presented by transportation, which are global concerns, such as congestion, safety, security, energy efficiency and the environment, will certainly come high in the agenda at short term.
Several Strategic Research Agendas, Roadmaps, and documents addressing the way forward for transport infrastructure have been elaborated: the RMMTI model aims to build up on these previous works ([USDOT 2015], [ERRAC 2015], [ERTRAC 2015] or [Shift2Rail 2015] – just as examples). However, except those elaborated by the REFINE initiative [reFINE 2012, reFINE 2013], none of these documents focuses specifically on the needs of the infrastructure sector.

A whole systemic approach along the whole life cycle of a new generation of intermodal networks, driven by cost-benefit considerations, is demanded. The system nature of the transport networks requires a coordinated approach to High Level Service (HLS) performance aspects such as safety, security, sustainability, efficiency, reliability and challenges regarding the demand of knowledge in building more resilient networks to natural and man-made hazards. The procedure followed to obtain this model is described as follows:

- The documents that have been elaborated by different technology platforms, transport sectorial associations, the European Commission and Member States have been analysed in order to integrate their partial approaches (by transport mode, technical aspect, business model…) into a unified multi-modal transport infrastructure model. A similar approach has been followed to select the KPIs that will allow the European transport infrastructures' managers benchmarking them against the RMMTI model. The most common KPIs that are already defined by different transport infrastructures' managers have been analysed and the most relevant from the RMMTI model perspective have been selected.
- The definition of this model has not been done only by the REFINET partners, but also by the members of the REFINET network who have been involved in the discussion through workshops and reviews of the proposed model.

The model offers a generic simple vision that can be shared by all transport stakeholders and research related organisations. In being a high-level non transport-mode specific model, it tries to promote acceptance from all transport related organizations independently of the transport mode they represent. This has been a major hurdle in all previous transport roadmapping initiatives.
In addition, the model is to be used:

- To exchange with the stakeholders so as to integrate their views and future R&I items in the REFINET vision (e.g. this model has been the basis for the work undertaken with invited experts during the REFINET workshop in London – 16/03/2016);
- to set up the basic structure of the Strategic Implementation Plan (SIP);
- To be used by infrastructure managers for the definition and evaluation of European infrastructures.

The model should be a living reference for the establishment of objectives and sustained criteria for defining the design and operation specification of infrastructure projects in Europe.

This model (and KPIs) will be shared in different planned dissemination actions in the project (already presented in TRB2016, to be further presented at TRA2016 & WCRR2016). The model will be opened to further development by the infrastructures sector through the different technology platforms and initiatives.
With respect to the KPIs, and starting from the initial identification achieved in the ECTP reFINE initiative, the objective in REFINET is potentially fine-tune the existing KPIs into a more focused potential KPI structure. Although it is not planned in the project to develop activities related to KPIs, REFINET will achieve the following results:

- review and detail KPIs identification through ongoing experimental studies, research and applied research investigations; especially, more progress will be done on KPIs after analyzing feedback obtained at the London workshop and other workshops;
- Knowledge sharing, review and thorough assessment of a complete set of KPIs for transport infrastructures;
- Future identification of relevant data streams and data sources to be further mobilised for appropriate KPI validation. Mobilisation is to be achieved through literature review, surveys, audits and interviews;
- Future use of KPIs in monitoring / assessing and follow-up validation of future applied research projects and demonstrator pilots.
- Future use of KPI and model for defining the specifications for design and operation of European infrastructure.

It is worth mentioning that more progress available in KPIs will allow further use and refinement of RMMTI.
All these aspects will be developed in terms of future recommendations related to the SIP deployment in WP4.

4. Analysis of technological demands

Road is the dominant transport mode in Europe, claiming 73.4% of passenger transport, and 71.8% of the hinterland freight transport, excluding sea transport (2011 value; EC, 2013a). This dominance of road transport has impacts on congestion, environment and safety, and limits the use of more resource efficient modes, impeding their growth and competitiveness.

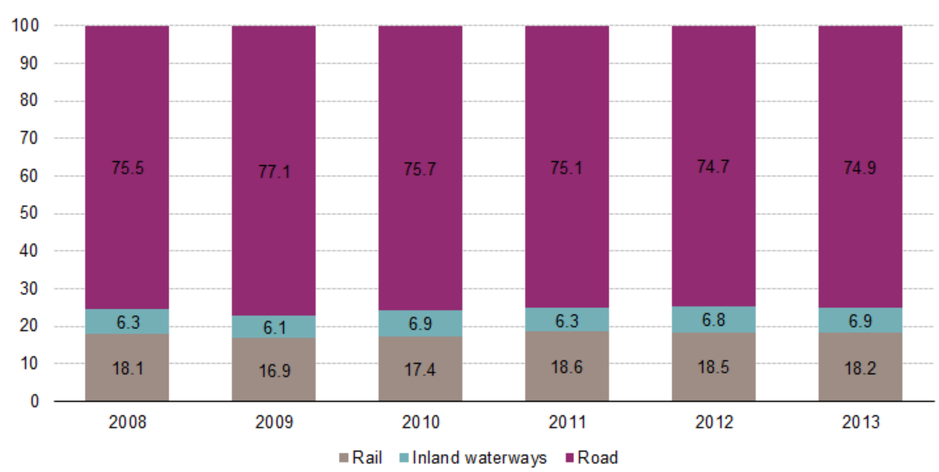


Figure 3 Freight transport in the EU-28: modal split of inland transport modes (% of total tonne-kilometres)[1]

As mentioned above, the RMMTI will build up on existing knowledge. The main conclusions obtained from some of the most relevant documents are summarised as follows.

4.1 Road sector

The **European Road Transport Research Advisory Council** (ERTRAC) mentions the following objectives in their roadmap in the field of infrastructures[14]:

- New, more durable materials, construction and management concepts to extend the intervals between maintenance measures and to reduce maintenance 'down time' of the capacity.
- Highly standardized communication technology based on open software platforms, allowing for real time, uniform interfaces to vehicle and user.
- Legislation streamlines to ensure projects are completed in the least possible time. Decrease of public funds.
- Efficient management of the infrastructure.
- Forgiving self-explaining infrastructure.
- The future transport infrastructures design requires cost-efficient and sustainable solutions for maintaining, redesigning and adapting the existing physical infrastructure including pavements, bridges, road equipment, parking, access to stations, platforms as well as new concepts for new construction.
- Integrated transport network: Integrated infrastructure network management.
- Upgrading of the existing infrastructure (e.g. electrification).
- Integration of automated transport.
- Climate resilient networks and infrastructures.
- Monitoring of bridges and tunnels is required to guarantee safety and reliability.
- New innovative designs and materials (drainage, pavement, substructure,…) increase safety and durability of the road transport infrastructure in thunderstorm and flood exposed regions.
- Dedicated Infrastructure. Research is needed on dedicated, variable use of the infrastructure (lanes and interfaces) as to allow roads, bridges and tunnels to be optimised for particular types of vehicles and services in particular situations (time of the day, etc.) reducing maintenance and environmental impact and increasing efficiency and safety of the road transport system as a whole. For example, dedicated systems for high-speed bus and taxi corridors, platooned trucks, electric vehicles, automated transport.
- How to integrate Roads to such extent that they become virtually invisible to the surrounding living environment (Good Neighbourship) in terms of all aspects of pollution, nuisance (e.g. noise), community severance and natural habitat fragmentation.
- How to integrate all the aspects of energy production from road pavements, tunnels and other structures, with the surrounding living environment.
- Intelligent and adaptive Infrastructure. An adaptive design supports the process of innovation implementation and allows for "retrofitting" of newly developed intelligent transport solutions.
- The systems will also interact with and will provide information to the infrastructure operator and manager about the current structural conditions and deliver input to modern asset management systems.

[14] See Refs [53] to [57]

- Road status monitoring. Road transport infrastructure is well monitored and large-scale data is used in innovative cross-asset management systems without traffic hindrance. This provides a sound data basis for optimizing maintenance planning and reduce transport infrastructure downtimes due to maintenance or repair works.
- Impact of connectivity on land use, spatial distribution of activities and mobility demand.
- Design, Construction & Maintenance of infrastructure. By 2030 dedicated road infrastructure should be able to support new transport concepts such as road-trains, electrification of freight transport and the first stages of automated transport. The design of new infrastructure and the upgrades of the existing, should aim for minimal carbon footprint, taken from a life cycle approach. In addition the design, construction and maintenance of the road infrastructure should consider on cost-effective measures to reduce down-time due to maintenance and repair.
- New materials that prolong infrastructure life, reduce the disruption caused by maintenance and replacement, to reduce the reliance of bridge construction on carbon intensive materials such as concrete and steel and to produce new pavements constructed solely from carbon neutral materials.
- Efficient infrastructure maintenance and reconstruction. Research is needed on time- and cost-effective maintenance and reconstruction technologies and regimes that maximise the uptime of the integrated road transport network by minimising the need for disruptive maintenance and repair interventions, especially in the urban areas (cables, pipes for water, gas, electricity and communication technologies) and congested corridors.
- Self-explaining and forgiving infrastructure. Research is needed to develop design concepts to the paradigm of 'self-explaining' and ' forgiving roads' as to develop a comprehensive safety standard accommodating the targets set by European and national policies.
- Integral Asset Management.
- Land Use Planning. Research on Land use and planning is concerned with the spatial interactions i.e. the nature, extent, origins and destinations of the movements of passengers and freight as well as the transport system, that is supporting the movements of passengers and freight.
- Assessment of (Urban) Accessibility.
- Integrated mobility planning. Research is needed on best practices to integrate land use and transport and mobility planning, considering in particular the location and opportunity of new transport infrastructure such as roads and interchanges for the movements of persons and goods.

Also, the **Smart Transportation Alliance** (STA) also identifies the following innovation topics in their Strategic Road Research Agenda [15]:

- Topic 1 – Smart and green road construction & operation
- Topic 2 - Road infrastructure safety
- Topic 3 – Road mobility & modal integration

4.2 Railway sector

The design, construction, operation and maintenance of (railway) infrastructure networks has to be safe, reliable, supportive of customer needs, cost-effective and sustainable.(…) There needs to be a elimination of network diversity through a migration towards a common high- performing infrastructure system architecture. [16]

[15] See Refs [5] to [10]
[16] See Ref [30]

As labour- intensive maintenance accounts for a significant part of the operating costs, most of the research initiatives are focused on their reduction. Besides, many parts of the existing infrastructure are incapable of offering the level of service demanded. A change in productivity of the assets is needed, they will have to be managed using lean operational practices and smart technologies. Finally, compatibility between infrastructures should be ensured, in order to support pan-European corridors and co-modal links.
Although the **Shift to Rail** Joint Undertaking (S2R)[17] objectives are not centered in the field of infrastructures as it is understood in the REFINET CSA, some of high level objective regarding these are:

- Improved services and customer quality.
- Reduced system costs.
- Enhanced interoperability.
- Simplified business processes.

S2R priority research and innovation activities: specifications for the RMMTI model in the railway sector:

- Reliable and efficient switches and crossings, adjusting point operating systems to trains running at much higher speed or with much higher loads. Embedded sensors that enable remote condition monitoring, self diagnosis and adjustment functions.
- Track design and materials that enable the measurement of stress, degradation, stiffness, etc. Integrated Health Monitoring Systems for damage prevention and mitigation strategies.
- Tunnel and Bridge solutions which are cost effective: with extended service lives with inspection methods that are fast and more accurate.
- Intelligent maintenance systems are built on cutting edge monitoring tools. Whole life costs are estimated with advanced system degradation modelling. Routine maintenance checks are automated.
- New modular, accessible multimodal stations.
- Energy efficient concepts and systems: to minimose losses and guarantee a flexible supply (smart metering, smart storage systems).

The European Rail Research Advisory Council ERRAC [18] depicts the following characteristics for its Transport infrastructure model on its vision and priorities for infrastructure:

- Integrated, advanced, affordable and acceptable to citizens.
- With optimised performance.
- Operation and Maintenance: reliable, supportive of customer needs, cost effective, sustainable, adaptable, automated and resilient.
- Interoperable.
- Self-learning.
- Intelligent, fatigue and wear resistant. Remote condition monitoring enables minimum interruption of service and maximum availability.
- Optimised processes

4.3 Waterborne[19]

It is necessary to narrow the gap in the point-to-point delivery time of waterborne transport relative to road transport. This can be achieved by various means, including minimising the distance from vessel discharge

[17] See Ref [30]
[18] See Ref [27]
[19] See Ref [61] to [62]

point to consumer; minimising docking time; minimising transfer time from ship to shore; minimising time to identify, select, transfer and clear individual consignments. To achieve this, several RD&I activities are important.

Regarding **Equipment and Systems for Faster Cargo Handling**, major European ports are equipped with modern rapid cargo handling systems, but there is scope to improve these and opportunities for improvement must be regularly reviewed. However, many smaller ports and harbours are not equipped with modern and standardised handling facilities. These have to be made available cost effectively for smaller applications, to fulfil the objective of delivering waterborne goods closer to the consumer and in less time.
Research activities are necessary to identify weaknesses in the existing port systems, including inappropriate and nonstandard handling facilities and to propose Europe-wide standard solutions. This must be done in conjunction with new concepts of vessels and innovative loading/unloading systems. Improvements are necessary to trans-shipment methods to reduce trans-shipment time and thus encourage greater use of short sea, coastal and inland shipping. Express, secure port network systems and procedures should be developed to facilitate more rapid and secure transit of goods throughout their entire transportation from door to door, including inter-port trans-shipment. This will reduce containers' dwell time in ports to only a few hours instead of days.

As for **Automatic Operations***, a*ppropriate and standardised automated docking systems have the potential to reduce point-to-point cargo delivery times. Any significant reduction in time will improve the competitive position of waterborne transport relative to road, but also will improve overall operational efficiency resulting in lower unit costs. This will be most significant for high value vessels such as large container ships and bulk carriers. A standardised cost-effective system should be identified and developed. The automation of marshalling areas is already a feature of a few large ports, but has yet to be widely adopted. Research is needed to determine whether automated marshalling can be safely and economically introduced to a wider spectrum of ports sizes and types.
Automated control of vessels approaching/departing port using intelligent systems and improved navigational aids could significantly help to increase efficiency and safety of ship handling. The technological aspects of such development should be investigated along with a consideration of the legal and regulatory aspects.

4.4 Multimodal

In its vision, the White paper on Transport[20] includes the following characteristics for a competitive and sustainable transport system:

- Growing Transport and supporting mobility while reaching the 60% emission reduction target.
- An efficient core network for multimodal intercity travel and transport.
- A global level-playing field for long-distance travel and intercontinental freight.
- Clean urban transport and commuting.
- Ten Goals for a competitive and resource efficient transport system: benchmarks for achieving the 60% GHG emission reduction target.

From their side, ERTRAC, ERRAC, Waterborne, ACARE, ECTP Task force, on their Roadmap[21] for cross modal Transport Infrastructure Innovation, highlight that key to improving the capacity and availability of the existing

[20] See Ref [63]

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).

For the Task Force the focus is on:

- NON-INTRUSIVE CONSTRUCTION, MAINTENANCE, ENHANCEMENT AND RENEWAL
    - Advanced and Automated Survey, Inspection and Testing.
    - Advanced Manufacturing and Construction Concepts.
    - Advanced and Automated Maintenance.
- TOWARDS ZERO CARBON FOOTPRINT
    - Energy Harvesting.
    - Low Carbon Construction.
    - Infrastructure for Low and Alternative Energy Transport.
- MULTI-MODAL TRANSPORT NODES AND CORRIDORS
    - Optimal location, operation and accessibility to and within terminals, hubs and gateways.
    - Seamless interchange of freight and passengers.
    - Synchro-modality over key transport corridors.

With respect to the European Commission, the New EU transport– background MEMO[22] highlights that, a particular priority of the EU transport infrastructure policy is that technical requirements must be interoperable across the network. For example, that means that ERTMS (the European Rail Traffic Management System) – the basic ITS systems to control the trains must apply everywhere. Equally, road safety standards in terms of tunnel safety requirements and road safety requirements must apply across the network, and the technology for ITS (Intelligent Transport Systems) must join up. Also if there are future electric vehicle infrastructure charging points to be built, logically, they must meet common standards, so the cars can use them all across the network.

4.5 Summary of Infrastructure Technological Demands

After the revision of the existing documents and the feedback from stakeholders and experts, the most repeated **technological demands in the field of infrastructure highlighted in the most impactful documents** mainly focus on the following fields:

- Safety.
- Environmental impact, energy efficiency and decarbonisation.
- Road mobility and modal integration.
- Urban mobility.
- Asset management.

[21] See Ref [42]
[22] See Ref [41]

- Financial and multi-modal transport infrastructure Business Model.
- Standards, communication and dissemination channels.
- ITS.
- Construction vs. maintenance.

4.5.1 Safety

Tunnels: A disproportionate share of accidents occurs in tunnels. Many are old and not designed for high traffic volumes. EU law sets minimum safety requirements for tunnels, including measures to prevent them becoming death traps in an accident.
Level crossings: Accidents at level crossings deserve a specific attention. Although they account for a limited proportion of road accidents (up to 2% of the road fatalities), they account for some 30% of fatalities from the railways perspective. In most cases, the primary causation is the inappropriate behaviour of road users (bad evaluation of risk, lack of attention, and misunderstanding of road signs)[23].

In the different documents analysed the following priorities have been identified in the field of safety:

- Track design and materials that enable the measurement of stress, degradation, stiffness, etc. Integrated Health Monitoring Systems for damage prevention and mitigation strategies.
- Life-cycle risk-based analysis and development of tools moving from risk engineering to risk transfer within an all-hazards approach.
- Technologies, tools and methodologies supporting the implementation of systematic road safety impact assessment, audits and inspections
- Innovative road safety solutions.
- Advanced road equipment.
- Accidentology and accident reconstruction[24].

4.5.2 Environmental impact, energy efficiency and decarbonisation

Transport infrastructure projects have a relevant impact in environmental issues and new technologies and management practices are required to reduce the negative impacts in the environment. In particular, to contribute to the "Resource efficiency roadmap[25]" which establishes targets to guarantee natural capital and ecosystems, biodiversity, minerals and metals, water, air, noise, land and soils, marine resources. Furthermore, identifies sectors like transport and mobility where special attention is required. "*The Commission will ensure that the initiatives in the Transport White Paper are implemented consistently with resource efficiency objectives, particularly by moving towards internalisation of external costs.*"

In terms of GHG emissions it is expected a 1% yearly reduction according to the roadmap. In spite of recent developments, a lot of progress has already been made by the car industry to reduce the pollution of individual

[23] http://ec.europa.eu/transport/road_safety/topics/infrastructure/level_crossing/index_en.htm
[24] See Ref [6]
[25] See Ref [67]

vehicles, although there is still a lot of work to be done. Noise induced by transport is still a big issue; as is air pollution, especially in built up areas[26].

The development of electric vehicles by the automotive industry should be complemented by the use of recycled or new, less environmentally burdensome materials and processes, which offer opportunities to reduce greenhouse gases. New materials that prolong infrastructure life, reduce the disruption caused by maintenance and replacement, to reduce the reliance of construction on carbon intensive materials such as concrete and steel and to produce new pavements constructed solely from carbon neutral materials.

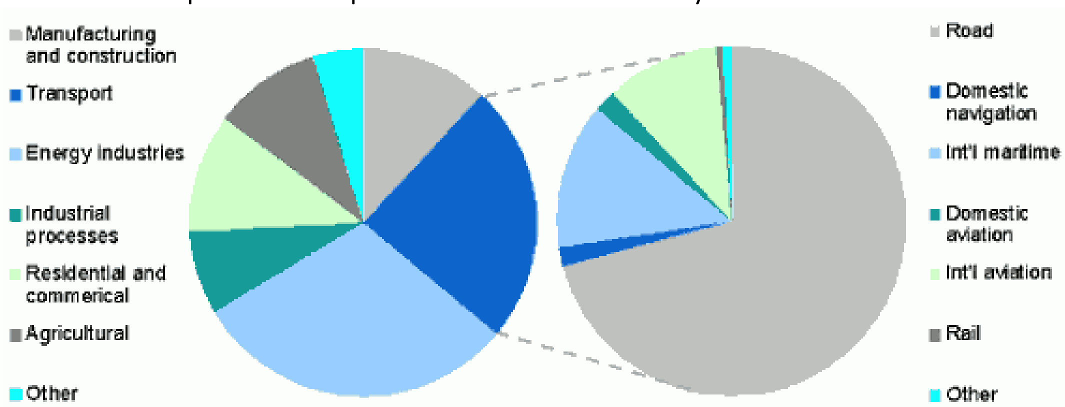


Figure 4 EU27 greenhouse gas emissions by sector and mode of transport, 2007 (Source: Policies - Climate Action - European Commission)[27]

Concerning energy efficiency[15]: Not taking into account particular situations, energy prices have increased significantly over the years and are anticipated to continue increasing in the medium-long term. Both constructing and maintaining roads in an energy-efficient manner are major challenges. Energy efficiency is extremely important. It is not only a matter of rising costs, but also of scarce resources. It was also noted that larger trucks, which are controversial in some European countries, do reduce the energy demand for freight transportation.

[26] See Ref [40]
[27] See Ref [41]

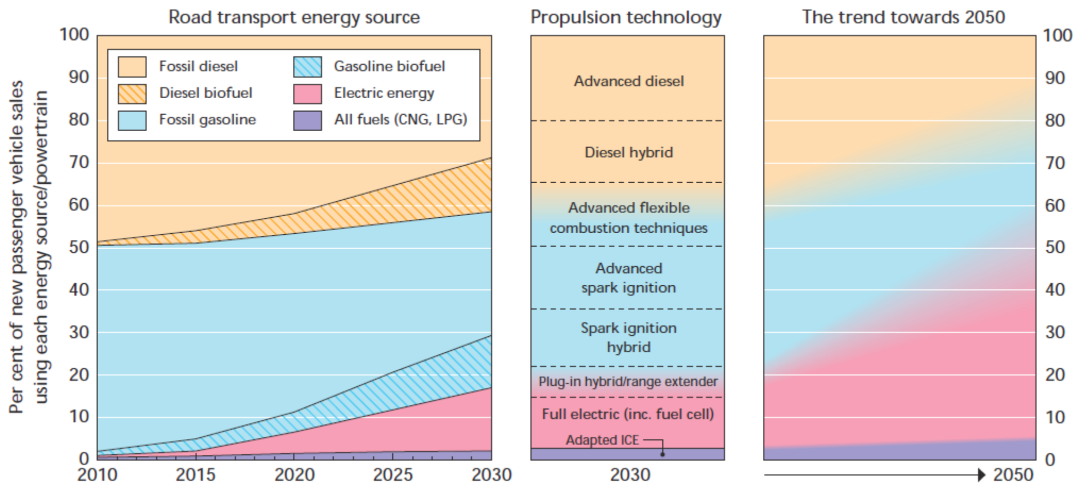


Figure 5 Trends of road transport energy sources
(Source: ERTRAC Research and Innovation Roadmaps).

4.5.3 **Road mobility and modal integration**[28]

An important aspect of local government planning for ports and airports is ensuring the accessibility of these facilities through the surface transportation system for the efficient movement of people and freight.
To become more multimodal and intermodal more choices should be provided for moving freight and people with seamless transfers across mode choices. Intermodal connectors – highways, rail lines, and waterways connecting hubs to corridors - are a core element of the statewide transportation system. Intermodal logistics, created to aid in the shipment of goods through a seaport, are an important connection.
The transportation element should identify all rail and roadway corridors used to access a port or airport facility. Corridor management plans or strategies should be applied to these facilities where necessary to improve truck operations or throughput.

- Transformation of the infrastructure to accommodate modal shifts and multi-modal uses.
- Impact of connectivity on land use, spatial distribution of activities and mobility demand.
- Intermodal Connectivity.
- Optimising the use of existing road infrastructure.
- Dedicated corridors.
- Mobility models adapted to the new generation of vehicles.
- Development and deployment of cooperative systems and cooperative transport.

[28] See Ref [26]

4.5.4 Urban Mobility

The EU highlights the need for research on the evolution of scenarios towards optimized solutions for urban mobility and logistics, and on establishing guidance on existing and future conditions analysis and mapping.

Urban mobility infrastructure is the n°1 priority for cities[29]. Urban mobility is one of the most intractable challenges faced by city governments, presenting economic, social and environmental implications. The provision of physical infrastructure is fundamental to enable mobility, yet there is a tipping point at which additional supply will no longer provide an efficient means to service demand. Patterns of mobility in many cities mean that there is significant under-utilised capacity on existing infrastructure for long periods of the day. As part of a package of measures, smart solutions can help to improve the efficiency of the system and redistribute demand across modes, routes and time. The smart mobility system requires a variety of infrastructure types, including physical infrastructure, operational technologies, and communication and information technologies. Coordination and integration between different layers in the structure allow improved operational efficiency, as well as new products for demand management.[30] Given that urban infrastructure is a key factor in luring businesses to cities, overloaded infrastructures would be highly damaging commercially.[31]

On the other hand, integration between regional mobility systems still remains very low in comparison to other parts of the economy as transport infrastructures were historically designed to serve regional rather than supraregional goals. In that context, there is a need for stronger alignment between regional mobility strategies.

Urban mobility is one of the toughest system-level challenges facing actors of the mobility ecosystems. In the future, innovative mobility services will be driven less by improvements in single transport modes than by integration. What is needed is system-level collaboration between all stakeholders of the mobility ecosystem to come up with innovative and integrated business models[33].

4.5.5 Asset management

Maintenance versus Construction[32]

The European transport network has roughly the shape and length needed for the coming decades. What must now be improved is the continuity of the quality of the network, from the number of lanes, to the interchanges, the comfort of users, and the traffic management measures. To keep the existing network up and running, the quality of maintenance is of paramount importance. With less money available in most countries, the maintenance of the existing network must be prioritised versus new construction.
Aged infrastructures, often need to operate beyond their design lifetime. For the European Community, in many cases, the utilization of these infrastructure, beyond their design life is essential to keep the various utility systems and, with them, the European system of systems functional. Besides, there is an increasing demand for better asset management within the various European sectors in order to meet the so-called

[29] See Ref [77]
[30] See Ref [35]
[31] See Ref [36]
[32] See Ref [40]

“grand challenges” defined by the EU (sustainability, energy consumption, environment, employment and social cohesion). In addition, the lack of balance between societal and political concerns and the resistance against major infrastructure development projects has to be addressed too.[33]
However, the effective agreed ageing issues are yet to be developed and consistently applied as importance of ageing concerns regarding infrastructures, will continue to increase due to:

- The need to continue operating beyond their design life-time.
- The need to operate under changed conditions and
- the demand for functional assets.

When and where it is not possible to maintain the whole network at a desired level, the introduction of service level agreements must set clear priorities which are understandable and communicated to the public. Asset management becomes essential as it provides a detailed knowledge of the network and a life cycle approach to infrastructure maintenance

Future maintenance approach will guarantee the service level of the existing infrastructure, to the same standards as those specified for the high level service new infrastructure.

The priorities identified by the strategic documents analysed are:

- Evolution of Asset Management systems and tools to ensure business continuity, taking into account current and incoming threats as well as the impact of climate change. Relevant and professionally accepted data sources and analysis procedures/tools.
- Intelligent maintenance systems are built on cutting edge monitoring tools. Whole life costs are estimated with advanced system degradation modelling. Routine maintenance checks are automated.
- Intelligent monitoring systems including for Structural Health Monitoring (SHM).
- Introduction of smart structures and systems in order to move towards a reactive infrastructure.
- Transport Infrastructure Information Modelling (TIIM) adapting the concept of BIM to infrastructure networks.
- Integrated transport network: Integrated infrastructure network management.

4.5.6 Financial and multi-modal transport infrastructure Business Model

[33] See Ref [29]

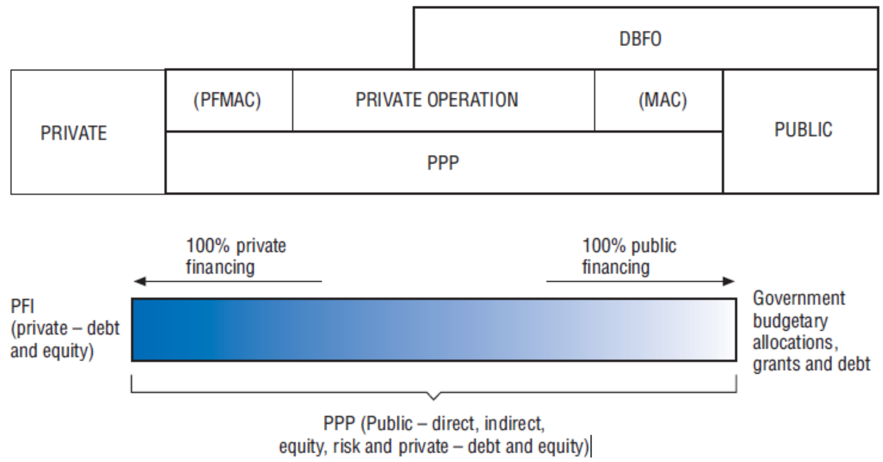


Figure 6 Actual Bussiness models[34]

- Public: Traditional purely Public sector funding drawn from taxation, together with a range of alternative public funding.
- Design-Build-Finance_Operate
- Public-Private Partnership
- Private operation. Private instruments for Operation and Repair
- Private: Build-Operate-Transfer (BOT) concession

Financing[35]: The reduced availability of public funds for construction and maintenance of road infrastructure has become a reality in most European countries. Providing better roads for less money is possible only in the short-term. In the medium- and long-term, it is an impossible challenge as the roads will continue to deteriorate and the backlog in maintenance will increase.
The gradual shift from fuel cars to electric cars affects not only road infrastructure, but also the tax policy and the revenues from fuel tax. Finding alternative funding of roads will become a necessity as today the fuel used in transport is heavily taxed, while alternative energy sources are subsidised; tomorrow both fuel and alternative energies will have to be taxed.
Instead of public funds, the PPP model is being used as a possible instrument, although the higher costs and the additional risks of private financing must not be underestimated.
User charging by electronic systems is seen as most promising for allocating equitably the costs induced by the infrastructure's construction and maintenance.

4.5.7 Standards, communication and dissemination channels

A standardization strategy is required in order to achieve the implementation of the RMMTI, being the standards themselves fed by innovation in the transport system. While research on equipment and services identifies smart and efficient ways to make transport seamless, the solutions need to be disseminated to stakeholder to stimulate market uptake. Promoting multimodal techniques and services and harmonized

[34] See Ref [75]
[35] See Ref [40]

standards and regulations contribute to market uptake of new solutions to streamline multimodal chains[36]. Research is required in the following fields in order to promote the shift to multimodal solutions:

- Establishing quality/ level of service standards and other performance measures or benchmarks.
- Integrated, advanced, affordable and acceptable to citizens.

4.5.8 ITS

ITS must be considered as a tool and not as a purpose. ITS will most probably play a major role in the implementation of user charging combined with other applications like: demand and traffic management, improvement of safety, reduction of congestion, saving of fuel. ITS technology shall become part of the infrastructure design and no longer be considered as a retrofit facility. Moreover, synergies from data provided by ITS should be enhanced.

Priorities highlighted by experts[37] focus on:

- the development of new user-centric methodologies.
- managing big data.
- visualisation and augmented reality and
- service-oriented architectures across future networks.

5. Unified REFINET multi-modal transport infrastructure model

The RMMTI model has a structure that, following the targeted multilevel approach presented above (see Chapter 2), enabled:

- the unification of all previous approaches from different organizations (see Chapter 3)
- address and host all technological demands previously identified (see Chapter 4)

Further on, a similar approach will be followed for selecting KPIs that will allow the European transport infrastructures' managers benchmarking them against this RMMTI model (See Chapter 6).
Following the above presented premises, on Figure 6 we can visualize the basics of the RMMTI, with a three level structure, aiming at the high level of service envisioned, through a systemic approach, supported on the technology as the foundations of the model:

- Performance will be defined mainly from a multimodal perspective
- Mode specific models will feed and will be interconnected within the systemic approach
- Technological Gaps will need continuous updating

The main added value of the RMMTI model as compared to other transport infrastructure models lies in the systemic multimodal approach. This ambitious perspective will enable the redefinition of cross modal performance targets throughout the transport as a system, allowing the identification of interdependencies, vulnerabilities, mainly focusing in the following fields:

[36] See Ref [37]
[37] See Ref [25]

- Safety.
- Environmental impact, energy efficiency and decarbonisation.
- Road mobility and modal integration.
- Urban mobility.
- Asset management.
- Financial and multi-modal transport infrastructure Business Model.
- Standards, communication and dissemination channels.
- ITS
- Construction vs. maintenance.

On Figure 6 we can visualise the structure of the RMMTI model, and its multilevel approach:

1. Vision: Level of service standards and performance measures
2. Targets: Systemic Approach
3. Priorities: Technological Gaps

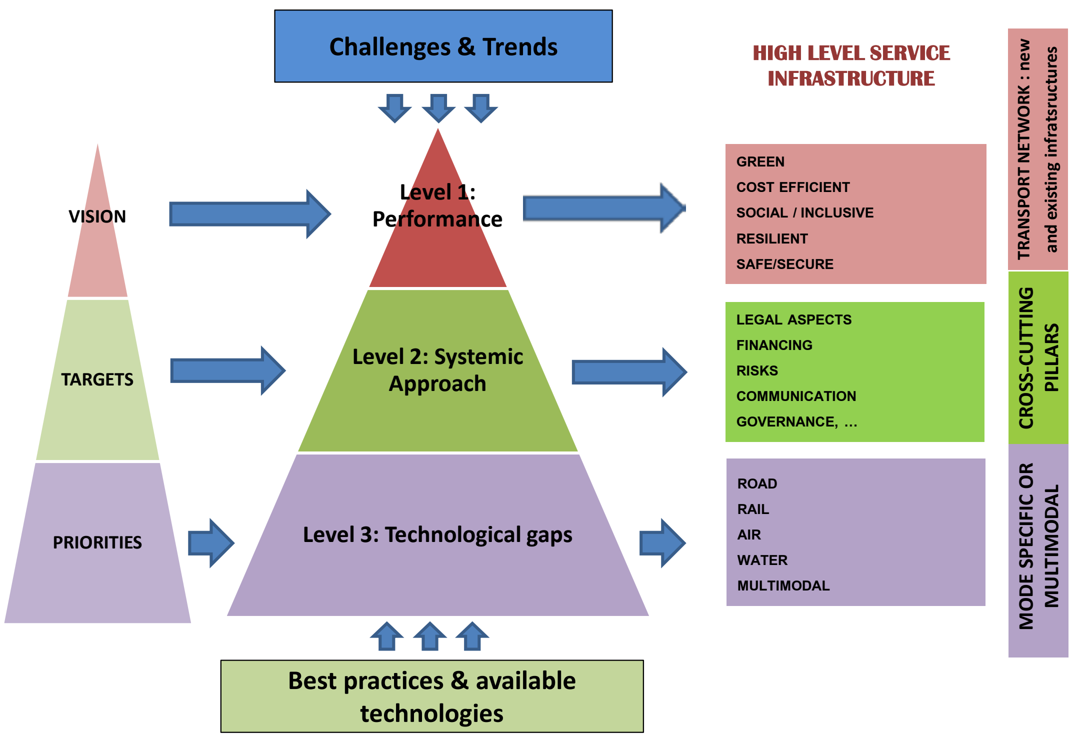


Figure 7 RMMTI model structure.

5.1 LEVEL 1: Level of service standards and performance measures

Figure 8 Future of Highways (ARUP).

Performance = Level of Service (LOS) aspects.

"Level of service" = indicator of the extent or degree of service provided by a facility based on the operational characteristics of the facility. Level of service shall indicate the capacity per unit of demand for each public facility.
(LOS) analysis is used in planning to determine available capacity based on existing and anticipated travel demand.
For example, Road Network Performance can be measured – Efficiency, Reliability and Productivity

Multimodal level of service standards ensure that the operating characteristics of other modes are maintained or improved to a locally desirable level. Standards may relate to a variety of operational characteristics of importance to each mode.[38] The RMMTII model is structured around the following target performance characteristics of the transport infrastructure system (See Figure 6), on the grounds of the revision of the existing documents and the feedback from stakeholders and experts:

- Green/Sustainable.
- Cost efficient.
- Low cost.
- Safe, reliable, resilient.
- Social/Inclusive.

5.2 LEVEL 2: Systemic Approach

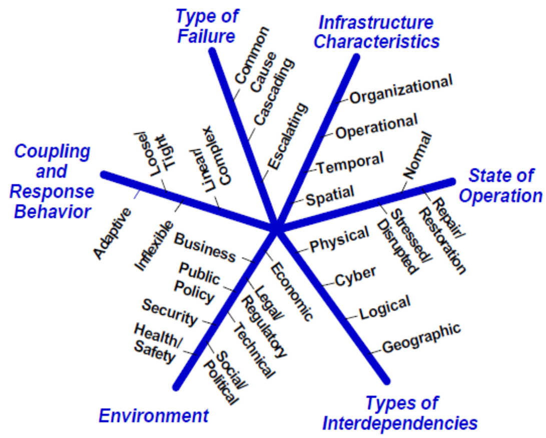
The second level of the structure of the REFINET model considers the systems of systems nature of the transport infrastructure networks, throughout the design, construction, operation and maintenance stages.

This interconnected system includes all types of transport infrastructure (roads, railways, busways, light rail, cycling and pedestrian paths), the routes used for different types of trips and infrastructure that is constructed, owned and operated by local and state government, government owned corporations and private entities. It is important that the transport network is considered as a whole system to maximise the performance and efficiency of all infrastructure in the network.[39]

The systems of systems nature of the transport networks requires a coordinated approach to High Level Service Infrastructure (HLSI) performance aspects such as safety, security, sustainability, efficiency, reliability and

[38] See Ref [26]
[39] See Ref [28]

challenges regarding the demand of knowledge in building more resilient networks to natural and man-made hazards.



A paradigm shift in the areas of safety and resilience will arise from the system of systems changing risk approach, as interconnected infrastructure networks. The holistic assessment of the transport infrastructure resilience will enable coordination and timely response throughout the interdependencies, with prevention, resistance to disturbance and failure recovery measures.

The improvement of accessibility and connectivity between modes will arise as a clear demand from this approach.

Figure 9 The six dimensions of infrastructure interdependency. [40]

In this second level, under the umbrella of integrated design, construction and operation, building on the conclusions extracted from several Strategic Research Agendas, Roadmaps, and documents addressing the way forward for transport (See Chapter 3), we will consider the following aspects of the infrastructure network, selected on the basis of cross-cutting issues that are most impacted if considered from a systemic approach :

- Legal aspects.
- Financing.
- Risks.
- Communication.
- Governance.

5.3 LEVEL 3: Technological Gaps

At this level, after a process of gathering, inventorying and analyzing information about existing transportation conditions, both the needs of the current transportation system as well as improvements needed to accommodate growth are included in our model.

Analyses of both current and future needs share several commonalities, such as quality/level of service analysis for all modes, analysis for network planning, and evaluating transit needs. Estimates of future travel demand in relation to planned future land use will inform the planning effort, as will estimates of potential future changes in travel behavior based on land use and the availability of additional transportation modes. Local vision statements and supporting goals and objectives can provide a framework for evaluating alternatives and for selecting appropriate projects and strategies for European multimodal transport infrastructure. Both mode specific and multimodal analyses will be carried out.

[40] See Ref [78]

As conclusion, this RMMTI model or framework intends to be an **OPEN, ACTIVE and QUALITY reference** for the future multimodal transport infrastructure.

- This model is specific for the **INFRASTRUCTURE** and **in short-term**, intends to:
    - **Assess the existing transport infrastructures and be a criteria for the new ones**, adequating and defining the different KPIs and their thresholds, specifically for each infrastructure, in a near future projects.
    - **Structure the priority areas and actions of the Strategic Implementation Plan**, around the identified 5 performance features which define the High Level Service Infrastructure in Level 1 of the model (Green, Cost-Efficient, Social/Inclusive, Resilient and Safe/Secure), as well as the other 5 performance features related to Systemic approach (level2 of model).
- This model could be a start point, **in long-term**, of a **European Quality Label** for transport Infrastructure.
- This model should be **updated by different technology platforms, associations and the Commission.**

6. EUROPEAN TRANSPORT KPIS

6.1 Analysis of most common KPIs for multimodal infrastructures

Performance Evaluation refers to a monitoring and analysis process to determine how well policies, programs and projects perform with regard to their intended goals and objectives. *Performance indicators* (also called *measures of effectiveness*) are specific measurable outcomes used to evaluate progress toward established goals and objectives. A *performance index* is a set of performance indicators in a framework designed to facilitate analysis. Commonly used performance indices include school grades, sports ratings, economic productivity indicators, and investment rating systems.

An organization's performance can be evaluated at various levels:

- *Process* – the types of policies and planning activities, such as whether the organization has a process for collecting and publishing performance data, and public involvement.
- *Inputs* – the resources that are invested in particular activities, such as the level of funding spent on various activities or modes.
- *Outputs* – direct results, such as the miles of sidewalks, paths and roads, and the amount of public transit service provided.
- *Outcomes* – ultimate results, such as the number of miles traveled and mode split, average travel speeds, congestion and crowding, number of accidents and casualties, energy consumption, pollution emissions, and user satisfaction.

It is often best to use some of each type of performance indicators. For example, when evaluating the performance of a government agency or jurisdiction it may be appropriate to develop a performance index that include indicators of process, inputs, outputs and outcomes.

Performance indices have many practical applications including trend analysis, comparisons, target setting, and incentives (such as rewards) for managers and employees. They provide a navigation system that indicates where the organization is, where it wants to go, and how to get there. They help to identify developing problems and the effectiveness of solutions. Indices can present data in various ways:

- Per capita
- Per vehicle
- Trends over time
- Comparisons with peers (other jurisdictions or groups)

Performance indicators must be carefully selected to accurately reflect goals and identify problems. Inappropriate or incomplete indicators can misdiagnose problems and misdirect decision-making (DeRobertis, et al. 2014; Gladwell 2011). For example, an index that only considers quantity will encourage organizations to produce abundant but inferior output, while an index that only considers quality can result in high quality but inadequate production quantity.

The following principles should be applied when selecting transportation performance indicators (Hart, 1997; Marsden, Kelly and Snell, 2006):

- *Comprehensive* – Indicators should reflect various economic, social and environmental impacts, and various transport activities (such as both personal and freight transport).

- *Data quality* – Data collection practices should reflect high standards to insure that information is accurate and consistent.

- *Comparable* – Data collection should be standardized so the results are suitable for comparison between various jurisdictions, times and groups. Indicators should be clearly defined. For example, “Number of people with good access to food shopping” should specify ‘good access’ and ‘food shopping.’

- *Easy to understand* – Indicators must be useful to decision-makers and understandable to the general public. The more information condensed into a single index the less meaning it has for specific policy targets (for example, *Ecological Footprint* analysis incorporates many factors) and the greater the likelihood of double counting.

- *Accessible and transparent* – Indicators (and the raw data they are based on) and analysis details should be available to all stakeholders.

- *Cost effective* – The suite of indicators should be cost effective to collect. The decision-making worth of the indicators must outweigh the cost of collecting them.

- *Net effects* – Indicators should differentiate between net (total) impacts and shifts of impacts to different locations and times.

- *Performance targets* – select indicators that are suitable for establishing usable performance targets.

6.2 KPIs from the RMMTI model perspective

As it is mentioned in the previous paragraph, KPIs are metrics to evaluate factors and performance. These metrics are established in order to monitor and reach a target value in their strategic and operational goals.

In the past the European initiative called reFINE defined certain qualitative and quantitative KPIs (reductions or percentage increases) in order to establish and identify the themes in which to work and put efforts in terms of investment in research and innovation.

On that occasion, three characteristics were considered fundamental (Environmentally friendly infrastructure - GREEN; Inclusive services at all times - SMART; and Cost-efficiency - LOW COST), Targets /KPIs were established generically for each mode of transport and in three levels of for transport infrastructure (URBAN MOBILITY, MULTIMODAL HUBS and LONG DISTANCE CORRIDORS).

An example of the document referred to KPIs in reFINE initiative in relation to targets and KPIs for multimodal hubs in Air transport mode is shown in the following figure. Other targets and KPIs for other transport modes and levels of transport infrastructure could be found in the public document from the ECTP webpage http://infrastructure.ectp.org/fileadmin/user_upload/documents/I_M/reFINE_Targets_Impacts.pdf:

MULTIMODAL HUBS - AIR		
DESCRIPTION	*EXAMPLES*	*TARGETS*
Innovation in infrastructure for air transport in Europe must accommodate the ambition of a pan-European network of intermodal airports hubs, while ensuring the delivery of extensive, integrated, efficient and sustainable air transport systems, primary for passengers, but also for airfreight that can be transported to its destination very fast and efficiently. The inland hubs need to develop new installations to ensure an easier and fast connection with the regional, national and also international railway infrastructure. Airport hubs infrastructure must be improved within environmental – including measures that reduce noise and air pollution, reduce impact on the environment in particular on noise for close resident areas.	Schiphol airport in Amsterdam with international railway lines access. Dusseldorf Airport and its access to the ICE high speed train. Frankfurt Airport hub (Fraport), connecting air to road and train (regional and long-distance) transport. Charles de Gaulle Airport in Paris and its direct access to the high speed train international corridors.	• By 2050, solutions are improved in terms of integrated management of the passengers transport systems at world level. Airports became the access doors connecting continents and this necessary optimizes the utilization of infrastructure. Up to 2030, more airfreight cargo needs to be transported inter continents and that means the need to ensure news solutions for fast transfers to the railway and road (truck) inland networks. Full integration of air transport infrastructure and traffic management systems with the other modes of transport (most notably rail, sea carriers and local and regional transport) is achieved. Seamless door-to-door travel of passengers and freight is the norm. • Integration of renewable energy production and utilization in airports infrastructure is generalized, and modal optimization of the infrastructure implies good environmental effects. Airport operations are resilient against weather and other disruptions. Environmental impacts are reduced in particular on quiet urban areas. • New products and services allow holistic air and railway operations monitoring, e.g. for passengers landing and take-off times that can be synchronized to the high speed trains arrivals and departures. For cargo the streamlining of the dispatch of goods transported by cargo aircrafts to the distribution transport networks is optimized. Delays are mitigated by highly efficient operations and through night operations enabled by ultra-quiet aircrafts. Congested airports are no longer a bottleneck due to action taken by the Single European Sky, SESAR, successor programmes, connections to other ATM systems worldwide and new aircraft concepts. • The Single European Sky is fully implemented and the successor programmes of SESAR and similar interoperable programmes globally have ensured that capacity meets expanding demand in the air and at airports. These developments have optimised the access and trajectories of air vehicles, ensured equity of access and safe and efficient vehicle operations with the most efficient possible fuel consumption and emissions at the lowest possible cost. • A comprehensive framework (methods and tools, including the use of ICT systems for the required exchange of information and coordination) is deployed for the optimization of logistics chains, the process optimization, and the realization of appropriate infrastructure components (e.g. fast handling systems). It also supports optimised and interconnected services by providing real-time information to professionals and travelling public for enhancing system resilience in the event of disruption and crisis.

		KPIs for Environmentally friendly infrastructure • By 2030, full integration of LCA (Life-Cycle Analysis) in air transport infrastructure is achieved.	*KPI for All-inclusive services* • By 2050, all inland airports hubs are interconnected with roads and rails. The intercontinental traffic ensures its fast and inclusive connection to its final destination in all Europe areas.	*KPIs for Cost-efficiency* • Generalization of hubs airports infrastructure cargo handling and passenger boarding systems, in order to provide safe, reliable, fast and cost efficient airport operations. • Full integration of air transport with railway and road transport networks in order to minimize costs.

In the contrary, the REFINET project, through the definition of its model RMMTI, aims to establish an open, active and reference framework that encourages the following strategic atributes for European transport infrastructure:

-GREEN
-COST-EFFICIENT
-SOCIAL / INCLUSIVE
-RESILIENT
-SAFE / SECURE

Since it is understood that the European multimodal transport infrastructure should cope with the different challenges that could be included under these five areas or atributes. Thus, it is intended to establish a potential benchmark index (REFINET INDEX) that would serve to value, assess and compare the aforementioned characteristics, based on the specific strategic and operational objectives particular to each case and through the specific indicators defined for it. The definition of specific values is beyond the scope of REFINET project and it could be a clear follow up of this activity but the need, relevance and motivation are clear.

The definition of specific and individual KPIs should be in accordance with the stakeholders´goals, the defined target values linked to these objectives, which also depend on the transport infrastructure type (multimodal hub, long distance corridor or urban mobility) and the nature of these KPIs (reasonable, technically measurable, economically feasible aspects)

However, it has been made a first classification of indicators that fits the model defined in the project and gives greater specificity to the aspects under the criteria of the REFINET partners and the conclusions drawn from the various workshops. It will also clearly contribute to establish the principles to monitor monitor and evaluate research programmes oriented to transport infraestructure.

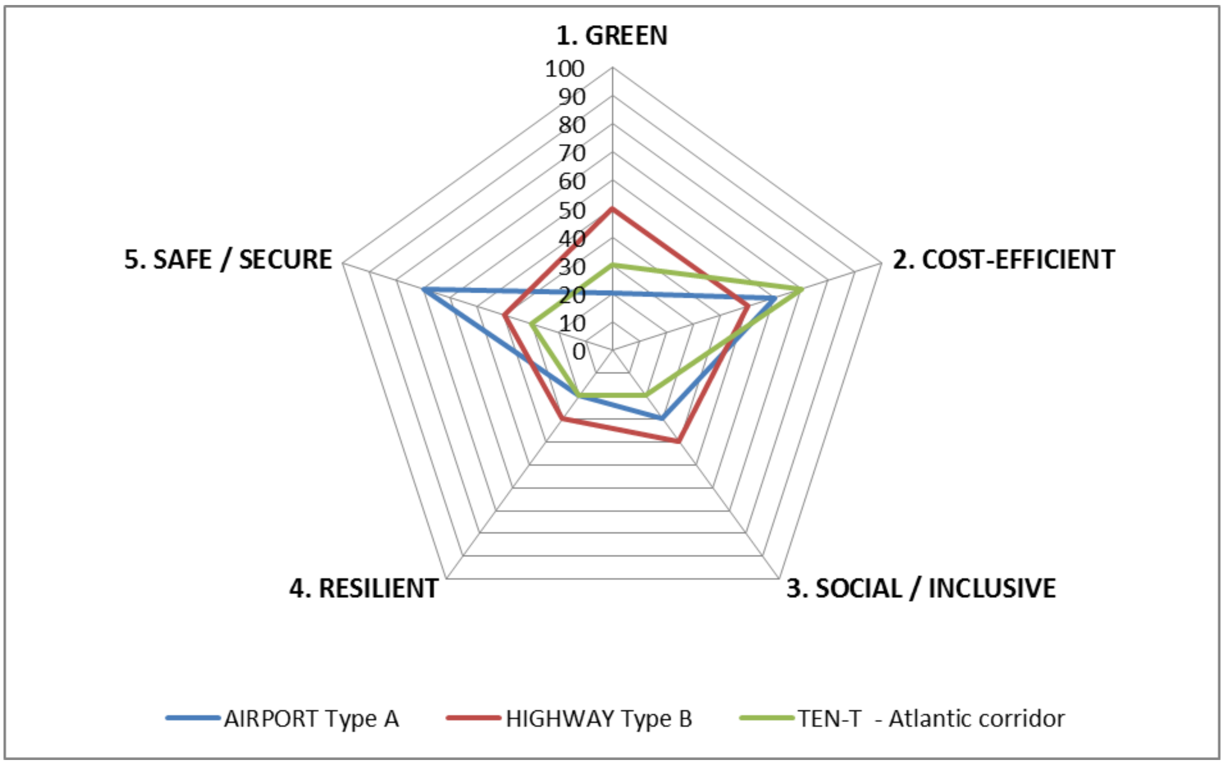
In the table below you can see the definition and areas of study that would result from each of the five factors that define the performance of the multimodal transport infrastructure of the future.

PRIORITY AREA A/B/C	CLASSIFICATION	MEASURE TYPE	DEFINITION
GREEN		Emissions	**ENVIRONMENTAL IMPACTS measures effects on the environment, including air quality, ground-water, protected species, noise and natural vistas**. Output.based performance measures may also be defined for acions critical to mitigating the above impacts (eg, protecting wetlands, constructing wildlife passages across transport facilities, using snow and ce chemicals that protect groundwater and air quality, and monitoring and controlling hazardous materials).
		Air Quality Standard Attainment	
		Length or Extent of Air Quality Problem	
		Water Quality, wetlands, Aquatic life	
		Hazmat Impacts	
		Energy Impacts	
		Noise Impacts	
		Recycling	
		Completion of Mitigation Steps	
		Customer Perceptions	
COST-EFFICIENT	Preservation performance measures	Pavement condition/ride quality	**PRESERVATION measures the condition of the transport system and actions to keep system in a state of good repair.** Measures are often specific to the type of asset. Performance measures may be expressed, for example, by physical condition (eg, extent or severity of distress and deviations from nominal track gauge), by indexes that combine a number of condition measurements or that relate to user perceptions of condition (eg, pavement condition index, present serviceability index, or rideability index for pavements or bridge health index for bridges). For purposes of this study, preservation also includes actions to mantain a state of good repair in emergency situations other than terrorist attacks (eg, severe storms, earthquakes, landslides, scour around foundations, and flooding).
		Bridge condition	
		Asset Condition (General)	
		Remaining Life/Structural Capacity	
		Asset Value	
		Customer Benefit or Disbenefit (or Surrogates)	
		Customer perception	
	Operations and Maintenance Performance Measure	System Operations efficiency	**OPERATIONS AND MAINTENANCE measures the effectiveness of the transport system in terms of throughput and travel costs and revenues from a system perspective and maintenance level of service measures focused on the customer experience of the system.**
		Incident Response/winter operations	
		Capacity and Availability	
		Maintenance level of service	
		Cost efficiency	
		Occupancy	
		Fuel efficiency	
		Customer perception	
	Transport Delivery Performance Measures	Accomplishmet	**DELIVERY measures the delivery of transport projects and services to the customer.** Key performance measures include output-oriented accomplishment measures that complement outcome-oriented measures in the other categories, **measures of efficiency and effectiveness in use of resources**, and impacts on customers that need to be considered in evaluation of alternative delivery strategies.
		Quality	
		Efficiency	
		Schedule and budget adherence	
		Responsiveness	
SOCIAL / INCLUSIVE	Mobility and Accesibility	Congestion	**MOBILITY AND ACCESIBILITY measures the ease of movement of people and goods**. Accesibility is the **ability of people and goods to reach desired activities or destinations**. Mobility and accesibility are grouped together here because they are related and share common measures. Mobility measures **include the time and cost of making a trip and the relative ease or difficulty** with which a trip is made, especially congestion and trip measures related to congestion. Some of these trip measures reflect a **supplier perspective** (eg volume-capacity ratio and capacity-related level of service), while others reflect a **user perspective** (eg, speed, travel time, delay, trip reliability, and user cost). Accesibility measures include a "density" of opportunities enabled by transport services (eg number of households within a 30-minute drive of key regional centers or number of employment opportunities within a 10-minute walk of transit stops) or the ability of a facility to serve a particular user group (eg a particular segment of population or type of freight). Availability of modes and modal choice can also be treated as an accesibility measure. Accesibility is often expressed from user´s perspective.
		Speed	
		Travel Time	
		Travel Time Reliability	
		Delay	
		Travel Cost	
		Acccesibility to destinations	
		Accesibility to facilities and services	
		Accesibility to different modes	
		Customer Perceptions	
	Transport Social Impacts Performance Measures	Social, Societal, Neighborhood, Community Quality of Life	**SOCIAL IMPACTS measures effects on broader society (eg, neighbourhoods adjacent to transport facilities) or on population groups (eg, disadvantaged).** This is in contrast to "quality of life" impacts, which are interpreted by some operators to mean customer satisfaction specifically.
		Customer perceptions	

RESILIENT	Exposure	Temperature	**Exposure** is defined as the nature and degree to which a transport infrastructure is exposed to significant climatic variations or man-made hazards. In other words, it is an important aspect of vulnerability that measures whether something will experience a stressor. Exposure can be thought of in terms of What man-made or natural hazards will be experienced in my location?
		Sea Level rise	
		Precipitation	
		Wind	
		Terrorist attacks	
		blast / arson	
	Sensitivity	Indicators of Roads Sensitivity to Temperature	**Sensitivity** - Whether a transport infrastructure will be damaged or disrupted from exposure to a stressor
		Indicators of Rail Lines Sensitivity to Temperature	
		Indicators of Ports Sensitivity to Temperature	
		Indicators of Airports Sensitivity to Temperature	
		Indicators of Roads Sensitivity to Sea Level Rise (SLR)	
		Indicators of Rail Lines Sensitivity to Sea Level Rise	
		Indicators of Ports Sensitivity to Sea Level Rise	
		Indicators of Airports Sensitivity to Sea Level Rise	
		Indicators of Roads Sensitivity to Heavy Precipitation	
		Indicators of Rail Lines Sensitivity to Heavy Precipitation	
		Indicators of Ports Sensitivity to Heavy Precipitation	
		Indicators of Airports Sensitivity to Heavy Precipitation	
		Indicators of Roads Sensitivity to Wind	
		Indicators of Rail Lines Sensitivity to Wind	
		Indicators of Ports Sensitivity to Wind	
		Indicators of Airports Sensitivity to Wind	
		Indicators of Roads Sensitivity to man-made hazards	
		Indicators of Rail Lines Sensitivity to man-made hazards	
		Indicators of Ports Sensitivity to man-made hazards	
		Indicators of Airports Sensitivity to man-made hazards	
	Adaptive capacity	Indicators of Roads Adaptive Capacity	**Adaptive Capacity** - How well the transport system at large can cope with damage or disruption to a specific asset (e.g., redundant routes may be able to accommodate transport requirements while a particular asset is restored to service)
		Indicators of Rail Lines Adaptive Capacity	
		Indicators of Ports Adaptive Capacity	
		Indicators of Airports Adaptive Capacity	
SAFE / SECURE	Safe	Crashes	**SAFETY measures the quality of transport service in terms of crashes or incidents that are harmful to people and damaging to freight, vehicles, and transport infrastructure**. Performance measures also reflect infrastructure conditions that contribute to or to detract from safety. While safety is often gauged by the number, frequency, severity, and cost of accidents, recent trends recognise a wider sphere of interest in the vehicle- and driver-related causes of crashes and in harm to agency work crews, particularly in work zones.
		Crash Impacts	
		Transport Infrastructure	
		Customer perception	
	Secure	Incident rates	**SECURITY measures protection of travelers, freight, vehicles and system infrastructure from criminal and terrorist actions.** Protection of infrastructure and users of this infrastructure against other emergencies (eg severe storms, earthquakes, landslides, flooding, and scouring of foundations) is included in preservation.
		Prevention Activity	
		Customer Perception	

The follow up activities of this activity beyond REFINET should be oriented to develop speficic targets and measures while establishing specific weights for each defined pecific KPI and clumping thereof, REFINET index. Each infrastructure manager should adapt this approach to their strategic and operational targets considering individual specifities and starting point. A clear addedd value at European level is foreseen as the progress of european infrastructure could be monitored, compared and assessed. As it is said, this approach would give a justified objective and demonstrable value of a score on the performance of the transport infrastructure.

In the picture below, It is shown the potential REFINET index applied to different infrastructure types. As it is mentioned, we believe that each infrastrucutre owner / manager should establish their individual targets but it could be a EU wide tools to evaluate and improve the European Transport Network.



However, the project REFINET what is delivering in the framework of the project is also set of indicators that are the basis for establishing a method to monitor and evaluate the impact of research and innovation actiiones in the field of transport infrastructure. The SIP will be organised according the RMMTI model and the KPIs structure, therefore, it would be a coherent way to identify the areas of investment and evaluate the impacts.

Example of various types of performance indicators: [41]

[41] See Ref [23]

Mode	Service Quality	Outcomes	Cost Efficiency
Rail	Rail line supply Rail service speed and reliability	Rail mode split Rail traffic volumes Rail crash rates	Cost per rail-km Cost per tonne-km External costs
Multi-modal	Transport system integration Accessibility from homes to common destinations User survey results	Total transportation costs Total average commute time Total crash casualty rates	Total cost passenger-km Total cost per capita External cost per capita

Table 1Performance Indicators

6.2.1 Service quality for multimodal transport networks

- **Reliability** - The variability of travel times is extracted from the same survey and is reported as part of the MOT transport indicators. This indicator describes reliability under day-to-day traffic variation. A separate indicator is published that describes road outages with a duration of 12 hours or more due to weather and other natural events, long duration road incidents and planned closures. This is reported as part of NZTA's long term monitoring. There is a gap between day-to-day variation and the longer period closures, for most road incidents such as crashes, spillages and other causes. Higher reliability means road users need to allocate less 'buffer' time when travelling, which reduces the implicit cost of transport and increases welfare.
- **Capacity utilisation** - In terms of traffic volumes is measured by vehicle-kilometres travelled per network kilometre or passenger boardings (patronage) per seat-km of services operated. As this indicator aggregates areas where traffic flows have declined, but where an ongoing commitment to retain road access remains, with areas where traffic growth has led to congestion, it should be treated with caution as an increase will not necessarily indicate greater user welfare or better matching of road supply to demand. An indicator that quantifies severe congestion, measuring where and when capacity is exceeded, would be more relevant.
- **Safety** –The infrastructure providers have direct influence over design, traffic control and other operational aspects of the multimodal network. The primary indicators of multimodal networks safety overall are fatalities and injuries expressed per vehicle-kilometre or per capita or passenger boardings (patronage) per seat-km of services operated.
- **Environmental performance** – The direct environmental impact of the multimodal transport infrastructure networks arises mainly from visual impact and land and community severance effects, together with indirect impacts of resource depletion (construction materials and land use). Road and rail traffic are the main sources of environmental impact through air emissions, noise and vibration. Emission controls at source through less polluting transport equipment offer the best opportunity for improvement, but otherwise by mitigation measures in relation to local adverse effects. Two indicators are suggested, growth in total CO_2 emissions from multimodal transport and on a per capita basis, and total emissions of fine particulates (PM10 and possibly PM2.5) on a similar growth and per capita basis.

Althought REFINET does not plan to undertake the development of specific KPIs, this deliverable indicates the necessity of further future work to be carried out.
The Strategic Implementation Plan (SIP) will include a set of relevant areas for investment in research and innovation. Among this areas, one specific action to be included as a concrete actions will be dedicated to the development of KPIs at multimodal transport interchanges. The SIP will include a description of the objective, the problem to be solved and actions to be undertaken, potential players, impacts, etc..

6.2.2 Outcomes for multimodal transport networks

- **Door to door travelling time** in passenger/cargo transport by corridor in minutes/hours (accessibility increase). Measured for urban, peri-urban or rural area.
- Share of users of public transport on the population (notably for metropolitan/urban areas)
- **Changes in the modal split** (passengers/freight) by corridor or destination (and, if possible, globally in the region/country).
- **Road fatalities** (fatalities per number of vehicles, per number of vehicle kilometres, per population)
- **Rail crossing fatalities** (reduction in number of level crossings/km).
- **Road accidents** (serious injuries, serious accidents and slight accidents per vehicle kilometres or per population, kilometres, together with supplementary information on accidents involving specific groups such as pedestrians, cyclists and children)
- **Congestion** (average speed as compared to the free-flow speed)
- **GHG emissions** from transport in kt of CO2 equivalents
- **Noise levels** in db (share of population exposed to level higher than xx dB in the target area)

6.2.3 Cost efficiency for multimodal transport networks

- **Cost/Price alignment**–Yet there is no direct pricing for multimodal transport use, although the technology that would allow vehicles to be metered for the time and place of their use essentially exists (basically transport unit positioning detection coupled with a charging regime). Cost recovery for transport network is through petrol excise and the user weight/distance charge for diesel and heavy vehicles. It would be possible to report a ratio indicator of transport network provision costs, excluding new construction (but possibly including renewals), to transport network revenues. This would be indicative of the extent to which the existing network operational costs are being met.
- **Productivity for multimodal transport infrastructure** - Productivity can be measured as the annual user output supported by transport infrastructure, which desirably would be as the activities or as a proxy the number of trips facilitated, but more practically as the transport unit-kilometres travelled, as a ratio of the annual recurrent costs of operation and maintenance of the network. The costs of those inputs that occur on a recurrent basis are maintenance, operation, policing, the cost of renewals, in fact almost all costs apart from new construction and a share of administration costs. Once this is corrected to a fixed cost base, using the index of cost escalation for transport network maintenance activities, then this will provide a suitable indicator to track overall efficiency changes and geographic variation.
- **Productivity for passenger transport** – An indicator of revenue passenger kilometres divided by multimodal transport provision costs can be provided. A price index to correct for inflation in provision costs can be applied to put the indicator on a real cost basis to show efficiency changes from year to year.

7. Conclusion

It is already acknowledged across Europe that there is need for a common European-wide approach to the development and delivery of innovative design, construction, maintenance and upgrading concepts and solutions to improve and extend in a customer-centric way the capacity of the existing network.

One of the pillars on which relies the REFINET CSA, which intends to be a major step towards addressing the tremendous challenges of the European infrastructures, is the multi-modal transport infrastructure (RMMTI) model and framework. This document has defined the following structure to house the required specifications:

- Level 1: where to allocate target service level specifications.
- Level 2: to enable the integration of a systemic perspective for cross cutting specifications.
- Level 3: to place the technological improvements required.

Furthermore, the need for level specific KPIs has been outlined and addressed at an initial stage. However, there is still a lot of work to be done in this field of multimodal level specific KPIs. Further work should include the development of a system, in the form of a weighed matrix in order to enable the labelling of multimodal infrastructure networks. Althought, REFINET does not plan to undertake the development of this weighed matrix. This deliverable points out the need for further work to be developed in the field of metrics and weights of KPIs. This will be included in the concrete actions to be described in the Strategic Implementation Plan (SIP). The action area of multimodal KPIs will describe its objective, the definition of the problem, actions to be undertaken, potential players, impacts, etc..

The model will be used for structuring the priority areas and actions of the Strategic Implementation Plan, around the identified 5 performance features which define the High Level Service Infrastructure in Level 1 of the model (Green, Cost-Efficient, Social/Inclusive, Resilient and Safe/Secure), as well as the other 5 performance features related to Systemic approach (level2 of model).

The reasoning is that all research and innovation strategies for the infrastructure sector should be aligned with the model. Therefore, the research priorities can be aligned with the elements of the model and the project results monitored and quantified in terms of their contribution for achieving the desired infrastructure performance.

It is important to highlight that this model needs to be dynamic, requiring continuous updating. This model has been outlined with the aim of serving as a reference, against which the gradual shift to multimodal networks could be benchmarked through the presented KPIs, with the ambition that the deployment of the labelling will contribute to greener, more cost efficient, resilient and safer multimodal transport infrastructure, and, in order to pave the way for its implementation, a Strategic Innovation Plan has to be set up and agreed at a large scale in order to launch a pan-European Programme in that field.

It is ambitioned that at the end of the REFINET Coordination and Support Action, all the necessary ingredients will have been gathered to be able to launch this Programme of Actions with the support of public and private stakeholders.

After REFINET completion, different organizations such as the ECTP through its Infrastructure & mobility committee, or ENCORD (European Network of Construction Companies for Research and Development) will define the different actions, as a result of their interest in the field of Transport Infrastructure.

The involvement of ETPs and associations such as FEHRL and UIC does not respond to the aim of accomplishing a research project, but of being involved in a long term initiative.

The model and the SIP should guide the research and innovation investments of the infrastructure sector for the next period with the support of EU, national and regional bodies.

REFINET will structure this innovation path whilst at the same time inform:

- The funding bodies (including the European Commission and Member States funding agencies) in terms of future priorities for funding R&D developments – as well the various associations (including the ECTP through its Infrastructure and Mobility Committee);
- Both the Transport and Construction (infrastructures) stakeholders by coaching them on the relevant next steps of technology and services integration and exploitation, as well as delivering incentives on future technology deployment improving their market potential and customers satisfaction. Such identification process has to be a continuous one, allowing new projects as well new available results to be assessed and involved in the process.

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8. Annex 1: Conclusions of workshop held on Madrid (2nd December 2015)

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REFINET
INFRASTRUCTURE MOBILITY

REthinking Future Infrastructure NETworks

REFINET

Project Duration: **2015.05.01 – 2017.04.30**
Grant Agreement number: **653789**
Coordinated and Support Project

WP3

Activity Report from T3.1 | TECNALIA

Conclusions of workshop held on Madrid (2nd December 2015)

Dissemination Level

PU	**PP**	**RE**	**CO**

Project Coordinator: Alain ZARLI (CSTB)
Tel: +33 493 95 67 36
Fax: +33 493 95 67 33
E mail: alain.zarli@cstb.fr
Project website address: **www.refinet.eu**

REVISION HISTORY

Date	Version	Author/Contributor	Revision By	Comments
18.12.2015	V01	TECNALIA		
29.06.2017	V02	TECNALIA	Jon Aurtenetxe	Final version submited to EC/INEA with changes linked to publication on CORDIS (EU emblem, disclaimer).

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Abbreviations

Acronym	Full name
RMMTI	REFINET Multi-Modal Transport Infrastructure
HLSI	High Level Service Infrastructure

1 INTRODUCTION

This workshop activity, held at Instituto de Ciencias de la Construcción Eduardo Torroja (Madrid) in 2nd December 2015 and organised by TECNALIA with strong support of PTEC, is included in Task 3.1 “Definition of the REFINET multi-modal transport infrastructure (RMMTI) model”, which objective is to define the model and to be a reference for the future evolution of the European multi-modal transport infrastructure within the Work Package 3 “Defining Vision and SIP”.

The definition of this model has been carried out by the REFINET´s partners with the assistance of the members of the REFINET network, who have been invited and involved in the discussion through the mentioned workshop, in order to involve different and all stakeholders´ perspectives related to transport infrastructure (user, Administration, operator/owners, construction companies, engineering firms and Universities and Research centres)

27 experts were invited to attend the workshop in Madrid and finally six experts, from different two companies (from Spain and Portugal), two research organisations (from Sweden and The Netherlands) and two universities (from Lithuania and Czech Republic), and seven REFINET partners (CSTB, PTEC, FEHRL, DRAGADOS, DAPPOLONIA, OAPIL & TECNALIA) could attend to the workshop.

The European initiciative reFine, whose aim was to foster Innovation for Transport Infrastructure of the Future, was stablished as a background. Concepts, such as “High Level Service Infrastructure “ or “ the three pillars of transport network” were regained in order to present the experts a draft version of the framework to work with during the all day workshop session.

2 OBJECTIVES

The workshop has been divided into two specific themes in order to gather valuable and useful information to define the REFINET multi-modal transport infrastructure model, according to the following agenda of the day:

REFINET INFRASTRUCTURE MOBILITY

REFINET WORKSHOP

Technological demands of transport infrastructures
2nd December 2015, Madrid

Instituto Eduardo Torroja
Calle de Serrano Galvache, 4, 28033 Madrid
91 302 04 40

<u>Agenda</u>

Wednesday 2nd December	
9:00	*Arrival*
9:15	<u>Welcome</u>, organisation
9:25	Overview of REFINET project (Luc Bourdeau, CSTB)
9:40	**WP3 – Defining vision and SIP** (by **TECNALIA**) *Vision, definition of the RMMTI model, collecting Best practices, Overview of projects and initiatives, Analysis of available technologies, REFINET selection & evaluation criteria for European & International research on REFINET topics*
10:00-10:15	**Q&A**
10:15.10:30	Coffee break
10:30-12:30	**Participants view on challenges, opportunities and approach to multimodal model of transport infrastructures** Introduction to the workshop objectives and methodology. María Zalbide (TECNALIA) Moderators: María Zalbide (TECNALIA), Miguel Segarra (DRAGADOS) Rapporteurs: Jon Aurtenetxe (TECNALIA) and Ben Kidd (ARUP)
12:30-13:00	**DEBRIEFING from the workshop by the rapporteurs**
13:00-13:45	*Lunch*
13:45-16:15	Definition of the framework for the analysis of demands of transport infrastructure: **REFINET multi-modal transport infrastructure (RMMTI) model and multimodal KPIs** Introduction to the workshop objectives and methodology. María Zalbide (TECNALIA) Moderators: María Zalbide (TECNALIA), Miguel Segarra (DRAGADOS) Rapporteurs: Jon Aurtenetxe (TECNALIA) and Ben Kidd (ARUP)
13:45-14:00	Cataloguing of technologies: Ben Kidd (ARUP)
16:30-16:45	*Coffee break*
16:45	**DEBRIEFING from the workshop by the rapporteurs**
17:15	*Wrap up and Conclusions*
17:30	*End of workshop*

REFINET Workshop Agenda — Page 1/1

The two workshop sessions have focused on different targets with the following specific objectives:

The objective of the **morning workshop session** was:

- To identify and prioritize the major **trends and challenges** within the transport infrastructure sector.

The objective of the afternoon workshop session was:

- To define a **framework for the analysis of future multi-modal transport infrastructure RMMTI model**, thinking of new and existing transport infrastructures.

3 METHODOLOGY

As mentioned before, some concepts from the European reFINE initiative were recovered to define the context about the objectives and framework of the REFINET project as a starting point, in order dynamise the participation of all attendees.

TECNALIA presented some explanatory slides with specific focus on the following two concepts in order to facilitate the development of the workshop:

- **High level service infrastructure HLSI** has the following features:
    - Providing infrastructure for **high quality mobility services for people and goods** while using resources more efficiently.
    - Ensuring overall better service and performance, **including multimodal integration and intermodal continuity for the end-user**, less congestion, optimised transport time, etc.
    - Higher degree of **convergence and enforcement of social, health safety, security and environmental rules** for infrastructure, with the adequate service standards at all times,
    - **Interconnected solutions** for the next generation of multimodal transport management, including information services and systems for all infrastructure

- The **three identified pillars of the high-Level service infrastructure "HLSI"** concept were: Urban mobility, multimodal hubs and long distance corridors, which articulate the transport network.

3.1 Methodology for morning workshop session: Challenges and opportunities for multimodal model of transport infrastructure – Identification and prioritisation

The group of fourteen people was divided into two groups, and they were seated along the longest sides of the table.

The participants in each team were required to identify individually with post-its at least five challenges regarding each of the categories: urban mobility, long distance corridors and multimodal hubs during one hour.

After this time, they discussed in group and prioritised the challenges of each categories from 5 (most important) to 1 (less important) for thirty minutes.

The rapporteurs (Ben Kidd and Jon Aurtenetxe) in each group reported to the larger group and then the discussion followed using the post-its as a starting point for debate. (30min)

3.2 Methodology for afternoon workshop session: REFINET multi-modal transport infrastructure (RMMTI) model and multimodal key Performances Indicators (KPI)

The group of fourteen people was divided into two groups, to be seated along the longest sides of the table.

The participants in each team were required to identify individually performance concepts and their associated key performance indicators with post-its at three levels: Performance (level1), Systemic Approach (level2) and Technological gaps (level 3) during thirty minutes for each level. Some questions were provided in order to aid the identification.

After one hour and a half, a discussion was launched on the results obtained by each team for thirty minutes and the rapporteurs from each group (Ben Kidd and Jon Aurtenetxe) reported to the larger group and then a discussion followed using post-its as a starting point a debate for other thirty minutes.

4 RESULTS

4.1 Morning workshop session

High-Level Service Infrastructure "HLSI"

	Multimodal hubs	Long distance corridors	Urban mobility
Security challenges			
Cost Efficiency challenges			
Environmental challenges			
Safety challenges			
Smartization challenges			
Inclusiveness challenges			
Social challenges			
other			

Following the methodology described above, the two teams started the morning workshop session with the aim of identifying and prioritising the challenges and trends of European multi-modal transport infrastructure. To help doing this, the table above was presented, in order to organise the different contributions under the same scheme, based on three pillars of transport network and the different themes.

The contributions of the two teams have been gathered as follows:

Group A:

URBAN MOBILITY (green post-its)

- Need of standardisation in design- signalling
- European brand for Multimodal transport Infrastructure model.
- Improve the social acceptance of infrastructure.
- Reduce the time distance to specific main services (hospitals, schools,…)
- Smartening versus vulnerable group of people (disabled, old people,…)
- Clean and healthy transport.
- Seamless transport – no barriers.
- Zero Accidents (especially vulnerable group of people)
- Cost barrier in public transport.
- Man-made and natural hazards, from user and infrastructure perspective.
- Emergency routes
- Terrorist Attacks
- Recycling materials and its standardisation.
- Adaptation for climate change.
- Holistic strategy (governance)
- Nanotechnology: self-repairing materials and self-reporting materials of structural health.
- Drive assistance.

- Smart use of the available data.
-

MULTIMODAL HUBS (yellow post-its)

- Need of standardisation design- signalling
- Smartening versus vulnerable group of people (disabled, old people,…)
- Barriers to mobility (security controls,…)
- No Barriers – seamless travel
- Emergency routes
- Multi hazard- resilient infrastructure
- Terrorist Attacks
- Business models – Balance between transport and commercial use.
- Virtual and lean construction.
- Recycling materials – need for standardisation.
- Sustainable materials and processes.
- Communication among USER-VEHICLE–INFRA.
- Interoperability.

LONG DISTANCE CORRIDORS (orange post-its)

- European brand for Multimodal transport Infrastructure model.
- Improve the social acceptance of infrastructure.
- Best value – Social return of investment
- Zero Accidents (especially in maintenance works in rural areas)
- Cost barrier in public transport. (hinder use of certain modes)
- Holistic and systemic approach (governance)
- Introduction of innovation of procurements (governance)
- Multi hazard- resilient infrastructure
- Adaptation for climate change.
- Durability.
- Recycling materials – need for standardisation.
- Link cost-environment: LCA versus LCC. Need for standardised method.
- Sustainable materials and processes.
- Assess optimal distance for each transport mode.
- Working closely with vehicle industry to introduce innovations in infrastructure (others).
- Skid resistance.
- Nanotechnology: self-repairing materials and self-reporting materials of structural health.
- Smart use of the available data.
- Interoperability.
-

Group B:

Note that the number indicates the priority level assigned by the group (1-most and 5-least).

URBAN MOBILITY (green post-its)

- 4 - Safety – reduce accidents via proper maintenance criteria for optimal management.

- 2 – Environmental: Adaptation of urban infrastructures to new vehicles with reduced environmental impact or supporting.
- 3 – Smartening: Automated connected vehicle -> how to adapt road infrastructure.
- 4 – Environmental: Electric vehicle in city-> inductive technology.
- Social and safety: Integrating cycle networks and walkability into cities alongside other transport nodes.
- More underground transport infrastructure must be developed.
- 3D printing technology using in construction.
- 3 – BIM for urban infrastructure including existing underground infrastructure.
- Environmental: traffic jams.
- 5 – Smartization: connect smart infrastructure to smart cities.
- Smart – Conserve cultural heritage.
- Smart – Provide access to actual information on traffic.
- Smart – Provide complex service for business and community, aging population.
- 1 – Integrate infrastructure planning and urban planning.
- 1 – Urban land management versus transport infrastructure (urban sprawl).
- More healthy transport system.
- Seamless door to door multi modal mobility.
- Integration into regeneration of cities.
- 2 - Modular infrastructure and recycling infrastructure.
- More compact urban territories (cities) must be designed.
- Societal challenge: Single ticketing – parking – public transport.
- 3 – Inclusiveness: Improvement for aged/ disabled/,… people.
- Inclusiveness integrated approach for all urban infrastructures (high connection with ICTs)
- Inclusiveness: ageing population and active mobility: how to design for improving active mobility versus inclusive design for disabled people etc. and increased demand?
- 4 – Prepare for new ways of collaboration/virtual offices etc.

MULTIMODAL HUBS (yellow post-its)

- 2 – Environmental integration in the city.
- Good governance of innovation.
- Long term vision roadmap and organisation on implementation.
- 4 – Environmental+social: indoor air quality and passenger comfort – moving from one mode/ vehicle/ space to another without significant changes in environment.
- Environmental: energy management.
- 2 - Passenger accessibility in ageing Europe.
- 1 – Synchro-modality (ALICE): networks of networks and physical internet.
- 1 – Heritage buildings + infrastructures
- Sensitive designs for upgrade /retrofit.
- Global design to perform all multimodal high level services.
- Cost- efficiency: Virtual reality used in design to model passenger flows + improve efficiency (plus identify opportunities for retail clients – footfall) -> how to make software affordable for all multi-modal designs.
- Security – BIM models – cyber security (particularly if model used for operation/asset/facilities management (see British Standard for BIM Part5)
- Societal Challenge – passenger security: balance between free travel + control?
- BIM modelling
- Smart security systems

- IT smart technologies using for information for motion of travelling, time saving, …
- Warning systems, cyber monitoring system.
- 5 – Smartening: Embedded condition monitoring sensors, access+management issues: different companies managing utilities (telecom, energy, water, etc.)
- Traffic management and pricing across the modes based on real time information.
- 3 – Safety & resilience: climatic change events.
- Safety: Overheating of braking systems on high speed trains when sat idle at stations (fire risk), (being studied at Enston HS2 station design).
- Security: Bomb resistance.
- Increase robustness across modes: capacity, natural hazards, climate change.
- 1 – Smart
- 2 – Social
- 3 – Security
- 4 – Cost-efficiency
- 5 – Environment

LONG DISTANCE CORRIDORS (orange post-its)

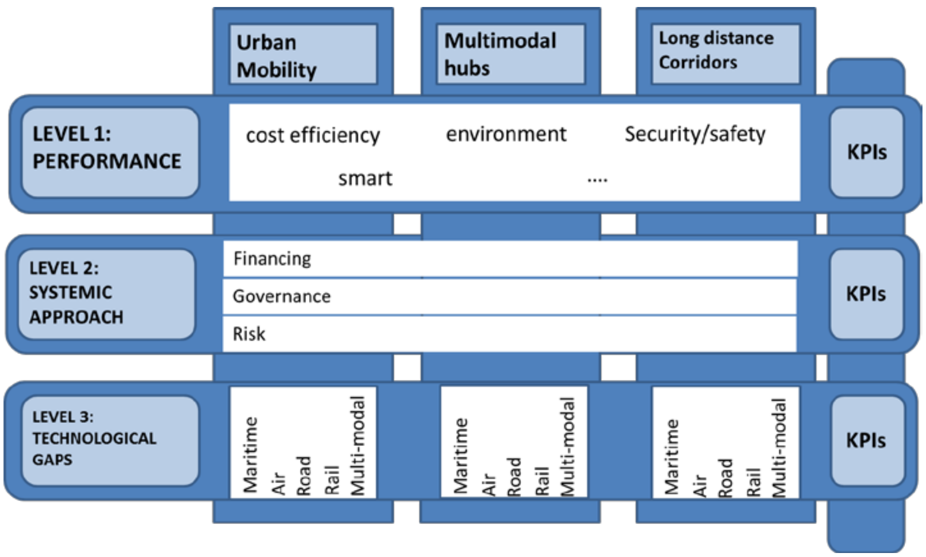
- 1 – Lifetime extension of critical objects, based on condition monitoring.
- Upgrading of existing infra and accommodating new vehicles.
- Durable and self-healing materials and structures using for infrastructure construction.
- 2 – Improve safety during upgrading works (traffic, workers,…).
- 3 – Increase cost efficiency when upgrading infrastructures (bridges …) via new design rules or new construction processes.
- 2. – Social challenge: equal opportunities for rural areas.
- Cost efficiency + resilience: Avoid duplication and look for synergies.
- Increase resilience to natural hazards/climate change.
- 3D printing technologies using for freight of some products.
- Multimodal corridors (others).
- 1 – Recycling of structures (i.e. existing bridges) instead of demolishing to reduce environmental impact.
- 3 – Minimize Natural resources use and impact Environment.
- 4 – Environmental challenges: Shift to rail, “4 hours door to door” (ACARE).
- Noise + vibration from high-speed rail plus habitat loss (See Arup HS2 Soundlab + EIA best practise example)
- Increase Durability through advanced materials
- Technology helping reduce accidents (safety).
- Guide to reduce jumps using IT tools (Smart).
- Interoperability.
- 1 – Environment
- 2 – Cost Effective
- 3 – Safety
- 4 – Smart
- 5 – Interoperability
- 4 – Smartening – monitoring solutions for management, traffic monitoring.
- 5 – safety – accident management
- Cost efficiency - how to balance need for multiple stakeholder engagement with cost efficient?
- Common standards and approaches across disciplines / suppliers (e.g. ECTMS in HS Rail) (others)

- 3 – Safety, cost-efficiency and environment: Inspection and maintenance (long-lasting pavements, self-healing, self-monitoring + drones
- 5 – Safety and smartening: bridges and platooning (trucks).

4.2 Afternoon workshop session

The afternoon workshop session aimed at collecting contributions from experts regarding the definition of the framework for the analysis of demands of transport infrastructure, therefore being linked to the outputs obtained from the morning workshop session. However, the main objective was to define the REFINET multi-.modal transport infrastructure (RMMTI) model and their associated key performance indicators (KPIs).

As an introductory explanation to the afternoon workshop session, TECNALIA presented the framework below, as a draft starting point composed by three pillars of transport network and three defined levels.



Level 1, PERFORMANCE, corresponds to identifying which key features should be considered in order to define the European Multi-modal Transport Infrastructure of the future from the all stakeholder´s perspective (end-users, operators/ owners, construction companies, engineering firms and administration), and which they should match with the transport system strategy from a local, regional or global point of view.

Level 2, SYSTEMIC APPROACH, corresponds to identifying which key aspects should be considered in order to have a systemic approach from multi-modal and whole mobility chain perspective This level aims at gathering all aspects related to "holistic integrated transport infrastructure" concept, identifying the main targets which enable the provision of high level service.

Level 3, TECHNOLOGICAL GAPS, corresponds to identifying which key technology/knowledge has to be developed or adapted in the following years/decades to cope with identified challenges and to fulfil requirements of upper levels (1&2). The technological gaps have been structured into transport modes and into the three pillars as components of the transport network. However, it is true that some technology or knowledge could be cross- cutting through modes or the transport network.

These three levels, which try to define the REFINET multimodal transport infrastructure (RMMTI) model, are also linked to their respective key performance indicators, as qualitative or quantitative measurements of implementation level in multimodal transport infrastructure.

The contributions of the two teams have been gathered as follows:

Group A:

This group A worked in the afternoon session focusing on different levels, considering the whole pillars jointly.

- Level 1: Performance

- Security Challenge:
    - Resilience to terrorism attacks (preparedness, prevention, robustness and recovery) => KPIs: time to recovery, % of damaged level of service, ability to be bypassed.
- Cost-efficiency and environmental challenge:
    - Optimal balance LAC and LCC=> KPIs: existence of EPD (environmental product declaration).
    - Use of Environmentally friendly materials => KPIs: % use of environmentally friendly materials.
    - Durability => KPIs: extra years that we can extend the life of an element/component.
    - Energy efficiency
- Smart challenge:
    - Smarter infrastructure that uses available data and communicates with the users /operators.
    - Interoperable
    - Active infrastructure, Structural Health Monitoring, self-healing system, self-reporting

    KPIs: number of downloads of apps for finding one's way at multimodal hubs.
- Cost-efficiency and environmental-safety challenge:
    - Resilience to climate change. => time to recovery (resilience metrics)

- Level 2: Systemic approach

- Security Challenge:
    - Network planning,
    - Cascade effects,
    - Communication protocols between modes.
    - Codes: lack of multimodal standards and tools related to multi-hazard resilience.
    - Energy efficiency
- Cost-efficiency and environmental challenge:
    - New procurement process including optimal balance LAC and LCC.
    - Lack of standards for recycled materials.
    - Financial models that guarantee the life extension of the networks => life span extension.
- Smart challenge:
    - Protection of the information system: data, access…=> KPIs: Creation of European standards regarding operability between modes, number of stakeholders that make use of these data.
    - Communication infra – vehicle – operator.
- Cost-efficiency and environmental-safety challenge:
    - Procurement processes implementation of innovation => KPIs: number of: innovative implemented products, contracts that implement innovation and bidding proposals that include innovation.

- Level 3: Technological gap

- Security Challenge:
    - Lack of tools to analyse: vulnerabilities, mitigation measures at systemic levels
    - Lack of construction materials and processes for rebuilding (quick recovery).
    - Blast resilient design. Lack of codes.
    - Monitoring that enables fast structural assessment.
    - Move from deterministic to probabilistic design.
    - KPIs: time to recovery, measurement of redundancies of the systems, operation capacity after the disruptive event.
- Cost-efficiency and environmental challenge:
    - Lack of protocols for all transport modes to standardise the information.
    - Lack of methods for calculating he LCC.=> availability of protocols and methods to calculate LCC.
    - More durable materials.
    - Structural alternative – use of recycled materials => % of implementation of new solutions/materials/processes.
- Smart challenge:
    - Open standard interfaces to be more operable.
    - Smart use of data.
    - Integration data in asset management systems.

Group B:

This group B worked in the afternoon session focusing on different levels and under one of the three pillars of Transport Network. But, they did not have time to work in the last third level.

URBAN MOBILITY (green post-its)

- Level 1: Performance

- Better planning of transport with land.
- Measurements in travel time reduction by X%.
- Infrastructure to support the traffic.
- Environmental impact in connection with the health of population.
- Adaptation of infrastructure to greener transport means for: pedestrians and cyclers, self-transport and environmental impact.

- Level 2: Systemic approach

- Cooperation between administrations and with “economic actors” that could maximise the benefit of the infrastructure.
- Access to jobs.
- Standards.
- Regulation and incentive.
- Globally design standards and safety.
- Success stories

MULTIMODAL HUBS (yellow post-its)

- Level 1: Performance

- Holistic design that meets the needs of mobility.
- Design that accommodates for 30% more of passengers and 30% more of freights.
- Design that enables 30% of modal shift.

- Level 2: Systemic approach

- Design standards/regulations.
- Incentives/investment
- Operators involved in the design stage.
- Business model/financing aspect.
- End-user.
- Adaptable to future needs.

LONG DISTANCE CORRIDORS (orange post-its)

- Level 1: Performance

- Cost-efficient resilient transport infrastructure
- Construction, maintenance and operation disturbance (noise, vibration, disruption).
- Circular economy (recycling)
- Reduction of waste materials.
- Reduction of maintenance by X% (reducing expenditure and keeping the same or better performance).
- Lifetime extension /upgrading by X% (20% ??)

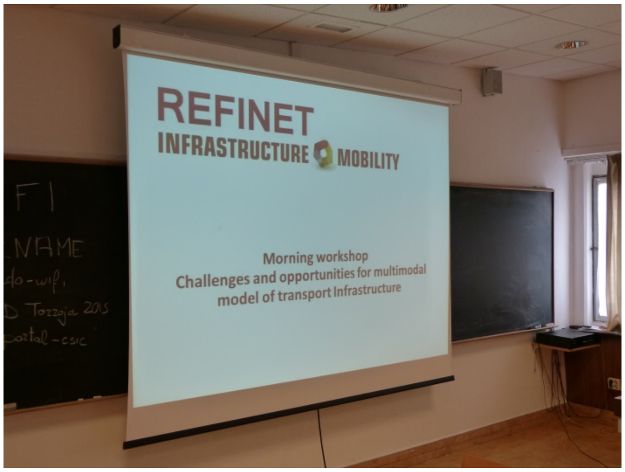
- Level 2: Systemic approach

- Risks assessment tools
- Optimisation
- Harmonisation (across borders)
- Availability of data for the assessment of the network.
- Measure cost-effectiveness within the regulatory period (day to day management).
- Energy savings.
- Carbon footprint.
- Standards for recycling 100% of existing materials.
- New testing methods.
- Improvement of construction and maintenance processes (e.g. prefabrication).
- Communication (with the affected people).
- Legislation.

5 CONCLUSIONS

All contributions gathered in the two workshop sessions, will be used, among other activities, for the definition of the REFINET multi-modal transport infrastructure (RMMTI) model. The different levels (PERFORMANCE, SYSTEMIC APPROACH and TECHNOLOGICAL GAP) of the framework will also be established, in order to respond to the identified challenges and finally to achieve the final objective of work package 3, which is to define the Vision and the Strategic Implementation Plan in order to guide the evolution of European transport infrastructure.

6 ANNEX I


REFINET
INFRASTRUCTURE MOBILITY
Morning workshop
Challenges and opportunities for multimodal
model of transport Infrastructure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7 REFERENCES

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