STRIA Roadmap

Network and Traffic Management Systems

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1. Executive Summary

1.1 Setting the scene

Network and Traffic Management (NTM) envisages a dramatic paradigm change. Up until now, the traffic related elements of traditional NTM have monitored and managed road traffic of vehicles carrying persons and goods from a macroscopic point of view. Except for some very specific applications (i.e. bus priority), almost all road traffic management algorithms monitor, assess and influence vehicles and persons in a collective way. Now in the era of C-ITS and upcoming connected and automated driving, the full potential of direct interaction with the vehicle's control intelligence is becoming at the disposal of NTM. This implies that every single vehicle can be individually included in NTM considerations and decisions. Rail, air and waterborne traffic management systems already include the management of individual vehicles from a microscopic point of view, at least in bottleneck areas (i.e. complex and busy stations, main airports and large ports). Thinking in a visionary way, NTM evolves towards a globally coordinated and pro-active control process for the transport of persons and goods, connecting the intelligence of infrastructure and vehicles. Traditional traffic management, which today applies more or less restrictive measures (i.e. access control) to ensure mainly security, safety and efficiency, will evolve to a very flexible "slot management" type toolbox. Whilst today's NTM efforts can be inefficient in trying to improve traffic flow management, the focus of NTM can turn to unprecedented new arbitration and incentive models, enabling entirely new traffic management strategies. The coordinated and collaborative intelligence can decide for each individual journey to be served by the assignment of a bespoke time and network slot on its journey from A to B.

As always, any system will have to have safety and (cyber-) security at its core. When developing a NTM system towards 2050, it will be critically important to integrate safety and (cyber-) security in all technical and operational functions at every stage of their development. On no account must safety and (cyber-) security be compromised and every technological advancement or operational improvement must be carried out within the framework of a totally safe and (cyber-) secure environment. As technology evolves, the issues that need to be considered from a safety perspective will inevitably change. The integral place of safety within an NTM system will remain critical, irrespective of the form that technological evolution takes.

The creation of a comprehensive and all-embracing NTM system that covers the broadest range of modes is a goal for 2050. Some modes will be easier to integrate into this structure than others. Cross-modal NTM already exists between certain modal pairs, such as bus/rail, but are not so common between other modal pairs. The creation of cross-modal working between modes that have traditionally experienced little interaction with one another (e.g. sea to road/rail/air) will be an integral element of an NTM system appropriate for the year 2050.

As travellers become more accustomed to being bespoke recipients of travel services, it will be critical to resolve the potential conflict between the needs and demands of the individual and the efficient operation of the traffic and travel management system, within which an individual is undertaking his/her journey. The desires and requirements of the individual traveller will need to be evaluated within a NTM system that is designed in a way that prioritises the optimum operation of the network, over the stated travel demands of the individual. This could result in some potential conflicts, which will need to be assessed and addressed by the operating system, e.g. it may not always be possible or desirable for an individual to be granted their first choice of travel mode(s), while the system must be sophisticated enough to be able to offer the most practical and efficient journey choice to the individual, within the context of optimum system operation.

Any NTM system must be flexible enough and dynamic enough to be able to respond to unforeseen perturbations and disruptions. Incidents such as natural disasters and terrorist attacks lie at one end of this spectrum, to minor accidents or congestion at the other end of the spectrum. The visionary NTM system must be designed to accommodate efficient and timely reallocation of journeys in the event of all unforeseen incidents, major or minor. Ideally, this will take the form of diverting the journey routing, if feasible, or alternatively encouraging change of mode, if required. Naturally, this should take place as quickly and as seamlessly as the NTM will allow. If the perturbation in question does not allow immediate journey reallocation, it is important that the incident management element of the NTM system provides timely and high quality information to the individual traveller, prior to subsequent journey reallocation.

Underpinning any strategic NTM system will be the provision of high quality and universally accepted data. Generated data must be shared between all interested stakeholders to facilitate the creation of an NTM system, which is appropriate for the year 2050. This will mean a change in practice for some key players, who will have to be encouraged to give others access to their data, in a manner which currently does not happen. Protocols relating to other key issues such as data privacy will also need to be introduced, to ensure data can be used productively by all relevant parties, without prejudicing the rights of the individual.

The growth of interaction and inter-working of different technologies and transport modes, using common infrastructure, will also need to be addressed by a 2050 NTM system. One example of this currently can be seen in the growth of autonomous / semi-autonomous road vehicles. These will need to co-exist with traditional driver-operated vehicles, as well as with non-road vehicles (e.g. tram), at least for the foreseeable future, and therefore a NTM system will need to be designed, which encompasses safe and efficient operation for a wide range of vehicle technologies and transport modes, sharing common infrastructure.

Finally, the evolution of NTM requires moving away from traditional public sector / private sector roles. Each sector has a key role to play in design, development and implementation of NTM systems, but the boundary between the ways in which they interact with one another will become less clearly defined over time, with both sectors becoming involved with issues such as data ownership, management and revenue raising.

1.2 Key messages on selected topics

Energy Union Targets

How can the considered technology area contribute to the Energy Union challenges of decarbonisation and energy security?

This Roadmap highlights the important contribution of an advanced NTM capability towards achieving the Energy Union and other EU policy objectives. Even if low emission vehicles, smart infrastructure and new mobility services become available, the entire transport system will still not be able to perform without an efficient NTM function. This is the key enabler, ensuring a smooth and uninterrupted flow of passengers and freight across the entire network, seamlessly optimising traffic and network performance from a truly multi-modal perspective. Fewer traffic jams, dynamic re-routing, prioritisation of low-emission vehicles, cross-modal optimisation, integrated passenger / freight routes are only a few examples of how NTM can contribute concretely towards the Energy Union targets. Chapter 4 provides an in-depth analysis of the overarching performance framework within which NTM functions and how technological progress and improving operations can deliver significant contributions towards EU / Energy Union targets.

Integrated Approach

Where is an integrated approach; both in terms of integration across sectors as well as integration across technologies needed? Within each roadmap clarify what integrated approach means, which are the concrete R&I implications of such approach and specific requirements

The creation of a next-generation multi-modal NTM capability requires a strong integrated approach at all levels. First of all, integration, information sharing and interoperability across systems are critical within, but also across transport modes. An integrated approach is also required in addressing technological, as well as non-technological aspects, such as multi-sector operations, framework/regulatory conditions and organisational/ business models. Furthermore, an efficient NTM operation requires stronger integration of the user into the system, an integrated approach from all public/private actors, as well as higher integration between passenger and freight mobility. Finally, closer integration is necessary between R&I developments and actual experiences from deployment. This entire multi-layer integrated approach is proliferated throughout this unique integrated NTM Roadmap and across all top 10 priorities / building blocks highlighted for future R&I (Chart 1 below).

Timeline

Outline the timeline of actions and initiatives. Specify which innovations/solutions could be deployed within 5-7 years. Specify as well the possible bottlenecks/barriers related to the actions/initiatives envisaged.

This Strategic R&I Agenda for NTM covers comprehensively all phases of development, from short-term (5-7 years), to medium term (until 2035) and long-term (until 2050). In parallel, the deployment of successful R&I

solutions will be progressing continuously, until ultimately there is sufficient implementation of innovation in next-generation NTM operations to deliver substantial benefits. Short-term R&I actions need to focus firstly on the design, architecture and concept of operations for a new multi-modal NTM system. This includes R&D on technological aspects, as well as on business models and the integration of all the elements into a multi-modal network (vehicles, infrastructure, systems and services). However, several challenges need to be addressed: technical, such as traffic management interfaces across modes; organisational, relating to information exchange and the public/private roles; as well as financial, such as sources and uses of NTM R&I and implementation funds. Chapter 5 outlines the key milestones for NTM capability in the timeline until 2050.

Roles

Which are the roles of the public (EU, national and local level) and private? Who should do what?

The development, financing and operation of a multi-modal NTM function in Europe would require close collaboration of the public and private sectors. A new culture of public-private cooperation is needed and for this to succeed, the public and private sectors need to re-define their roles and responsibilities and enter a mutual understanding of needs. At the same time, the two stakeholder groups need to respect each other's requirements for a "win-win". For instance, the public sector could have a facilitating role in the warehousing and management of multimodal information, provide an appropriate regulatory framework (harmonised across the EU) and ensure overall delivery of policy objectives. On the other hand, the private sector could be engaged in the market for data exchange, network and traffic management functions, as well as service provision to the end user. The process of clarifying roles will inevitably involve some trading off between public interests and the achievement of policy goals, vs. profit and customer satisfaction. Chapter 6 provides a more extensive analysis.

Impact on CO2 Reduction

What is the overall impact in terms of CO_2 emission reduction and the use of cleaner energy that can be expected by the development and deployment of the considered technology/technology solutions? Specify other relevant impacts resulting from the development and deployment of the considered technology.

The development and deployment of an advanced multi-modal NTM system will be a key contributor in raising the environmental performance of transport – enabling the reduction of CO_2 and other emissions (e.g. SOx, NOx, particles). Quantifying such a contribution however is not simple. This would depend not only on endogenous factors such as the level of NTM capability on offer (supply side), but also on exogenous factors, such as user needs and travel behaviours (demand side), as well as on the pace of change across major trends (e.g. digitalisation / automation). Nevertheless, considering a few facts and basic assumptions (Chart 1 below), it is estimated that NTM could deliver a preliminary contribution in the range of c. 7%-10% of the overall 60% EU transport decarbonisation (GHG) target by 2050. Furthermore, NTM will also deliver a wide range of additional performance improvements, raising the levels of safety and (cyber-) security, optimising capacity and enhancing cost efficiency of both passenger and freight transport.

Gaps

Which gaps (science, technology, innovation, market, policy, customer acceptance, user needs) and potential game changers need to be taken into account?

Moving forward from today's patchwork of modal- and national-specific NTM systems, towards a truly integrated and interoperable multi-modal NTM capability in Europe requires a major step change. This would need not only coordinated R&I on "hard" technological systems and information exchange, but even more emphasis on addressing gaps in "soft" organisational, human factor, cross-national, regulatory, business case/financing and public/private multi-actor responsibility issues. Furthermore, the broader trends and game changers also need to be taken into account, such as higher levels of connectivity and automation, increased multi-modal mobility and changing user needs. Finally, the role of Safety in NTM will be radically different, with game-changing implications for NTM, as highlighted in Chapter 6. Safety is of paramount importance in NTM operations and also in how future policy and performance optimisation should be calibrated against multi-criteria objectives (Safety vs. Environment vs. other targets).

Policies

How policies driven by demand could contribute to the development and deployment of the considered technology (i.e. public procurement)

Demand drivers such as user mobility needs are critical in the design of a multi-modal NTM system. For instance, dynamic demand and capacity balancing to deliver effective journey management is one of the features of an efficient NTM function. An important challenge in this context however, is how to arbitrate between the demand from the user (travel needs) and the overall system (network needs). Putting this dimension in context, future policy will need to increasingly reflect on the demand side and user mobility needs (passenger and freight). With higher (or lower traffic growth) across transport modes, increasing traffic complexity and demanding operating environments (e.g. urban), policies driven by demand changes can accelerate the development and deployment of an efficient, resilient and flexible NTM system, capable of accommodating any possible (planned or unplanned) situation. Finally, demand is also a key lever in balancing public/private interests and funding resources. Chapters 6 and 7 elaborate further.

International Cooperation

Where does international cooperation in R&I represent an added value? How?

International cooperation in R&I is critical to deliver interoperable systems, uninterrupted services and seamless NTM operation across national borders. This would range from international research cooperation and large-scale regional/cross-border demonstrations, to international standardisation and multi-stakeholder coordinated and synchronised deployment. International R&I in turn could be supported by both the public sector (e.g. EU R&I Programmes), as well as other international organisations and private sector actors engaged in R&I.

Summary (Chart 1)

STRIA NTM – Top 10 Priorities / Building Blocks for Research and Innovation

Building block	Phase	Key R&I themes *("What")*	Timeframe *("When")*	Instrument *("How")*	Lead actor *("Who")*	Cost[1] *("How much")*	Impact on Energy Union[2] *("Benefit")*
1	DESIGN	Architecture and Concept of Operations for an efficient, resilient and adaptable multi-modal NTM system	Short term	Research	EU	Low	Low
2	DESIGN	Development of multi-actor Organisational and Business Models with shared responsibilities	Short term	Policy Support	EU	Low	Medium
3	DESIGN	Research and validation of next-generation multi-modal NTM systems (including intra-modal optimisation and development of interfaces)	Short term	Research / Innovation	EU / Industry	High	Medium
4	DESIGN	Integration of infrastructures, vehicles, systems and services into a truly multi-modal network	Short term	Research / Innovation	EU / Industry	Medium	Medium
5	OPTIMISATION	Demand-Capacity Balancing for efficient journey management (passenger & freight)	Medium term	Research / Innovation	EU / Member States	Medium	Medium
6	OPTIMISATION	Calibration of arbitration models for complex NTM scenarios and multi-actor settings (optimising multiple performance targets and user vs. network needs)	Medium term	Research	EU	Low	Medium
7	OPTIMISATION	Traffic optimisation of conventional, (semi-) automated and unmaned vehicles within a multi-modal NTM system	Medium term	Research	EU / Industry	Low	Medium
8	EXECUTION	Large-Scale Demonstration of fully multi-modal NTM capability in any operating environment (Urban, non-Urban)	Long term	Innovation	EU	High	High
9	EXECUTION	Resource and asset management optimisation for advanced NTM systems	Long term	Innovation	Cities / Regions	Medium	High
10	EXECUTION	Piloting an efficient multi-modal NTM system across European hubs / nodes (incl. integration of non-EU traffic)	Long term	Innovation	Member States	Medium	High

1. Cost of NTM Roadmap:
Preliminary estimate in the range of c. EUR 7-10 billion for R&I by 2050.
NB: This includes EU, National and Industry R&I resources, on top of existing budgets. As a reference, only SESAR (traffic management for one of the four transport modes) has received R&I funding over two 7-year periods until 2020 of c. EUR 3.7 bn (1/3 from the EU). Furthermore, EU Transport R&I budget for 2018-2050 could amount to c. EUR 30 bn (i.e. five 7-year periods, c. EUR 6 bn each as in H2020), to be allocated across all 7 STRIA Roadmaps (e.g. EUR 4 bn each) and attract further public/private leverage (at least 1:1). Finally, deployment / investment costs are not included, hence only referring to R&I cost (NB: SESAR deployment costs are c. x10 the costs of R&I).

2. Contribution of NTM Roadmap towards Energy Union:
Preliminary estimate in the range of c. 7%-10% of the overall 60% transport decarbonisation (GHG) target by 2050.
NB: This estimate refers to the benefit realisation from the actual deployment and operation of next-generation / multi-modal NTM systems up until 2050. As a point of reference, SESAR estimates a reduction of up to 10% in Aviation CO2 emissions. Furthermore, all 7 STRIA Roadmaps are estimated to contribute on average 8.5% towards the 60% GHG target. Applying a sensitivity of +/- 20% (i.e. 1.5 percentage points on each side), this implies an estimated range of 7-10%. Finally, any contribution from NTM is also dependent on the delivery of the other STRIA Roadmaps, all together being required to make a collective contribution towards EU / Energy Union goals.

2. Introduction

2.1 Background and objectives of the Roadmap

The importance of **Network and Traffic Management (NTM) Systems** has never been greater, as the challenges facing all **modes of traffic and transport** increase with greater traffic levels; more interaction between traffic modes; and factors such as opening up of international markets, increasing levels of international migration, growing car usage and increasing urbanisation, creating demand not just for increased **urban** journeys but also for **inter-urban, regional, national and international** travel.

An efficient NTM system is absolutely critical for the future of personal, public and freight transportation. Significant technological advances can be expected in vehicle design and operation, e.g. development of (semi) autonomous vehicles and creation of appropriate infrastructure to accommodate such technical advances. However, all these advances will be completely nullified if a system to manage the anticipated volume and mix of traffic and transportation cannot be effectively managed. It will be pointless to promote and develop advanced transportation modes if they cannot operate efficiently due to unacceptable levels of congestion, potentially unsafe interaction with other vehicles, or absence of appropriate infrastructure. NTM is critical in this respect. It provides the framework within which all technological advances will function and it is a vital prerequisite for all successful traffic and transportation operation.

The demographic makeup of the European Union area is forecast to change over the coming years. By 2050, 30% of the population will be over 65 years old and 60% of people will be living in urban areas. This will present a specific transport challenge for any putative NTM system. Elderly people will want to retain and perhaps even increase their level of individual mobility. These aspirations will need to be incorporated and possibly encouraged within a NTM system.

Traditionally, road network and traffic management has focused on optimising the mobility of private cars. This has been the case both at an urban and inter-urban, regional and national level. Over recent years, this focus has begun to change subtly, as the needs for **public transportation, cyclists and pedestrians** have become increasingly significant, while traffic and transport policies are refined to give greater importance to these categories of local traffic. The demand among users for greater **inter-modal NTM** has also become an increasingly important factor, as travellers expect greater co-ordination amongst all transport modes, such as between **road** transport and **rail, waterborne and aviation.**

The Energy Union has laid down challenging targets for the reduction of greenhouse gas emissions in Europe by 2030 and it is against this background that the European Commission is producing a series of roadmaps on major environmentally focused traffic and transportation issues. This NTM Roadmap should be viewed in conjunction with other complementary roadmaps in this series. **The primary objective of this Roadmap is to provide a steer on the priorities for Research & Innovation in NTM systems between now and the year 2050.**

2.2 Approach and structure of the report

The report is based on a NTM **Vision for 2050**, which provides the foundation and rationale for the substantive content and conclusions / recommendations that are drawn at the end of the document. The 2050 Vision highlights a number of common themes, which we believe will be essential to efficient NTM systems. First and foremost among these is **safe and (cyber-) secure mobility**, about which there can be no compromise. All NTM systems must incorporate safety as an overriding element. The challenge will be to deliver safe NTM systems, whilst at the same time delivering the requisite **decarbonisation** targets and an **efficient operation**. The 2050 Vision will place the **individual traveller and their trajectory at the centre** of its field of interest. This, in many ways, is a logical and understandable development. The individual traveller will be seeking and expecting high quality level of **connectivity**, receiving bespoke information for his/her journey. The concept of journey management is likely to be an integral element of an efficient and publically acceptable NTM system. The individual traveller will want and expect a system that allows him/her to travel safely, (cyber-) securely, quickly and efficiently, with an acceptable degree of spontaneity and flexibility throughout local, regional, national and international traffic networks. Whilst acknowledging the central position of the individual within a future NTM system, this does in turn pose significant challenges for NTM operation. Is prioritisation of individual journeys necessarily compatible with a high quality NTM system? The roadmap attempts to address this issue throughout its content. The pace of technological change has been rapid in recent years. There is no way of knowing how this will develop between now and 2050. The roadmap attempts to address uncertainties around this, by identifying attainable milestones at defined points in time.

Changing network operation systems of the future will undoubtedly have an impact on mobility and society. Scenarios that represent the different levels of automation and economy sharing in our society are already being the subject of research. Mobility as a Service; Fully or Partially Automated and/or Multimodal and Shared Automation are the prevailing scenarios in academic research. They all have their own impact on public transport systems, sustainability objectives, available public space and societal needs. Business models behind car manufacturing, car sharing or public transport for example, will be greatly impacted. However, only time can tell with certainty how the mix of scenarios will look like in the next 4 decades.

For instance, Road Capacity and Traffic Management are going to follow suit in being affected by the rapid change in technology and in all possible scenarios. Cooperative Intelligent Transport Systems (C-ITS) and exchange of essential information among the vehicles (V2V) and with the infrastructure or general environment (V2X) are seen by transport experts as mandatory for the future of mobility. Controlling what routes self-driving vehicles should drive on and when to depart, for example, will be a key task for the traffic manager and will enable better control of vehicle availability, while at the same time it will force Traffic Management to shift its action focus from the 'now' to the immediate short future. Better use of the road network over the day will be a key objective for public authorities and traffic managers responsible to maintain low congestion.

2.3 Methodology for the development of the Roadmap

The methodology that underpins this roadmap highlights the move towards **multi-modal operation**. NTM systems need as far as possible to be standardised across different modes, with examples of good practice being chosen from various modes to inform the development of multi-modal systems. The movement towards multi-modal NTM systems reflects the ever increasing demand for seamless (and predictable) journeys for individual travellers and freight transport alike.

Individual road based travellers generally neither know nor care in whose administrative area they are travelling. Their primary desire is for an efficient, seamless operation and management of public infrastructure. The same also applies to movement of freight. This offers particular challenges to standardise NTM systems for **urban, inter-urban, regional, national and cross-border** journeys. Currently these remain very disparate in terms of their governance and management regime.

The provision of **freight** movement will be an integral element to be addressed in the evolution of the Roadmap. Shipment of freight by the most green and sustainable transport mode must, of course, be encouraged. A particular issue for urban authorities will be to evaluate the desirability of the most appropriate mode for 'last mile' link in the freight journey chain. Various break bulk modes such as drones, small vans, e-bikes and cargo bikes, present opportunities for sustainable delivery practice in urban areas.

The wide spectrum of modes covered by existing NTM systems makes their complete integration and standardisation particularly challenging. A journey will often include a number of different modes from e.g. **walking, road transport, rail, aviation or waterborne**. Devising a multi-modal NTM system that encompasses such a wide range of modes may not be attainable even by 2050. However, even if this is the case, there remains considerable scope to improve the **interface between different modal NTM systems**.

The 2050 Vision must inevitably be vague at this juncture, as there are so many uncertain factors related to the development of NTM systems. This roadmap contains a range of scenarios related to the vision, which have been incorporated to attempt to present possible different speeds and scale of development. This has led to the definition of high, medium and low impact outputs at certain key checkpoint dates.

The idea of mobility is also central to the methodology employed in this roadmap. NTM systems exist to aid and facilitate **mobility**. This concept is likely to become more prevalent between now and 2050, as ideas such as **Mobility as a Service** become more commonplace.

Whilst the roadmap is designed to steer Research & Innovation initiatives, it is also important that a chronological path is created which includes and prioritises deployment. Deployment can take many forms, starting from small scale trials through to larger demonstration projects, to general rollout and delivery.

As always, the relationship between the **private and public sector** will be critical in delivering the 2050 Vision. How this relationship evolves towards 2050 may be critical in defining the nature of the NTM systems that can be delivered. The roadmap also attempts to take into account how this relationship may develop and the effect it could have on future NTM systems.

3. Baseline and state of the art

3.1 Technological systems and operations

Principles and historical evolvement of NTM

Network and Traffic Management uses systems and techniques in order to manage traffic behaviour (flow, speed, choice of route, etc.) on a given network. This involves devices to detect real traffic conditions, traffic managers sharing information, optimisation processes that may involve human interactions and finally the distribution of control actions via signs, signals and other end-user devices. The overall aim of the whole management process is to optimise a specific range of target performance criteria, which may be directly traffic related (e.g. delays) or indirectly aim on other key performance indicators (e.g. air quality).

Recent developments (particularly – but not only - in the road domain) have enabled Traffic Management (TM) to evolve to a very effective tool, as well on the strategic as on the tactical level. This comprises:

- alternative methods of vehicle detection and the integration of data / information of multiple data sources (different sensor technologies and devices);
- the integration of upcoming new technologies like internet, GNSS, smart-phones, C-ITS, into legacy proprietary TM systems;
- the provision of high quality real time information to drivers, as well as via devices mounted in the field as in-vehicle devices;
- the development of very sophisticated traffic management strategies to prevent/minimise traffic congestion, which were enabled by selective detection methods (i.e. C-ITS), to incorporate particular groups of road users in the management decision (i.e. public transport vehicles, emergency services vehicles, cyclists and pedestrians) and which use both traffic control measures and traveller information to influence the network user in multiple ways;
- the exchange of data with external stakeholders, e.g. other network operators, third party information service providers, public transport operators, or navigation systems providers.

Against the background that transport demand and traffic volume is steadily growing, accurate traffic planning is an indispensable base of every traffic management function. This implies primarily an exhaustive understanding of traffic demand, as a crucial prerequisite to finally deliver a better quality of traffic management services. Real-time traffic management, which is based then on monitoring of traffic flows during operations, requires modifying the integrated traffic plans, in order to deal with unexpected events. The current trend is for leaving more flexibility during operations to modify the plan. This is especially required in case of totally unexpected events. Dynamic management of traffic flows enhances a more efficient traffic management if the vehicle routing and timing alternatives are carefully evaluated and the best solutions are selected and implemented. For example, the Dutch rail infrastructure manager uses dynamic assignment of train platforms inside busy station areas, allowing an efficient dynamic rescheduling. In this dynamic traffic management context, multimodal applications can be better implemented across the various transport modes.

The current attention to deal with a more flexible transportation environment is a key element to improve the efficiency of the overall network and traffic management. Levels of flexibility can be used to better integrate the solutions provided for different sub-problems related to the management of crews, vehicles and other resources. Furthermore, objectives and plans proposed by the various stakeholders should be better managed. For instance, railway traffic management needs to deal with the conflicting requirements of the infrastructure managers and by the various train operating companies. Additional non-technical elements (such as standardisation, administrative, organisational and operative procedures, regulations and business models) need to be strongly improved in order to maximise the efficiency of each transport mode and to favour a multimodal dimension.

Major challenges NTM is facing today

A major challenge in the current status-quo of the transport sector is related to the existing administrative, managerial and organisational barriers between the stakeholders and actors (at political and operational levels) of the various transport modes. Appropriate stimuli and legislative frameworks from the political side are strongly required to foster their commitment, cooperation and inter-working, including removal of operational problems at national boundaries. The administrative, organisational and operative barriers for a coordinated cross-sector NTM development are particularly evident when looking at the lack of cooperation in planning and operating the NTM plans between the private and public sectors in any transport mode. As long as these challenges are not understood and finally accepted by all bodies, the present situation, which is characterised by the waste of capacities and resources within all four transport modes, will continue in the future. Sub-optimal levels of transport performance are produced with the consequence that severe capacity constraints, daily nearly unmanageable traffic jams and undesirable environmental/emissions outcomes will remain. For many years, there have been no doubts that an uncontrolled evolution of transport and mobility services cannot be beneficial in terms of goals and objectives for the society as a whole.

Cities and metropolitan areas have their own short-term agenda to shape and develop the living space of their citizens and currently their mobility and transportation plans are primarily oriented on the enhancement of public transport and the creation of convenient (timeline, comfortable, accessible, door-to-door) environments, which are aimed to motivate people to use bicycles or to walk. In a truly multimodal approach, the softer modes (e.g. pedestrians and bicycles) can play a very important role, both in themselves, but also as a complement to the more traditional modes (e.g. car, train, tram, bus). An excellent example is the Netherlands, where it is possible to safely ride a bike in any city, thanks to dedicated lanes and signalling systems. In general, cities are not interested in the extension of individual car traffic, even if current petrol operated and driver steered cars will be replaced by low emission (free) and/or autonomous driving vehicles. Particularly an increasing number of autonomously driving cars - so cities fear - will provoke the contrast, fostering new business models (i.e. Uber), which hold the danger that the number of individual cars in cities and conurbations will dramatically increase and the use of public transport and soft modes will decrease. It is very important to notice that cities' strategies have a 3-5 year time horizon and changes happen dynamically with political transformation, therefore quick projects are usually given priority, while looking beyond this horizon for the majority of cities is not of primary interest.

Another key challenge is the quality of available data and the lack of regulations regarding the exchange of open data between the various stakeholders and actors from the different transport modes. The on-going transformation of business models and data availability strongly requires data handling and exchange strategies to support the digital infrastructure requirements.

A further issue is related to security and cyber-security. The risk of crime and terrorist attacks has to also be addressed, as well as the cyber-security threats to the transport systems, relying in an increasing manner on information and communication technologies, systems and services.

The above discussed challenges become particularly difficult to solve in presence of disruptions that seriously alter the planned traffic management schedules. Examples of disruptions are natural phenomena (e.g. 2010 eruptions of Eyjafjallajökull or 2009 heavy snowfall in the Netherlands), or other unexpected disruptive events.

3.2 Framework conditions

Currently ongoing European initiatives

The state-of-the-art in Network and Traffic Management is facing a deep transformation, in order to tackle the upcoming challenging objectives and to deal with the system constraints. This transformation is made possible by three major evolving factors (**TEN-T** and **CEF** regulations):

- the improvement of the existing infrastructure and facilities;
- the gradual introduction of new generation vehicles;
- the development of new technological systems, governance and procedures to better manage traffic operations and to offer new types of passenger and freight services. These three factors are currently addressed in parallel in all transport modes.

In accordance with the TEN-T and CEF regulations, the current infrastructure investments are concentrated in construction, upgrade, and modernisation of the infrastructure, in order to enable improved interoperability and enhanced efficiency. This is made possible by improving cross-border sections, removing the existing bottlenecks and bridging missing links. For example, the removal of level crossings is a key undergoing action to alleviate traffic on both road and rail lines and to reduce the risk of accidents. Another action is the improvement of the connection between air and rail networks, inland waterway and maritime transport, in order to reduce both the passenger and freight transportation times and to stimulate a modal shift from road to more eco-friendly transport modes. There are also actions dedicated to the improvement of the connection between the busiest European ports, rivers and canals with the rail and air networks. In road traffic, efforts are currently dedicated to improve the capacity of the busiest arteries and of the highly dense urban environments. Another key issue is the interconnection between the existing freight terminals and the other transport modes.

Semi-automated and automated vehicles are undergoing definition, development and deployment, such as the European "green car" and "clean sky" initiatives. These interrelated processes aim to put in operation new types of vehicle, allowing immediate positive effects on the environment, shifting from fossil to alternative fuels. Alternatively-fuelled vehicles together with alternative fuel infrastructure in urban areas are an example of progress towards improved energy efficiency, greater use of renewable energy and lower CO2 emissions targets. Hybrid and fully electric vehicles based on technologies reducing CO2 are going to be deployed according to “Clean Power for Transport Directive 2014/94/EU”.

Large-scale intelligent and interoperable traffic management and information systems are a key to better use the capacity of the existing and future infrastructure and to optimise traffic flows with heterogeneous vehicles. The collaborative decision making and system-wide information management proposed for air traffic management (**SESAR**), the advanced signalling and railway traffic management system (**ERTMS**), the safe and secure maritime traffic monitoring and information system (**SafeSeaNet**), the real-time river traffic information system (**RIS**) and cooperative intelligent transport systems (**C-ITS**), as well as initiatives on multimodal transport management and information systems play a key role in speeding up the deployment of smart and intelligent mobility systems for improved traffic monitoring, control and communication to the traffic controllers and vehicle operators.

Research and innovation in new technological systems is currently dealing with several parallel challenges:

- European global navigation satellite system (**Galileo**) has the potential to allow new opportunities for efficient tracing and tracking of vehicles, e.g. pilots are currently being under investigation for train control. As a result, traffic management will have more frequent and reliable real-time information.
- Digitalisation of information and improving data gathering through smart, monitoring-enabled components and actors is currently taking place. Dealing with big data also needs to be carefully managed and filtered, in order to be used effectively for real-time traffic management purposes.

General technological and social trends to be considered

Data is a major challenge for transport and network planners, including big data collection/fusion/management, floating vehicle data, data collection via social media, etc. Increasing real-time information availability can create a seamless connection, although it does not necessarily mean a clearer picture of the current traffic state. The information has to be verified, filtered, elaborated and communicated via customised interfaces to the user.

The level of automation of vehicle-to-vehicle and vehicle-to-infrastructure connectivity plays a key role in automated traffic management systems, including common standards and technical specifications. Driverless metro lines in Paris or Lille are examples of successful application of high levels of automation. Another example is the high level of connectivity potentially achievable with the use of (C-) ITS technologies, such as automated highway systems or advanced urban signal control systems.

Decision support systems have the potential to guide the traffic controllers towards optimised solutions via the use of greatly sophisticated traffic flow models, allowing not only the high quality reproduction of current traffic and traveller conditions, but also optimising the future traffic situation in a highly reliable manner and for any kind of traffic situation, including during severe network and traffic disturbances.

In addition to the IT/technology discipline, the recent approaches demonstrate that transport is closely related with other disciplines and especially psychology (human factors), since behavioural patterns play a critical role in traffic management, e.g. it is difficult to predict route choice behaviour in case of road congestion. Human factors play a key role in the realisation of innovative solutions, especially in relation with the improved level of automation and intelligent decision support.

Today’s and future benefits of NTM

The transport sector is facing a deep transformation related to the above discussed challenges and to the introduction of new services for all types of users, with the aim of maximising the benefits and minimising the costs. The EU added value of these factors can be measured in terms of multiple factors:

<u>Safety</u>: This is a hard constraint to be satisfied by any network and traffic management system (e.g. road and rail traffic is expected to converge to nearly zero fatalities, air traffic is expected to improve its already impressive safety level by a factor of 10). There are multiple ongoing development directions (including guidelines, directives

and regulations) to prioritise this aspect by adopting, refining and incorporating systems designed to prevent accidents and collisions. In road traffic management, this can be seen in autonomous/semi-autonomous vehicle sensors, intelligent speed adaptation systems, etc. In rail traffic management, safety is even more central in the existing traffic management systems, via new automatic train protection systems (ATP), advanced trajectory planning and modern signalling systems (including ERTMS). In Air Traffic Management safety has always been the top priority, with numerous lines of defences being built and continued to be refined in ground and airborne systems. Safety also means enabling an efficient monitoring, repairing and maintenance of the traffic data, infrastructure and vehicles.

Security and cyber-security: This is another hard constraint that is inherently required, especially in highly dense public transport environments, such as air hubs, major railway stations, truck and highway parking places, busy inland ports and seaports. In Europe, excellent examples of high-level security are e.g. the metro systems of densely populated cities, such as London Underground, or European airports. Similar level of security is envisaged in any intra-mode transport and in inter-modal connection points. A high level of cyber-security is required to prevent hacking, jamming and unauthorised manipulation traffic management and network operation systems, while also ensuring a satisfactory level of data security and privacy in transport.

System transformation: All transport modes present very interesting multimodal opportunities. For example, rail-air interconnection has been recently improved at some European airports, contributing to a modal shift from road to rail, both for freight and passenger traffic. Another example is the recent focus on improving the management of containers at maritime terminals, including their movement from the rail yard to the ground and from the ground to various types of vessels. On road, car, bike and even aircraft sharing are interesting opportunities to improve the connection between transport modes.

Performance: The quality of a mode of transport can be defined as efficient, safe and integrated into the inter-modal chain and with high environmental standards. However, the modernisation of traffic management systems primarily focus on well-established performance indicators related to cost efficiency and return on investment. For example, throughput maximisation is considered important in air traffic management, delay minimisation is a main performance indicator in railway traffic management, maximising the use of vehicle capacity is a key concept in inter-modal maritime-based logistics chains. In general, optimising vehicle routes and schedules can improve the network capacity utilisation in multimodal door-to-door logistics chains. Smooth vehicle flow is an important concept common to all possible definitions of competitive and efficient transport system. Some transportation modes are directly moving in the direction of prioritising performance indicators aiming to reduce decarbonisation and energy consumption, e.g. SESAR's contribution to ATM modernisation is expected to result in a reduction of 10% of the effects that flights have on the environment. In other cases, the adopted objectives are conflicting with the performance indicators that would generate positive impacts on the environment. As a result, the indicated climate and energy targets are still far from being fully addressed.

3.3 Potential for future development

Trends and issues making the difference in the future

In the coming years, there will potentially be a revolution in network and traffic management, since transport infrastructure, vehicle, digitalisation and other advanced technologies are progressively improving, while movement of people and transport of goods is expected to continue to increase dramatically. The implementation of the TEN-T core and comprehensive network, including the improvement of rail-air, rail-rail, rail-road, air-road or rail-maritime links, and the use of semi/automatic vehicles will offer opportunities for achieving an efficient future EU transport system. The improvement of the precision of estimation of the current position and speed of vehicles and the development of smart, sustainable and agile traffic management systems will enable better safety, connectivity, interoperability, multimodality, sustainability, accessibility.

The transition between the current state of the art and future network and traffic management should address the development of concepts to increase multimodality, by offering customers integrated door-to-door transport solutions and to explore the full potential of the re-organisation and re-optimisation of traffic flows in an overall EU transport network. Exploring this potential will create new business opportunities (e.g. inter-modal tickets could be sold to passengers, strengthening public-private partnerships). A major improvement will consist of increased customer satisfaction levels, a better use of complex infrastructure resources with limited capacity, including interconnecting modal points, to ensure smooth last mile connections and transhipment between long-distance and urban transport. The gain achievable by the future transformation of the industries, technologies, operations and frameworks in a single mode can be strongly improved by adopting cross-modal and multimodal strategies, enabling an effective management of the substantial expected growth in both passenger and freight traffic, provided that technologies, systems, and services are compatible and at the same level of development.

Understanding the needs of the infrastructure and travel modes can aid in mitigating congestion. For instance, congested road networks result in a loss of time, money and energy, which have an impact on both the city and its citizens' lives. Taxpayers' money is invested in infrastructure construction and maintenance, although it is proven that a better solution lies with introducing alternative travel modes and dynamic (real-time) advice on alternative routing (load balancing). Dedicated driving lanes, carpooling, tolling and other traffic management measures do not seem to have solved the problem. Real-time traffic information based on the use of Floating Vehicle Data (FVD) for example, already puts drivers in the position of making decisions and choices that go beyond the individual benefit (of fast travel), to that of the general benefit of the city, contributing thus on the optimal use of the traffic management network.

Intra-modal improvements will be possible thanks to the availability of more precise information on the intra-modal traffic flows and the development of ad-hoc efficient traffic optimisation approaches. There will be an increasing need for integrated decision support systems to help the human traffic controllers and drivers to deal efficiently with mixed manual and automatic/semi-automatic vehicles. Such systems should be able to analyse almost all possible traffic management solutions and deliver efficient solutions in a short computation time. The decision support systems would need to prioritise the performance indicators, giving precedence to the ones focused on generating positive impacts on the environment, e.g. reducing energy consumption and gas emissions. At the same time however, they will consider the well-recognised performance indicators (e.g. throughput maximisation, punctuality, customer/user satisfaction), numerous hard problem constraints (including noise, safety, security and cyber-security aspects), and combining network and traffic management solutions with social and economic development. Therefore, the resulting approaches will need to solve integrated multi-criteria multi-actor optimisation problems efficiently, i.e. finding equilibrium/equity solutions.

The resulting multimodal transport network will offer a huge number of alternative solutions to the users, thanks to the enabled interconnection between intra-modal transport solutions.

Needs and the challenges to exploit the potential of NTM

The development of efficient multimodal transport systems will be challenging for a number of reasons:

i. There will be a need for coordinating travel timetables and synchronising real-time decisions by all the actors of the different transport modes. A clear understanding of the positive and negative effects is required. It may be that some stakeholders/actors/users will take advantage of the synchronisation, while others will be penalised. It is also possible that the role of business and industry will change.

ii. The availability of huge amounts of data regarding the interconnection of infrastructure, vehicles, people, goods, management and operations will offer new opportunities and challenges to better optimise traffic flows. However, it is a key issue to define and implement harmonised and standardised concepts for (cross-border) exchange of data between authorities, operators and/or users, to enable an easy and reliable synchronisation and to interconnect the national systems with (Pan-) European systems.

iii. All decision makers are expected to access/share information and responsibilities at various organisational levels, collaborating in order to achieve the given EU policy objectives, including decarbonisation, efficiency, investment, jobs and growth goals. An example of collaborative decision making is the strategic and tactical European air flow management regulated by Eurocontrol.

iv. The role of the user will change in view of new information systems (either public or provided from the market only, to those who are willing to pay for it) allowing a better knowledge of the multimodal transport solutions on alternative clean fuel infrastructure. New business models for EU-wide real-time multimodal travel information services (including ITS applications for higher level service booking and ticketing) will be required to attract the user, in view of enabling and easing people's mobility (including accessibility of transport infrastructure to all kind of users), while stimulating shift from private cars to walking, cycling and public transport. These models will offer win-win solutions, in which the combination of transportation modes would stimulate an increase of traffic demand in all modes.

4. Achieving policy objectives and targets

4.1 Performance framework

General long-term goals

As it was stressed in the early stages of the Europe 2020 strategy, Europe needs to better use the available resources under emission-reduction commitments. These commitments have been reinforced with the Energy Union paper and more generally in the EURICS context that provides the framework to respond to the energy, emission and climate challenges.

The 2050 Energy Union policy objectives and targets include the following quantitative elements:

- Decarbonisation: -60% GHG emissions by 2050 (vs. 1990 levels) and -40% domestic GHG emissions by 2030;
- Efficiency: 27% energy savings by 2030;
- Jobs, Growth & Investment: Significant contribution to EU R&I leadership, economic growth, jobs creation.

In addition to these elements, further relevant EU goals and policy objectives are considered – in the context of Energy Union, White Paper on Transport and beyond (e.g. digitalisation, automation, system transformation, industrial competitiveness, safety, security, cyber-security, other non-green parts of "smart, green and integrated transport", etc.). Reaching and exceeding these intermediary objectives will allow the EU to pursue the goal of an 80-95% decrease in greenhouse gas emissions by 2050.

Transport sector goals and the possible role of NTM

The transport sector plays a key role in this context, since it accounts for about ¼ of all GHG emissions, about 1/3 of all energy consumption. The Transport White Paper has called for 60% reduction in transport GHG reductions by 2050, while at the same time drastically reducing other negative impacts (accidents, emissions/noise, congestion) and achieving sustainable mobility services for citizens and transport services for businesses.

However, transport has been inherently difficult to decarbonise and improvements in energy efficiency have been offset by increasing transport volumes/distances, while the uptake of alternative fuel technologies has so far been limited. The next generation of a unified and modernised EU transportation environment will require the development of new coordinated research programmes, funding opportunities, innovation strategies, business approaches, state-of-the-art technologies, best practices, directives and norms.

The combination of transformative factors and the implementation of the outcome of successful studies and pilots carried out under previous projects will directly contribute to the EU policy objectives on Energy and Climate being realised:

by 2030: with the completion of the TEN-T core network, at least 40% domestic reduction of greenhouse gas emissions, at least 27% share of renewable energy consumed and at least 27% improvement in energy efficiency.

by 2050: with the completion of the TEN-T comprehensive network, the reduction of EU CO2 emissions from maritime bunker fuels by 40%, halve the use of fuelled cars, the shift to other modes 50% of road freight over 300 km, a move close to zero fatalities in road transport, the connection of all core network airports to the rail network, a move of the majority of medium-distance passenger transport to rail.

The 2011 Transport White Paper already acknowledged that the development of a competitive, intelligent, multimodal, integrated and resource efficient transport system requires advanced network and traffic management capabilities, in order to contribute considerably to the reduction in CO2 emissions and comparable reduction in oil dependency by 2050 compared to 1990 levels.

Major gaps and barriers to overcome

The existing operating Network and Traffic Management systems are slowly contributing to the realisation of the Energy Union strategy and the Transport White Paper targets. Furthermore, transport is facing a significant growth forecast for mobility of people and transport of goods up to 2050 (e.g. double European air traffic vs. 2005), as well as increasing global market competition within and beyond the EU (amongst industry, operators/users, etc.). Consequently, there is a need to determine how the transport system should adapt to the decarbonisation challenge, while ensuring that increasing mobility needs are met. In this context, an overall European network management strategy must be developed and agreed between the various stakeholders and actors: with the final aim of accommodating the substantial growth in both passenger and freight traffic and in order to fully achieve the realisation of the European policy objectives and designated targets by 2030 and 2050.

The transition towards an advanced multi-modal transport system requires the effective optimisation of the entire transport network, across a number of performance areas. Active network management and a better orchestration, organisation and optimisation of traffic flows in the system play a key role in this process.

At present, there are numerous bottlenecks within the four modes of transport (air, rail, water, road) and across multiple operating environments: producing sub-optimal levels of transport performance, severe capacity constraints, unmanageable traffic jams and undesirable environmental/emissions outcomes. The lack of efficiency in the management of traffic flows can be a major cause in the decrease of attractiveness of collective transportation for passengers and share of railways and inland waterways for freight transport. Other major causes are lack of timely information, reliability, coordination, passenger comfort and accessibility.

Air: In the aviation sector, the objective is to achieve a Single European Sky, in order to improve air traffic management in Europe. The current bottlenecks are hub capacity, management operations (improving the movement of aircraft, cargo, passengers, baggage at gateways, taxiways, runways and during landing/take-off procedures) and en-route coordination of traffic flows between/outside European hubs. The key elements to improve are modernisation, harmonisation and synchronisation of air traffic management systems (including better aircraft trajectory & route planning, collaborative network management, flexible airspace management, integrated management of en-route and terminal control areas, inter-modal air transport connections).

Rail: In railway traffic management, the increase of heterogeneous (local, international and freight) traffic flows requires an improvement planning and management of traffic flows (including better train timing, ordering and routing decisions). The key elements to improve are the management of traffic flows at cross-border sections (especially when using different signalling and train operating systems), rail terminals connecting rail with other transport modes (including rail-road terminals, advanced rail-rail trans-shipment yards, shunting yards, terminals in inter-modal logistic areas, depots for rolling stock), complex and densely used conventional railway stations for passenger trains in urban areas (hosting local/high-speed/international/freight traffic).

Road: On urban roads, a significant improvement of mobility of people and transport of goods requires a better management of all kinds of vehicles (from conventional to autonomous vehicles), vehicle fuel technologies (from fossil to alternative fuels), bicycle and vehicle sharing, dial-a-ride, road public transport and paratransit, walking and cycling. This problem is particularly evident in highly dense urban and metropolitan environments. For modal shift and effects on GHG, short trips play an important role. Also due to growing urbanisation, shorter trips will increase and these short trips will need to shift to soft modes of transport (e.g. bicycles).

On extra-urban roads, the requirements are to achieve a safe, efficient and sustainable road transport in order to offer connected mobility, less congestion, fewer accidents, less pollution, improved levels of EU-wide multimodal travel information services. These objectives require investments on (C-) ITS and connected driving technologies.

Water: The European ports, rivers and canals play an important role in global supply chains, since a very large percentage of global merchandise trade is carried by sea and handled by ports worldwide. The current challenge faced by carriers, port operators, freight forwarders and shippers includes the following issues: improving the traffic flows between ports, better handling of loading and unloading requirements in each port, better synchronising the management of resources and vehicles inside/outside the port areas, effectively managing inter-modal connections with expanding port hinterlands, providing seamless door-to-door inter-modal transport services for customers, increasing maritime connectivity via trade liberalisation strategies.

Reconsideration and enhancement of KPAs and KPIs

The enhancement and standardisation of performance objectives and requirements should be considered for effective NTM optimisation. This would include performance enhancements in a number of Key Performance Areas (KPAs), such as environmental sustainability, capacity, safety, (cyber-) security, cost effectiveness, predictability, efficiency, flexibility, customer mobility performance and satisfaction levels, as well as other/qualitative objectives (e.g. increasing automation levels, cross-modal integration, evolving human factors).

This is particularly important, given that the development of advanced NTM systems requires several performance trade-offs to be considered. For instance, regulating traffic vs. longer journey times; providing extra capacity vs. additional cost; prioritising low-emission vehicles vs. cost of retrofit/forward fit.

As a boundary condition however, there should be "zero compromise" on Safety: even with new advancements, higher network density and traffic throughput capability, safety targets at EU and UN level must be maintained.

Next-generation NTM solutions must focus on decarbonisation, safety, (cyber-) security, interoperability, sustainability, accessibility, multimodality, efficiency, better customer mobility performance and predictability, improved traffic operations and network management. These systems imply a global view (which involves coordination between the different aspects of transportation), versus a local view (e.g. one domain focusing on new generation vehicles only, one mode focusing on car traffic regulation only, etc.).

The uptake of efficient technologies can also significantly reduce the investment costs of new vehicles, infrastructure and (non-) technical solutions. The development and production costs of innovative technologies could be reduced by the introduction of business and standardisation processes, in terms of simplification and harmonisation of technical specifications and administrative, organisational and operative procedures. In general, a common agreement framework must be established between the various stakeholders and actors.

In order to support the fundamental changes in how NTM will differ from today, strong change management support has to be provided. This should be based on R&I taking into account the business goals of the various stakeholders in a competitive NTM environment. The goal should be to get away from isolated decision making by a single stakeholder in competition with the other stakeholders, towards a *'co-opetition'*. In other words, opening the way for flexibility and most beneficial use of all transport means for a given transport mobility, while at the same time respecting the different business models of the various stakeholders.

4.2 Technological progress

The transport sector is facing an increasing emergence of new technological developments, vehicles, systems, operations and infrastructure, as well as modal shift, increasing cross-modality, changing mobility patterns and travel behaviours. The challenges surrounding "classic" Network and Traffic Management are evolving rapidly. This is no longer a simple capacity management issue focusing on volumes, but also on the type of vehicles (e.g. platoons); movements (e.g. domestic vs. cross-border); traffic mix and complexity (e.g. conventional vs. low-emission or automated vehicles); infrastructure usage (e.g. "smart" maintenance); and eventually the degree to which all Key Performance Areas (KPAs) are being optimised (Environment KPA being one of them).

The realisation is that a multi-modal inter-connected transport system requires carefully addressing of the evolving problems related to each intra-modal dimension. The understanding of the technological progress needed in each intra-modal dimension plays a key role in achieving a clear picture of the overall potential of future NTM. Existing/future NTM systems need to be adapted to accommodate not only rising volumes/growth, but also different types of vehicles, infrastructure, movements, traffic mix & complexity. Advancement and performance optimisation of existing/future NTM systems is next addressed within each mode of transport, taking into account specific sectorial characteristics, needs and requirements. This is particularly pertinent, in view of the varying degrees of technological progress and adoption across the various modes of transport, different NTM challenges, ongoing R&I initiatives, regulatory frameworks, EU policies, travellers needs and behaviours, levels of public acceptance, etc.

The development and deployment of Europe's GNSS, Galileo is a common feature across all transport modes which is assumed to contribute significantly to an advanced NTM capability. With the new tracking technologies, positioning systems are expected to work in a reliable and accurate manner, also under difficult topological and meteorological conditions. As a result, vehicle positions and speeds will be available in traffic management and information systems, allowing better control of vehicles and more accurate maps and navigation systems.

Next generation multi-modal inter-connected transport systems will be self-regulated/optimised in relation to Network and Traffic Management, capable of absorbing both planned events (e.g. maintenance/Olympics) and a range of unforeseen traffic-related circumstances (e.g. accidents, volcanic ash). Such capability will potentially arise with the development of advanced cross-modal V2V, V2I or X2X connectivity, enabling vehicle self-separation, "smart" and adaptable infrastructure, etc. In addition, these future solutions will help ensure safe and secure interaction also with transport users, who deliberately or unknowingly are not "in" the system.

Air**:** In the SESAR framework, there is an increasing trend to optimise the use of airspace and ground resources. This can be maximised when combining ongoing and expected technological, administrative, organisational and operational improvements, including an increasing level of automation support, system-wide information management (SWIM), the provision of next generation air navigation services (ANS), the implementation of virtualisation and digitalisation technologies, the use of standardised and interoperable systems, and the full integration of hub operations into the air traffic flow management at a network level. Several improvements are potentially achievable thanks to the ATM modernisation, such as improved ANS operations productivity and efficiency, enhanced air-to-ground and air-to-air interoperability, increased collaboration and operational predictability, improved airport performance and access, improved flight trajectories, enhanced safety and (cyber-) security. Example initiatives are AirPort Operations Centre (APOC) with respect to collaboration of various stakeholders and Extended-Arrival MANagement (E-AMAN) with respect to 4D trajectory management, both contributing towards more predictability and better use of limited resources.

Rail: Full deployment of ERTMS is expected on the European Core Network by 2030. However, various technical solutions are available for implementation of this technology, thereby hampering interoperability and increasing costs. As pointed out by Shift2Rail, this technology needs to be better combined and integrated with other technologies and practices, including use of satellite positioning technologies, data and voice communications systems, automation, as well as innovative real-time decision support systems for predictive and adaptive operational control of train movements. The potential of this combination of technologies includes a decrease of energy consumption, air pollution and carbon emissions, an improvement of rail capacity use, a reduction of operational costs, an enhancement of safety , (cyber-) security and better customer information and satisfaction.

Road**:** ITS is transforming the management of road transport via interoperable services, such as real-time traffic information provision, dynamic traffic flow management along trans-European corridors, EU-wide multimodal travel information services. C-ITS technologies allow vehicle-to-vehicle and vehicle-to-infrastructure communications and open the door to strong potential improvements in road transport safety and traffic efficiency. There are a number of technical and legal issues to be addressed for implementing C-ITS, including access to in-vehicle data and resources, (cyber-) security, data protection and privacy, choice of communication & information technologies. On top of this, NTM systems deal with both private and public vehicles. All these requirements must be coordinated at EU level as a unique legal and technical C-ITS framework. However, C-ITS and automated driving have not just to be regarded as a technological challenge, but mainly as a platform for better organisation, management and coordination of people's travel needs and goods transport in the future.

Water: VTMIS, SafeSeaNet, and RIS technologies enable effective port, maritime, inland waterway activity operations, vessel traffic monitoring and information exchange, surveillance and (cyber-) security, as well as water environmental protection. These technologies are collecting more and more monitoring data and information regarding infrastructure, people, vessels, management, operations and cargo, contributing to: the consolidation of the European Waterborne Transport, the integration of Waterborne Transport to the Core Network Corridors, the development of intelligent and automated tools for operations and management, the improvement of data gathering through smart, monitoring-enabled components and actors, the interconnection with ITS systems of other transport modes and facilitating passenger / freight movements across countries.

Freight and logistics: Another major challenge is the improvement of inter-terminal transport. This is crucial in consolidating demand to be sent to the hinterland via barge / rail and for dealing with internal flows to common facilities. The optimal vehicle configurations at the inter-modal logistic points will be determined in terms of network layout, amount of vehicles, interchange points. This technological challenge requires investigating sensitivity to system parameters and providing quantitative support for decision making, for long time horizon and cost-intensive equipment, such as quay cranes, automated guided vehicles, automated stacking cranes.

4.3 Improving operations

Truly multi-modal approach as background for NTM of the future

The ultimate goal of this Roadmap is to blaze the trail for the development and implementation of intelligent, dynamic, effective and truly multi-modal Network and Traffic Management systems, which are live, proactive and highly responsive to today's and future needs. The result is a list of R&I initiatives and solutions which are directly contributing to the timely realisation of the Energy Union and other EU policy objectives.

An essential prerequisite for truly multi-modal Network and Traffic Management is the availability of one unified European transportation network, which travellers and hauliers perceive to be seamless and barrier-free. This network comprises the partial networks of all modes (air, rail, road and water), which are connected by highly effective and barrier-free transitions (hubs), in a manner that is not imaginable today and which are shaped and equipped in a way to allow the operation of emission-free, automated driving vehicles, as well as highly integrated processes. At the same time, Network and Traffic Management functions may not necessarily be coordinated and performed centrally (e.g. at Air/Rail Traffic Control Centres), but may also be available at de-centralised level (e.g. through advanced in-vehicle capabilities and possibilities to engage directly with individual operators or travellers).

Against this background, future R&I efforts have to consider a more revolutionary approach towards the development of a brand new generation of holistic, truly multi-modal next generation network/traffic management systems, specifically designed and tailored from their construction to tackle complex cross-modal issues. In particular, new systems are foreseen to be capable of seamlessly integrating and processing real-time traffic and other types of information across modes (inputs), while providing effective network and traffic management, with open information access/sharing and a simple user-friendly interface (outputs) to actors (operators, infrastructure managers and customers) in the transport network.

There is a need to move from reactive to proactive traffic management, exploiting the resources and facilities of all modes in a completely interlinked multi-modal network, where especially inter-modal hubs will play a strategic role for the mobility of the future. A close cooperation and collaboration of NTM systems of all modes will result in highly efficient reactions to incidents and accidents, their proactive prevention occurring in the first place, being able to predict and detect the evolving risks and NTM consequences for incidents and accidents in advance. The NTM system must efficiently restrain disturbances due to external influences and should be able to recover more quickly after being disturbed. Furthermore, the new NTM systems should contribute to the minimisation of renovation, operation, maintenance and inspection costs for vehicles and infrastructure.

Cross-organisational cooperation and orchestration as a key factor for success

As in any other discipline, transport is closely related to a number of political and organisational issues to be addressed for a policy, a scheme or an infrastructure project to be implemented. In fact, the management of transport involves several processes such as monitoring, dynamic management and enforcement, while it is very often the case that different authorities are responsible for each one of them. Particularly, in cities at least three or four authorities are involved in transport network management, with the most common being national, local and city authorities and the police, but also being complemented by parent companies, public-private-partnerships and public funding initiatives. Good communication and coordination between those is, as expected, a necessity for any efficient transport network management process. However, it is often the case that there is a lack of effective communication between authorities and organisations, particularly when different authorities manage different parts of the transport network. The impact can be felt in many NTM aspects, such as, for example, a disruption situation, or an incident and emergency response, where it is essential to have a mechanism in place, which detects an accident, alerts the emergency services, informs the public and re-routes traffic, travellers and goods - also across different modes - where necessary.

The cross-organisational aspects of NTM have not been formally looked at on a larger scale in the past so far, and it is clear that great benefits can be gained from an integrated NTM approach, facilitating better communication, alignment and information sharing between relevant organisations. Hence, one of the main objectives for the future must be to progress from different organisations and agencies, each working to pursue separate goals, to an orchestrated virtual NTM organisation pursuing the global people mobility and freight delivery objectives.

Given that unified European transport and network management is a chain of tasks and processes that begin with distinct quality goals, decided by a political instance, which lead to measures decided on a tactical instance, and which are in turn implemented and validated by the use of dedicated technologies, a three-level organisational structure can be identified: 1) Institutional level, 2) Functional level, 3) Technical level.

A successful integrated NTM implementation requires the definition of a coherent architecture/meta-model and concept of operations across all those three levels, which includes goals, business / organisational aspects and technologies used by the organisations involved. Activities should aim at merging goals, processes and technologies, in order to create an appropriate cross-organisational NTM business architecture.

New arbitration framework

The availability of an intelligent, dynamic and effective cross-modal and cross-organisational traffic and mobility management system is of paramount importance. This system should be able to respond to different requirements of transporting individuals and the movement of goods. Today, autonomously acting traffic and mobility managers cooperate and work together with the capability to “switch” between all modes, in a way that their partial networks are perceived by travellers and hauliers as one single all-modes overarching borderless network (for instance, see approach of Traffic Management Centre Stuttgart).

As the reachability of individual persons and vehicles will be given at any time and at any place and as mature, highly efficient and reliable information and transportation technologies will be available, new business models will enable highly agile service providers to offer manifold new primarily “customer oriented” mobility and transportation services. Beyond that, new public-private cooperation and collaboration models will be the basis for public-private partnerships, in order to cover not only requirements of each individual customer in an ideal way, but also to ensure, that beyond the interest of private enterprises and their individual customers, public interests and mandatory regulations will be respected in an adequate manner.

An essential prerequisite for the future regulation and arbitration framework is to balance different requirements, which on one side derive from the business models of the mobility and transportation industry in response to the customers’ wishes/needs and on the other side reflect the needs and wishes of the society, in a form both sides can accept. The need for a regulatory framework for decision making in NTM (centralised or de-centralised) is a fundamental base. Furthermore, new “arbitration models” have to be developed, based on the regulation framework, for the following multiple purposes: leading to acceptable decisions, linking the demand for the transport of persons and goods with the related consumption of resources, linking the undesired impact on the environment to the offer of cost-efficient sustainable resources and to a healthy degree of emissions. For example, fleet operators of individual cars to be burdened with special fees, thus compensating for a greater consumption of resources and output of emissions, in comparison to public transport and soft modes.

5. Strategic implementation plan

The implementation plan has to follow an approach capable of reassessing continuously the operating conditions and changes in new technology opportunities and business / demographic developments. These are showing trends to urbanisation, with more and more people choosing to live in urban areas and on the other hand, a modified demand for travelling, triggered by pervasive communication, wide-band and offer for remote services.

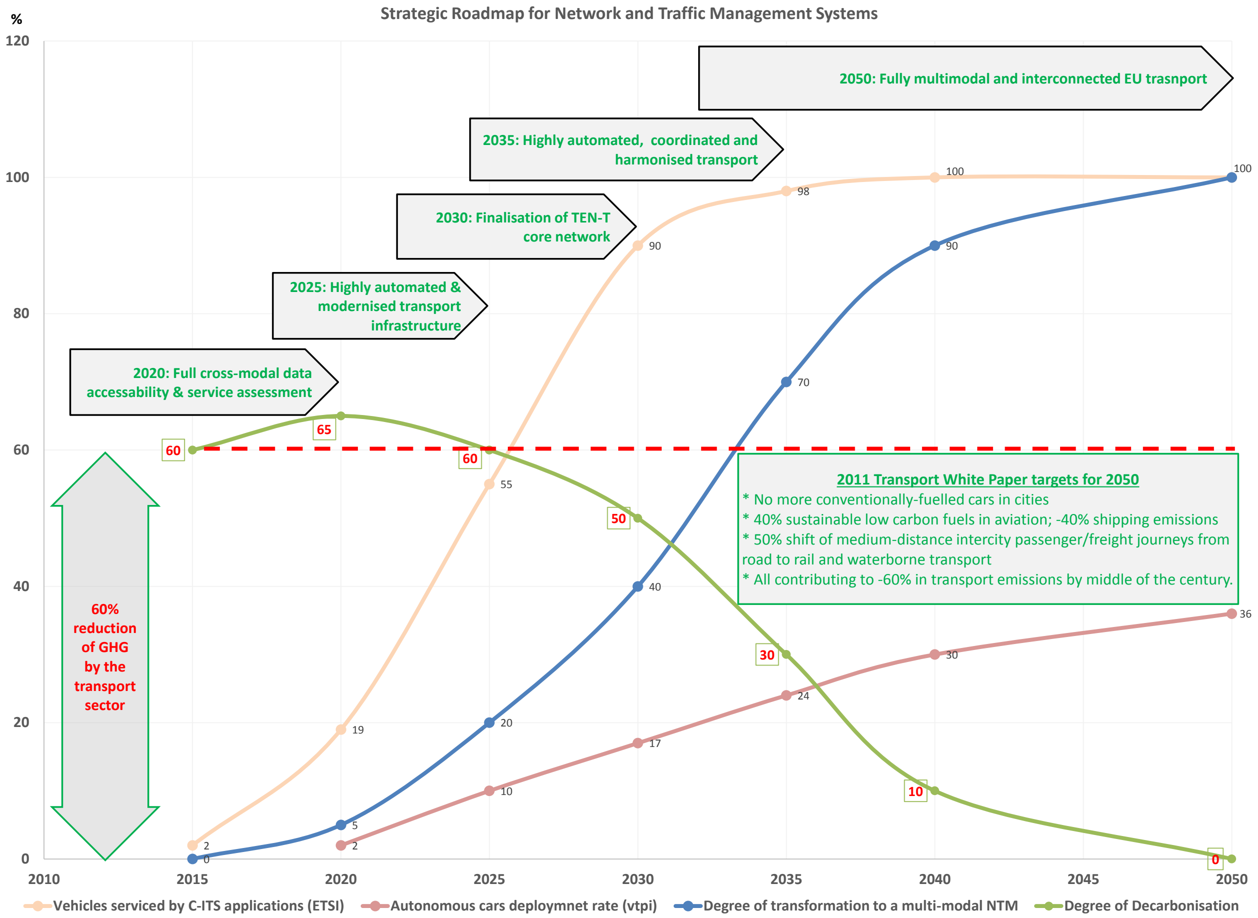
For these reasons, a **stage-gate approach** is proposed here. Reference indicators should be used to closely monitor the current state and the achieved milestones. Moreover, the strategic plan has to exploit the leverage on the technology progress roadmaps, envisaged for all the reference sectors, thus optimising the acceleration effects. This will be achieved through a close coordination between the NTM Roadmap and all the other related roadmaps, ranging from new technology to sector specific new developments and the operating organisations.

Different approaches might be adopted for continuously assessing different mobility contexts, such as local mobility (urban environment) and long distance mobility; these two contexts are expected to have completely different evolutions, resulting from the developments in technology and mobility needs.

Examples of most important **reference indicators** that will require continuous assessment and, consequently, real time monitoring on dedicated dashboards, are:

- Connected mobility devices (both in-vehicle and transport infrastructure units used to manage mobility) as a ratio on total implemented devices; to assess the level of maturity throughout the EU
- Vehicles, people and freight flows throughout the transport network, as well as incidents and events causing specific disruptions and inefficiencies; a continuous overall assessment of the mobility demand and occurrence of incidents and events will be essential
- Number, type and consequences of security and cyber-security incidents in transport of people and goods
- Mobility performance and appreciation of mobility/travel services; to assess the quality of the achieved impact of the ongoing transport innovation transformation
- Safety indicators, such as fatalities and injuries, in the different areas of mobility. This will ensure the verification of the trends and impact of the introduction of new technologies; moreover it will provide the social and political support/justification to any initiative in the roadmap
- Environmental impact indicators, such as the reduction of the GHG and energy consumption for transport and mobility. This will have to be closely monitored to respond to the political objectives to which the Network Traffic Management strategy is expected to have a significant impact

Reference indicators, constantly assessed and certified, can allow the visualisation of the actual state of implementation of the envisaged Roadmap; they will also provide the basis to better forecast the future NTM scenarios. An example of visualisation is reported in the following diagram:



The setup of the monitoring tools, systematic data collection from all available sources, and the set-up of analytic dashboards, will be an indispensable first milestone. It will be useful to set the scene and should be achieved from now to 2020. This first milestone of the plan is particularly important, because it will also provide the assessment of the reference scenarios, that will be used later to compare the trends.

The following key reference milestones are considered in the strategic implementation plan. Reference milestones will be subject to continuous revision, as a result of the continuous monitoring of implementation progress and changes of conditions:

2020 Milestone

*Identification and **definition of the key indicators** and the minimum data sources needed to assess them reliably and consistently throughout the EU. Collected data will have to allow for countries, areas and modal analytics.*

- Recommendations:
  - Require sharing of basic operational data, in real time, between operators/actors in the mobility space
  - Require continuous performance assessment of all the mobility services for each sector and actor
  - Create the condition for open data accessibility and analytics, stimulating dedicated initiatives
  - Develop interoperability standards and architecture of integrated transport system
- Proposed KPI:
  - Availability of the assessment of the starting scene and current trends (e.g. number of monitored reference indicators and their geographical extension)

2025 Milestone

*Highly automated and **modernised transport infrastructure**, needed in the early stage to support first automated vehicles and to prepare the environment for a highly automated mobility*

- Recommendations:
  - Incentivise **high safety performance** of transport services with proactive traffic management
  - Leverage on the technology evolution in all sectors, to accelerate the rapid deployment of new modal and intermodal **business models** (e.g. trend for automated, connected, electric and shared vehicles)

  - Require to address the smoothing of cross-border (critical cross-borders are between modes, more than between countries) and bottlenecks (i.e. allowing widening of these bottlenecks when physical saturation has been reached) in the transport network
  - Foster deployment of intelligent infrastructure to support autonomous operations (e.g. smart roads, self-checking railway, etc.)
  - Adopt measures to ensure **security and protection** to communication networks and automated services from jamming, misuse and hacking
- Proposed KPI:
  - Number of connected mobility control centres, and connected devices in the transport network
  - Kilometres of transport network with implemented and operating automated transport solutions
  - Number of identified, restrained and "successful" cyber attacks

2030 Milestone

*Finalisation of the **TEN-T core network***

- Recommendations:
  - Require sharing of data, resources and mobility space, in order to incentivise intermodal area
  - **Accelerate entrepreneurship** initiatives to exploit data availability and access to mobility services, so to create job opportunities in a **shared economy** scenario
  - Develop standards for ensuring compatibility and high level of quality
  - Require collaborative solution amongst mobility actors, with cross-related objectives and performance
  - Foster services requiring active participation of travellers and citizens
- Proposed KPI:
  - Corridor interoperability index, availability of multimodal seamless mobility services
  - Share of travellers using mobility services instead of private car
  - People and freight flows through cross-border corridors
  - Improvement of mobility performance (e.g. average journey times) and customer satisfaction levels
  - Domestic GHG reduction (-40% target) and energy consumption (-27% target)

2035 Milestone

Highly automated, coordinated and harmonised transport in the EU

- Recommendations:
  - **Reduce barriers** for introduction of fully automated services
  - Allow for redundant smart infrastructure
  - Delegate and distribute responsibilities for harmonised network traffic control
- Proposed KPI:
  - Geographical coverage of the offer for fully automated transport service on the territory
  - Proportion of people and freight which are reached by the offer for fully automated transport service
  - Availability of fully automated mobility services (% of time services unavailable for fault/maintenance)

2050 Milestone

Fully intermodal and interconnected transport system

- Recommendations:
  - Incentivise cross mode mobility and productive use of resources
  - Sponsor technology research, to reduce the barrier of cross-modal shifts for people and freight
  - Support sharing economy schemes, where **multipurpose resources are efficiently shared**
- Proposed KPI:
  - Number of EU-wide mobility services for people and freight
  - Total revenues from the mobility services
  - Average travel time and costs for people and freight along main corridors
  - GHG (-60% target) and consumed energy

5.1 Multimodal integration

The definition, development and deployment of the unified European NTM requires optimal interlinking of the transformation of infrastructures, facilities, vehicles, processes and technological systems in all transport modes, while accommodating growth in demand for transport capacity and performance. The multiple stakeholders and actors involved in this transformation need to be coordinated and synchronised, in order to provide optimal and integrated door-to-door mobility solutions to all kinds of (freight and passenger) customer, while taking into account any environment, legislation, policy, economy, society, customer-preference and technology factor. Each phase of the transformation requires an integrated multi-modal NTM framework of methodologies, models and data, plus a continuous feedback between the modernisation of infrastructure, facilities, vehicles, technological systems. Specifically, the multi-modal NTM solutions should address seamless interchange of freight and passengers, synchro-modality of logistical and mobility services over the European transport corridors, optimal operations and accessibility to and within urban nodes, terminals, gateways and hubs. Ideal NTM solutions should deliver optimal inter-connectivity between the transport modes, allowing more flexibility in generating multi-modal transport flow patterns and choices for any kind of transport user.

The proposed **2025, 2030, 2035, 2050** technological and organisational milestones are key check points to allow:

(i) Monitoring the development of this Roadmap in relation to other STRIA Roadmaps and EU initiatives;

(ii) Taking corrective initiative/actions during the transformation phases;

(iii) Refining the performance objectives, based on the real likelihood of achieving the EU policy goals.

An efficient and resilient NTM system requires offering the customer a door-to-door integrated planning, in which real-time information is provided on the alternative mobility solutions in a very highly predictable environment. An integrated mobility performance tool (simulation, optimisation and assessment) could be useful, to get a much better picture on a strategic and tactical basis on how and where the most significant progress has to be made, also helping to identify bottlenecks and/or prioritise measures.

The NTM system should aim to connect traffic management of all mobility modes. This can be perceived as the catalyst to R&I and fast track deployment of technological and organisational solutions, aimed at achieving the KPIs specified under the EU policy objectives and the umbrella of NTM systems of all modes which are interconnected in a web. As connectivity is perceived as a must in all facets of our daily lives, the NTM system should aim to provide transparent and accessible information, as well as efficiency and timeliness of service. This means that optimal planning in the NTM system will have to happen automatically and in a safe and (cyber-) secure way. The security/safety regulation and system of each mode needs to be integrated into the unified NTM system, taking into account all best practices and lessons across security/safety technology transport platforms.

The challenge is two-fold:

i. Developing **intra-modal** optimisation approaches that incorporate multi-modal transport considerations. Each intra-modal system should incorporate inter-modal constraints and/or objectives (NB: an NTM solution can be intra-modal efficient but not multi-modal efficient).

ii. Developing **multi-modal** architectures, interoperability standards and systems, in order to share data in an easy, safe and (cyber-) secure way (a very important issue since transport stakeholders may not see an immediate benefit from this); coordinate the various intra-modal solutions; integrate the travel options for the customers in a dynamic environment and for any type of traffic situation (incl. severe disruptions such as major incidents, track blockage, extreme weather conditions, terrorist attacks, etc.). Overall, the challenge requires testing the readiness levels (TRLs) of various technologies/systems and developing effective specifications, standards and guidelines for multi-modal NTM integration/cooperation.

The final vision is a transportation environment in which a person or a good can be transported from the origin to the destination when required, in a **reliable and predicable time and with a specified level of comfort**, without having to choose a specific means of transport. The different means of transport will not affect the quality of the mobility service, which will be bought by the user as an "all inclusive" package, in a seamless environment and with no multiple interfaces.

Multimodality is the most challenging task of the whole implementation plan, for this reason efforts have to start from the beginning and focusing on small scale at first and later to find step by step, application on a wider scale, up to the whole EU transport network. Starting from the smaller geographical scale to the longer distance transport, the following key focus areas are identified as reference for the network and traffic management:

Mobility within urban areas.

Network and traffic management will have to face the optimisation of the local network throughput by balancing demand and offer, in a similar way as it is today implemented for each single mode of transport. Inter-modal scenario will require a solid solution for the payments method and will provide leverage towards permanent connectivity for all individuals. Collective benefits such as safety, efficiency and sustainability will be the main drivers for the overall coordination. Last mile delivery of goods and personal mobility will have to coexist with one another, exploiting new schemes for mobility on-demand in a highly automated context, which will require new regulations. Priorities between different coexisting, and sometimes competing, modes of transport will have to be clearly managed: pedestrian, bicycles, public transport, vehicles, drones, etc. **The single trip is typically very short**; for this reason, while the options of the mode of transport will be many and can be different from day to day, it is unlikely there will be a change of mode during the same trip.

Mobility from city to city

The typical trip between two cities, both for people and goods, can require **change of mode** during the trip and roaming of the mobility service through different transport networks. Network and traffic management becomes the combination of optimised management of the single networks, strong interaction, as well as intense exchange of data between network operators. Highly automated solutions will help in the implementation of this complex scenario, as strategic planning is highly probable by the machine operated travels.

Mobility in regional areas

In regional areas the challenges of the two, previously described, simplified scenarios are combined and a **deep interaction between different mobility and traffic control centres** have to be achieved. The region can be as wide as a whole country, so standardised solutions and interfaces become essentials for compatibility and interoperability of the mobility services. A higher level of coordination has to be introduced, while at the same time, competitive alternatives have to be balanced with the overall Network and Traffic Management objectives, in order to maintain the fairness of the market opportunities.

Door-to-door "journey management"

Door-to-door mobility of individual people and goods, from **everywhere to anywhere**, with much-improved mobility performance, is the ultimate goal of the mobility service that, in order to be effectively offered, has to rely on the EU-wide Network and Traffic Management. The planning (using also itinerary data) and demand management functions are essential for the successful implementation and sustainability of the results. The integrated and automated scenario is probably the only chance to implement it efficiently, with the required level of service in terms of reliability, accuracy, (cyber-) security and safety.

5.2 Intra-modal optimisation

The unified European NTM environment would create opportunities to improve the management of traffic flows in any transport mode, since more and more potential service solutions can be offered to (freight and passenger) customers. In this context, there is a strong need to efficiently collect and filter the data coming into the system from the various input sources and tracking technologies. The filtered data are then sent to the intra-modal traffic management system that would need to compute an optimal solution from a global perspective. The intra-modal solution would then need to be communicated to the other intra-modal traffic management systems, to allow optimal coordination and synchronisation of the traffic management decisions. It will be important to create the necessary interfaces between the systems operating in the different modes, so that each decision can take into account the effects on the other mode and at the same time, shared information is used to evaluate the best traffic management action at each single mode operation. Through this approach, optimal coordination and synchronisation will be achieved via a strong interaction between heterogeneous systems. In the next decades, a strong focus is recommended to be dedicated on R&I initiatives related to these aspects. A discussion follows on how the intra-modal flows can be optimally organised and managed in a multi-modal NTM environment.

Aviation

Within Aviation there are various modes already connected to each other on an intra-modal basis, e.g. buses and automated passenger transport systems are coordinated within an airport environment. For the coordination of the various stakeholders at an airport and the pre-tactical planning of resources in order to meet the demand expected, the Total Airport Management (TAM) concept has been introduced. Within TAM all stakeholders are acting pre-tactically together towards common agreed goals (based on KPIs) for the day of operations. A commonly agreed airport specific plan for the airside operations of the airport is aligned and coordinated with an EU network plan and its management. This local planning is to be coordinated with the respective ground transportation stakeholders (public and personal transport) and their local network planning and management. This type of airport operations related planning and management will be supported by appropriate processes and decision support systems being part of the real or a virtual airport operations control centre (APOC).

Air Traffic Management is going into the direction to be managed via a centralised approach to optimally coordinate the flight stages (planning, pre-departure, taxi-out/take-off/climb/cruise/descent/landing/taxi-in, post-flight). The SESAR objectives are to achieve a seamless and interoperable ATM system, with a continuous exchange of up-to-date and consistent flight information (4D-trajectory) between all actors managing each aircraft at all its journey stages. This approach requires developing a new generation of decision support systems (DSS) for efficiently coordinating and reducing the workload of ATM actors. DSS help to provide a more efficient and flexible use of ATM resources and to deal with any kind of traffic disturbance and air traffic congestion. Such DSS can be incorporated into virtual air traffic control centres and remote towers, limiting the intervention of human resources and thus substantially improving the cost efficiency of ATM service provision. At the same time, specific traffic management solutions are needed for the transport of goods by drones (and their other uses), or Remotely Piloted Air Systems (RPAS) / Unmanned Aerial Vehicles (UAVs), forecasted to grow rapidly in the future.

Rail

ERTMS deployment opens new directions for optimising the use of railway capacity during operations. According the S2R objectives, ERTMS should be connected to automated, scalable, easily upgradeable, interoperable and inter-connected Traffic Management Systems (TMS) and Driver Advisory Systems (DAS). The TMS and DAS functionalities are to allow for predictive and dynamic railway traffic management in regular and disturbed traffic conditions. The idea is to use algorithms to look globally at the traffic flows, by using real-time status and performance data from the network and from the trains, and to select the best mix of traffic control measures (train re-timing, re-ordering, and re-routing) to recover from disturbances (avoiding getting stuck in dead-lock situations, especially in the case of disruptions), according to pre-defined traffic control objectives, providing a higher level of service to passengers and freight operators at peak times.

Road

Traffic management and control systems in the road environment, ITS, are well developed and mature throughout Europe, in the major cities and across all the most important interurban links. Smaller cities and interurban roads will be following and availability of Traffic Management as a Service solution will be enabling the acceleration of this process. Relevant differences in approaches are present across the various EU Member States, some more oriented to dynamic and adaptive traffic management solutions, others more focused on solid planning and some other countries with highly standardised rules. In the road environment, different modes of transport (i.e. bus, trams, cars, bicycles, pedestrians, light rail) are coexisting and traffic management systems already implement various levels of integration (e.g. bus priority at intersection, common ticketing solutions). A general trend to organise the traffic management in wider areas through exchanging data in regional areas (e.g. between cities, between cities and motorways, between motorways and national roads) is already showing a step towards the NTM concept and will have to be continued. New opportunities coming from the connected and automated vehicles (public transport, private vehicles, freight transport) will make traffic management evolve, by transforming each single vehicle as an active component in the traffic management (Traffic Management 2.0 concept) extending the value chain to new actors. Proactive traffic management based on predicting and preventing incidents/accidents will rely on integrating online simulation, self-learning and self-healing systems.

Waterborne

VTMIS, SafeSeaNet, and RIS technologies have to be embedded in the "green ship and port operations" concept, entailing more sustainable waterborne operations, synchronised inter-modal connections between expanding port hinterlands, increasing loading and unloading requirements. This can be translated into R&I activities regarding empirical data collection, advanced quantitative analysis and decision support systems for shipping, ports and maritime logistics. In sustainable maritime supply chains, there is a need to improve intermodal freight transport, port operations, shipping competition, environmental performance in shipping operations; proving seamless door-to-door intermodal transport services for customers while addressing the EU policy objectives.

The following table summarises the key milestones of the technology roadmaps of the respective modes of transport. In this way, it is possible to further assess them, together with the Network and Traffic management key milestones. The analysis of the correlation between the planned milestones makes clear where interdependencies are, so that indications can be derived on how to optimise the coordinated actions.

	2020	2025	2030	2035	2040 +	2050
Air	*High Performing Airport Operations; Optimised ATM Network Services; Advanced Air Traffic Services; Collaborative Decision Making; SESAR initiatives*	*4D Trajectory Management; Efficient Airport Ground Operations; Airport Collaborative Decision-Making*	*Advanced Support for Conflict Detection and Resolution with Application to En-Route and/or Terminal Manoeuvring Area Control*	*Coordinated Support for Conflict Detection and Resolution for some Pilot Areas or Operations, e.g. Military Operations (some airports fully integrated into the ATM network)*	*Coordinated Support for Conflict Detection and Resolution for the Single European Sky (all airports fully integrated into the ATM network)*	*(Semi) Automated Control of Multi-Area Traffic Management System on Single European Sky*
Rail	*ATP, ERTMS Level 1 / 2; Driver Advisor Systems; "Shift to Rail" Initiatives*	*ERTMS Level 2 / 3; Driver Advisor Systems; Efficient Decision Support Systems for Single-Area Traffic Management System*	*ERTMS Level 2 / 3; Driver Advisor Systems; Advanced Decision Support Systems for Multi-Area Traffic Management System on the Core Network*	*ERTMS Level 2 / 3; Advanced Decision Support Systems for Multi-Area Traffic Management System on the Core + Comprehensive Network*	*ERTMS Level > 3; (Semi) Automated Control of Multi-Area Traffic Management System on the Core Network*	*ERTMS Level > 3; (Semi) Automated Control of Multi-Area Traffic Management System on the Core + Comprehensive Network*
Road[1]	*Piloted parking Truck platooning*	*C-ITS deployment • GLOSA 2.0 • Roadworks Assistance • Lane-Merge Assistance • Area Reservation • Cooperative ACC • VRU Warning • Platooning*	*Highly automated vehicles • Cooperative Merging • Overtaking Assistance • Intersection Assistance • Dynamic Platooning • VRU Assistance*	*Robot taxis • Fully Automated Driving • Optimal Traffic Flow*	*…*	*…*
Water	*Vessel Traffic Management Information System (VTMIS); Safe and (cyber-) secure maritime traffic monitoring and information system; Real-time River Information System (RIS)*	*Efficient Decision Support Systems for Improving the Management of Inland Ports and Maritime Ports Operations*	*Advanced Decision Support Systems for effectively managing and synchronising inter-modal connections of the waterborne transport to the Core Network*	*Advanced Decision Support Systems for effectively managing and synchronising inter-modal connections of waterborne transport to the Core + Comprehensive Network*	*Coordinated Support for Global Shipping, Ports and Maritime Logistics*	*(Semi)Automated Global Control of Shipping, Ports and Maritime Logistics*
NTM	***Indicators and reference assessment***	***Highly automated infrastructure***	***TEN-T core network***	***Highly automated, coordinated and harmonised transport***	***Traffic management global efficiency***	***Fully multimodal and interconnected EU transport***

5.3 Strengthening framework conditions

The success of the strategic implementation plan will depend on the horizontal actions, which are taken at the European level, in order to create the conditions for successful deployment. Specific research programmes and funding of targeted initiatives will have the power to generate, with a bottom up approach, the enablers needed for the rapid execution of this Network and Traffic Management Roadmap.

To facilitate the achievements of the milestones, besides the technology research and innovation programs, dedicated focus should be applied to **high priority R&I** initiatives specifically targeting:

i. Introduction and operation of **new alternative business models** based on integrated mobility and logistics services (e.g. pay-per-use schemes) for both people and goods. Prioritising high performance services and reduced required investments

ii. Solutions for improving more and more the **productive use of the resources**, through sharing and reuse; the purpose is to drive, in this way, solution that implies a reduction of costs through efficiency (e.g. intense use of vehicles, reducing the idle time and consequently, reducing operational costs per unit of time). Cross-fertilisation between the different modes of transport has a high potential (e.g. optimised

[1] *Sources: http://www.ertrac.org/ ; https://www.car-2-car.org*

and intense use of aircraft in aviation could inspire the solution for the road vehicles; road network vehicle flow optimisation could inspire applications for rail and air).

Each local, regional, and national (public and private) authority/manager/operator should cooperate in the gradual achievement of EU policy objectives and targets, aligning their individual projects and programmes. Public stakeholders and actors have to closely cooperate with private entities in attaining efficiency and effectiveness of the NTM system, enhancing those partnership business models that incentivise mobility actors into focusing on the (passenger and freight) customer needs and ideally attaining a win-win solution tailored to their specific needs and to the required EU policy objectives.

However, stakeholders and actors can have a different prioritisation of the performance objectives, and compromised solutions will have to be found in a competitive environment, avoiding those barriers and gaps (including regulatory frameworks) that hinder the evolution/deployment of relevant technologies/solutions in any transport mode and for any stakeholder/actor. Outsourcing and purchasing of traffic management and network operation as a service will also increase the need for commonly agreed traffic management objectives and strategies on a regional, national and European level. Intelligent systems will need to be employed to provide a balance between these potentially conflicting objectives. Furthermore, fair and equal treatment of all stakeholders and actors should be ensured when strengthening the NTM framework conditions.

An efficient use of the multi-modal NTM systems would require the development of simplified business processes in order to improve standardisation, simplify certification and authorisation, enable the use of common data/information architectures and stimulate the creation of new travel information services for all customers. SMEs and large industrial corporations will play an important role to favour the harmonisation of NTM multi-modal procedures, in order to reduce friction when changing transport modes, e.g. ticketing, security issues and passenger rights. In this framework, a key issue is how to facilitate and reward innovation proposed by industry and to coordinate policy and knowledge transfer stakeholders.

Public authorities should promote the deployment of this Roadmap, favouring less-pollutant transport solutions via regulatory/legal/international trade channels. For example, roads should have more inside/priority lanes for public transport and low-emission vehicles, cycling and walking. Public and private cars would need to be shared, avoiding the current frequent situation: 1 person per vehicle and traffic congestion in peak hours. Road pricing offers an opportunity to provide a more equitable and efficient usage of the public highway. Road tolling strategies should be investigated to dynamically reroute vehicles in case of traffic congestion and to stimulate the customers to use the most appropriate combination of transport solutions. In this context, the modernisation of infrastructure and vehicles should support low-energy and low-emission multi-modal transport solutions.

The user's role will be very important in the dynamic environment of the multi-modal NTM system, since several alternatives will be offered for going from each origin to each destination. In order to achieve optimal door-to-door services, a key problem is related to achieving seamless processes for the transfer of passengers and freight at interchange points (e.g. inland/maritime ports, airports, urban nodes, commuting terminals, last mile distribution points), in order to offer time/cost efficient and predictable connections within or among transport modes. A better organisation of traffic flows will be mandatory, including the development of new interfaces between modes, higher predictability of transport performance, better harmonisation and choice of transport products, processes and services for the transport users (e.g. single tickets for the entire journey, dynamic reconfiguration of journeys in case of disruptions), proactive incident prevention, dynamic infrastructure capacity provision, agile dynamic allocation of responsibilities and related R&I activities. The specific user will need to be guided, considering his/her individual needs, to choose the best (eco-friendly, safe, cost-efficient, etc.) transport choice among an increased set of transportation options (e.g. what is the most suitable solution for elderly and disabled people?). The development of incentives is essential to influence the user to select the best transport combination (not necessarily the one reducing the travelling time or distance). It is therefore not enough to compute the best travel option, if this is not then frequently used. On top of this, the information needs to be filtered and communicated via a new customised user-friendly interface and to allow a flexible transport user response. All these efforts will result in a better utilisation of the overall transport network and an increased competition and involvement of all relevant transport stakeholders and actors.

6. Identification of the public and private roles

As already discussed in Chapter 3 of this Roadmap, Network and Traffic Management is being transformed at a fast pace and this is made possible by major evolving factors, such as developments in the existing infrastructure, the gradual presence of new generation vehicles on the road network and the evolution of technology in managing traffic operations. In the process of this transformation the needs of users have to be answered by truly multi and cross-modal environments, which form part of the integrated and holistic traffic management. A Europe with no physical borders has to offer to its citizens a mobility which is as seamless as it is efficient. Technical and technological change however, is not enough to guarantee this efficiency. **A new culture of public-private cooperation** is needed and for this cooperation to succeed, the public and private sectors need to re-define their roles and responsibilities and enter into a mutual understanding of needs. At the same time, the two stakeholder groups need to respect each-other's requirements for a win-win outcome.

Traffic Management has traditionally been a public sector task, while the private sector has been competing on providing alternative routing to its paying customers. Road operators for example, even if semi-public in their status, act on behalf of the public sector when managing traffic and have to execute the planning as conceived by the public authorities. The general public benefit prevails to that of the individual network user. Low CO2 emission targets or the prioritisation of environmentally-friendly transport modes such as walking or bicycle use over the use of private cars, are often used as traffic management measures by road operators and public authorities in managing traffic. Road operators, on behalf of the public authorities, deliver a service which is paid by taxpayers' money and comes from the general state/city budget. With more and more service providers gaining the trust of the users for the 'fastest' available route, public operators and providers are left alone in balancing a series of objectives and targets that are not suitable for profit-making exploitation. Road network balancing and optimising the network capacity are good examples of objectives that the private sector had until recently not seen as part of its responsibilities.

On the other hand, nowadays more and more **public and private transport actors are entering into partnerships** that go beyond individual projects. These private-public partnerships take the form of Platforms and Alliances that have no funding motive. Their aim is to combine the competences and strengths of the two sectors into addressing a need that is not strictly under the responsibility of only one of them and which has a long undefined life span. Platform cooperation schemes, such as TM 2.0[2], Lena4ITS[3] or the MaaS[4], by taking funding out of the equation, base the cooperation of the actors involved - be it private or public - on the real need to find a common answer to the common needs of users. The user of the transport system is both a taxpayer (making her a customer of the public sector) and a network user, who demands service for money spent on her preferred private transport service provider.

Anything but a win-win situation in the final service provided to the user falls short of the user's expectations, due to her dual status as a customer of both private and public sector. For instance, an example of a win-win for both the taxpayer and the public authorities is the case of 'end of queue' info. The navigation provider offering 'end of queue' traffic information advice (also called 'Jam Tail Warning') is a private company, but the actual road network is most probably publicly controlled by a road operator or a traffic management centre, that aims to satisfy public interest targets first and answer to private comfort demands at a second priority level. Both stakeholder groups' interests are met with this service.

Challenges in public sector spending have resulted in public sector actors outsourcing and purchasing many functions as services from the private sector. This is also a reality in the traffic management and network operation. In the Netherlands, there is a progressive move towards leaving traffic management operations to

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[2] *www.tm20.org*

[3] *https://mobil.hessen.de/?cid=2e7f6e46544120b319e0a5c58cb8dc8c. For English see (at the bottom): http://www.bast.de/DE/Publikationen/Foko/Downloads/2015-19.pdf?__blob=publicationFile&v=3*

[4] *http://maas.fi/maas-as-a-concept/*

private service providers and the Amsterdam Practical Trial (PPA)[5] is already forging this cooperation among public road administrators and the private sector. In that trial project, the public bodies monitor traffic management operations executed by private companies. A similar approach is taken by the Traffic Management Centre in Stuttgart, where separately acting traffic and mobility managers cooperate in ensuring the seamless 'switch' between modes of transport for the network users, in a way that their separate networks are perceived by users and hauliers as one single all-modes borderless network. The outcome of such outsourcing and purchasing actions by the public sector will depend on the successful integration of public sector objectives related to network operation, as well as on how well the aims for integrated multimodal network operation are included in the contracting processes and contents. The final aim of course is an NTM which will cover not only the requirements of individual travellers and the private sector, but will also respect public interest and priorities.

A key to the success of any cooperation is related to finding a win-win solution for all actors involved in the process of answering the needs of the individual customer and those of the public. Understanding the strength and constrains of the actors in the two sectors and being able to make a projection for 2050 is a challenge this Roadmap is facing. Traffic management elements such as for example Real-Time Traffic Information (RTTI) should not be taken for granted as a product of the private sector, as more and more public or semi-public organisations are able to collect it (e.g. in the form of floating vehicle data in road transport) by their own means and fuse them into their own traffic engines. This is already the case in the UK and Denmark. RTTI is able to enhance the service to customers and also the validity of traffic management plans, when fed back to the traffic management centres and operators. The changing roles and responsibilities of private and public actors within a non-vendor locked TM scheme, based on the understanding of the various actors' needs and the various possible roles they assume in a network, is only one of the two steps of reaching a win-win in Network and Traffic Management. The second step is ensuring mutual respect and cooperation.

6.1 Public sector support

Should public sector's role only be confined in defining transport policy? Is the role of the private sector only limited to the implementation of what has been decided by publicly-funded entities, be it mobility operators or traffic managers? Can profit or a business case be the guiding principle for the actions of a public body?

The potential role of National Single Access Points

In the Netherlands, the National Data Warehouse (NDW) is a public sector-controlled registry of (road) transport meta-data and safety related real time data, which ensures accessibility to this source to all interested parties on a non-discriminatory basis. This NDW registry makes private sector data service providers reluctant to 'share' their data in this warehouse scheme, as they (the private service providers) would rather be able to directly reach their business customers and have direct contractual agreements based on profit. In Germany, the counterpart of NDW is the Mobility Data Marketplace (MDM). The latter has assumed the role of a broker among those who provide and those who subscribe to access traffic and traffic related data, regardless of public or private sector status, since the agreement is a contractual one among those who choose to hold one. MDM only provides the guidance on how to link with the data owner (source). The role of the MDM, also a public sector body is seen more as a facilitator for the accessibility to transport data, rather than that of acting on a 'public benefit'.

Both the NDW and the MDM were set up as a result of the EU Delegated Acts (Regulations) on Priority Actions 'c' and 'e' of the ITS Directive, 2010/40/ EC. The EU Delegated Acts on the Priority Actions 'b' (RTTI) and 'a' (MMTIS-expected to be officially published soon) require the EU28 Member States to set up Single Point of Access (SPA) for the provision of information services for safe and secure parking places and provision of SRTI, RTTI, MMTIS. A Single Point of Access (SPA) is expected to be a central point where information can be found on all four data thematics. It can consist of just web-links, or web-links and metadata or even a database with metadata. An SPA can be created at national level, cross-national level or even at European level (e.g. for static information for truck parking). The SPA has thus the potential to serve as the transport data 'exchange place' for traffic management schemes that seek to serve the needs of multiple stakeholders, while its ability to host the data

[5] *http://praktijkproefamsterdam.nl/About+Amsterdam+Practical+Trial/default.aspx*

itself or the link to the data can serve a function that has until now not been allocated to one specific sector, but has been assumed to be the task of the public one - that of the accessibility point (registry or broker).

Projecting the idea of SPA to the future, which is very much like the System-Wide Information Management (SWIM) used in Aviation, one can see the role of the public sector being supportive to the tasks that will gradually become part of private sector market competitiveness. With regard to Network Traffic Management, this means a well-defined network of national or regional SPAs that work in synergy and alignment on the European level. **The EC can help this alignment by supporting harmonisation action in the form of guidelines. The EC can also provide R&I opportunities for SPA schemes that are able to work in a supra-national (regional) network.** An easily identified need that the SPA can cover is also that of the functions of a traffic management centre. Traffic management does not have to be central or even performed by one sector exclusively. Traffic management can take place in the network where traffic and network data are gathered. The operator can be public or private as long as the general benefit is understood, respected and cared for. **However, what is crucial for managing the traffic is not its constant monitoring, but the constant monitoring of the relevant infrastructure.** Traditional traffic management centres use the traffic and network data to provide information to the drivers, and although RTTI can be provided to them via the vehicles or the private service providers, they lack the necessary information regarding the real time status of the infrastructure. Information on the infrastructure such as road works, bridge openings and incidents can be provided by private sector traffic information providers, but important network features such as pavement conditions and maintenance related data are not monitored on-line. In today' s reality, traffic management centres cannot easily obtain crucial information which is however so much needed for the provision of accurate and safety-related information to the road users. The SPA, or a similar global transport data hub, can potentially also collect data on the infrastructure (physical and digital) and make it available to private/public stakeholders who wish to address the need of monitoring and exploiting its potential.

Last but not least, creating schemes such as the SPA, which can accommodate both private and public sector data (and services) makes the transport network more flexible in accommodating services for integrated synchro-modal systems (all transport modes interchanging in real time) and allows new actors in the transport arena, such as the freight, post (DHL for example) and port industry and its traffic management needs to become connected with the NTM and profit from what it has to offer.

6.2 Private sector engagement

The concept of holistic interactive traffic management is based on the collaboration of service providers and public authorities; this latest trend involves the enabling of vehicle interaction with the Traffic Management Centres (TMCs) via service providers (SPs). The concept is termed as TM 2.0 and is seen as the evolution of current traffic management practices, which are based more on loop detectors and static traffic data used by traffic management centres. In the current traffic management practice, traffic management centres do not have a direct collaboration with in-car data providers and OEMs. The increased use of Floating Vehicle Data (FVD) and the wider coverage this offers with regards to real-time traffic information is being exploited for advancing TM practices and providing better traffic information services. In TM 2.0, a number of road stakeholders are called to cooperate into providing a more holistic traffic management experience, which takes into account and accommodates the individual driver's needs, while at the same time it also satisfies the objectives set by the public authorities and the traffic management centres for the collective benefit of road network users.

High quality and detail in holistic traffic management

Real time traffic information is vital for the concept of interactive traffic management (TM 2.0) to succeed. Accordingly, it is imperative that high quality, detailed data on the current status of the road network and on the whole transport system should always be available, covering the entire road network. The collaboration among stakeholders working on TM 2.0 requires the exchange of data / information between the road vehicles and the Traffic Management control Centres, improving the total value chain for consistent traffic management and mobility services, as well as avoiding conflicting guidance information on the road and in the vehicles.

The Private sector, such as traffic information service providers on navigation, location and mapping or Vehicle Manufacturers, compete on quality and detail. Timeliness of service is a competitive advantage. It is well accepted by all transport stakeholders that the real-time traffic information (road-network status) has to be both 'true' (valid) and well-timed when reaching the user. This applies even more for safety related traffic information. On the other hand, it is the public sector that controls traffic management plans. If the latter is not accessible to Service Providers, the quality of the content, namely its reliability, availability and timing are not anymore able to guarantee a Network approach to Traffic management. Automated vehicles for example, are expected to have a different reaction to traffic advice coming from the Service Provider. With such information being typically dynamic, automated vehicles have to be able to acknowledge the receipt of the navigation message on an equally dynamic (real time) manner and be able to follow it as *an order* if it is safety related or assess its advantages if it is non-safety related (so in that case it is *an advice*). The affirmative response (if needed) by the vehicle in case of safety related information is imperative. No human-user can be expected to react in automated vehicle traffic. At the same time, a non-acknowledging vehicle or a non-responsive traffic management system raise the issue of distinguishing liability between the actors of the private and non-private sector controlling the different parts of the network traffic management (service provider - vehicle-traffic management centre).

As holistic/network traffic management is not confined within local/regional borders or within certain mobility modes prevailing over others, it necessitates that the required data and traffic management plans should be made available from all mobility operators (public sector included) to all public and private sector stakeholders. The data should cover the entire mobility network and all transport modes, including their inter-connection points. In a network, this is primarily a matter of safety and (cyber-) security.

Safety: the game changer in Network and Traffic Management

Taking a long term view on Transport Policy priorities, one cannot exclude the possibility of the changing priorities that will dominate the actions of public and private sectors in 2050. Priorities such as decarbonisation of transport and the promotion of alternative fuel propulsion solutions (biofuels, electric, hydrogen and natural gas) and the implementation of Directive 2014/94/EU on the deployment of alternative fuels infrastructure are EU policy targets that (if supported by strong political will) could be satisfied as EU policy targets well before 2050. What is and will be, however, **always one of the top priorities for EU and national transport policy, is Safety**. A hard safety constraint, as already mentioned in this Roadmap, is more than a target for technological developments in on-going and future R&I with regards to all modes of transport and their network / traffic management. The "zero tolerance" on human fatalities will be greatly impacted by the gradual transformation of the transport network, from a mixed (vehicles and infrastructure) towards a fully automated (vehicles and infrastructure) one. As crashes, even those without fatalities or severe injuries, are a major source of disruption and congestion in the operation of all modes, and thus to the network as a whole, the additional aim will be towards "zero crashes" in the long run. The traditional role of the public sector which has the responsibility to rank public safety as one of its top priorities, while leaving space to the private sector to exploit other factors, such as speed and efficiency (alongside that of safety) to its commercial benefit, **will bear a pivotal transformation when private sector stakeholders, such as service providers and OEMs, will compete on liability and claim on championing safety for not only their users but for all in the network.** It is questionable what would be the use of offering safety to only some of the users in a network that works as a system, where liability is shared among the public and private sectors. Taking as an example the scenario of already partially-automated transport modes, such as that of autopilot in aviation (where the aircraft pilot can use the option offered by the aircraft system to pass control to the automated pilot) the competitive advantage lies with the actor (the airline in the case of aviation or the mobility service provider in the more general case of traffic management) **who can substantiate the claim of using best the guidelines set by the Public-Private strategic cooperation.** The example of the guidelines agreed between the International Air Transport Association (IATA) and International Civil Aviation Organisation (ICAO) in defining regulatory frameworks and setting industry standards on safety is indicative. In the aviation sector, safety is already a factor upon which private actors (airlines and mobility service providers) can compete, while satisfying the wider public benefit of safety. Similarly, in a road traffic management scenario, mobility service providers (including OEMs) will have to take a step away from the current debate of following or not the routing advice coming from traffic management centres and move towards automatically acknowledging the receipt of the routing ***order*** (the word is used to denote the mandatory character of the *advice)* coming to the vehicle form the network system.

Performance trade-offs between private and public sector responsibilities, such as routing the network users on the longer but safer route rather than the faster one, will be based on the newly assumed liability of the private sector on what had traditionally been considered to be a public sector's priority: safety.

6.3 Public - private cooperation

The private sector uses factors such as the quality of the traffic information it provides as a competitive advantage and prices it for profit. On the other hand, the public sector, despite recognising the value quality traffic information has with regards to safety and security, rarely competes on these terms with either the private sector or its counterparts within Europe. Pricing quality on differing sets of objectives (service vs safety) is the result of the different priorities guiding the work of the two traffic management stakeholders (public sector vs private traffic information service providers).

A common understanding of priorities

A common understanding of the different priorities of traffic management stakeholders is the basis of successful collaboration models. If there is no 'win-win' in such partnerships, then there is little motivation for collaboration to take place.

Profit and customer satisfaction is what gives to the industry competitive advantage in the market. For private service providers, the public benefit has until recently ranked lower than individual demand for fast and efficient service. As a result, these two mobility-network actors (the publicly funded Traffic Management Centres and operators and the private mobility service providers) in their quest for user satisfaction and support, went on separate and sometimes conflicting ways. The TMCs focused on monitoring and informing the mass of mobility service users using their infrastructure, while private service providers aimed at addressing their customers' "individual requirements" (points of interest, avoiding tolls etc.).

Alignment

The alignment of the different stakeholder priorities can create the 'win-win' model sought for the collaboration between the private sector and public authorities. Taking again the TM 2.0 Platform as an example, its members' common vision on interactive traffic management and towards providing a holistic information loop between the vehicle, the infrastructure and the TMCs, aims to align the public interest while still being able to satisfy the needs of the individual drivers for fast and efficient driving. According to the TM 2.0 concept, traffic information service providers or the TMCs (depending on who assumes the role of alignment and coordination) will be able to inform and guide the road network users to their destination (individual driver's need), while at the same time contributing to the optimisation of the road network throughput and responding to the prevailing traffic conditions (collective benefit).

The TM 2.0 collaboration model involves public authorities and private traffic information service providers and aims at building trust among the various transport stakeholders involved. At the same time, it supports the creation of new business models and efficient services. Innovation is key for development and change. New trends on Mobility and Transport, such as self-driving vehicles, the concept of mobility as a service (MaaS), green mobility etc. necessitate a change, not only in technology but also in the way business is conducted, aiming at profit and also in the way services are offered to the user, who is a tax-payer as well as a private sector customer. Catering for the individual user needs as well as those of the collective, collaboration and alliances among public and private stakeholders shall ensure the 'win-win' of the business models in Network Traffic Management.

The EU could help this process of public/private sector alignment, by providing support to the development of multi-actor organisational and business models, where responsibilities on the functionality of the various parts of the NTM system will be shared, based on the ability of the actor to satisfy essential competences - and not according to status (public or private). The need for a regulatory framework for decision making in NTM (centralised or de-centralised) is of fundamental importance. New cooperation schemes necessitate new arbitration models, which should be based on the regulatory framework and will lead to solutions that match the demand for transport and goods, to the acceptable consumption of resources, taking environmental impact and cost-efficient resource management into account. Pricing on consumption of resources and output of emissions in comparison to soft transport modes is expected to be a functionality of NTM.

7. Resources and financing

7.1 Sources of funds

Realisation of the NTM Roadmap will not be cheap. Pushing back the boundaries of the requisite technology to be used in a cross-modal network management system will inevitably be not just a scientific and intellectual challenge in itself, but will also be a time consuming and costly undertaking. Whilst it is trite to talk about private-public partnership, there will, of course, be a role for both to play. The challenge will be to determine issues such as relative timescales, levels of contribution, identification of research priorities.

Public sector support has traditionally focused on pump priming to stimulate subsequent uptake and development by commercial enterprises. This pattern will probably continue but it will be important that clear R&I themes and channels are identified to give commercial enterprises, including OEMs the confidence that they require to take up the reins and develop R&I in a co-ordinated and comprehensive fashion. On the public side, there is currently quite a disparate situation in that funding sources for different modes across different European countries is very variable. Also within a given mode, different sources of funding exist for cities, regions, national and international services.

The European Commission has been proactive in promoting the TEN-T network across all four transport modes. This model works relatively well at a pan-European level in identifying national and trans-national corridors, where efficient movement of people and goods is identified and prioritised.

Major national / trans-national corridors traverse densely populated areas and particularly with respect to the road network, this is where potential friction between journey purposes can and does arise. For example, the M25 orbital motorway around London was originally conceived and designed to be a diversionary route for drivers within neither origin nor destination in Central London, to avoid having to enter the city to make a through journey. Recent data suggests that the majority of journeys on the M25 cover a distance of three exits, which equates to approximately 8-10 mile journey lengths. This shows that a national / trans-national facility is being heavily used by local traffic. Similar situations exist on the German Autobahn network in the Rhein / Ruhr area, the motorway network in Northern France, in the Lille / Roubaix / Tourcoing conurbation. It is important a future NTM system recognises the nuances of different journey times on the same section of the network and sources of funding are applied that fully recognise and appreciate this distinction. Traditionally funding for NTM systems has been driven by the type of infrastructure being provided / used. A future NTM system should be sophisticated enough to disaggregate different types and purposes of journey and sources of funding should reflect such nuances. In this context, this would mean cities / regions being potential funding sources for NTM systems serving national / trans-national roads.

Public sector funding sources are likely to be under growing pressure in coming years. Public authorities with revenue raising powers are more likely to be in a position to provide funding for functions such as NTM systems. Models such as Verkehrsverbunde in Germany are likely to provide more stable future potential funding sources than ‘standalone’ urban authorities. It may be appropriate for more cities across Europe to retain the local taxes that they raise. This could encourage city / regional authorities to take a wider view of the projects that they are prepared to fund.

Business models in the private sector have traditionally been based on the need to achieve an acceptable profit margin. By 2050, it is probably safe to assume that this paradigm will remain relevant, though concepts such as "*co-opetition*" have recently become more prominent.

Ultimately the private sector will only be willing to commit significant time and resources to R&I initiatives, if they believe this will produce a commercial return on the capital that they choose to invest.

The public sector and other advocates of R&I projects relating to NTM systems must continue to liaise with the private sector at the earliest stages of any embryonic project. Early joint working will lead to a joint ownership of a given project, with consequent greater probability of the private sector taking commercial risk at an earlier stage in the project development than has traditionally been the case. It is interesting to note that at the present time traditional motor vehicle OEMs are not taking the lead in designing and developing semi-autonomous and autonomous vehicles. Hi-tech communication companies such as Google and Apple are investing heavily in developing driverless vehicles. There is an opportunity for such companies to also become more closely involved with financing the crucial support services such as NTM systems, upon which such vehicles will rely in the future. For this section of the private sector to become centrally involved, it will be necessary for advocates to clearly make the case that the link between the vehicle and NTM systems is a critical and unbreakable one.

7.2 Instruments to support R&I

Coherent and long term development of NTM systems will be dependent on a consistent and reliable funding stream. The composition of the funding stream will, in all probability, be subject to practical constraints. Continuing pressure on public sector funding will mean that local and regional authorities will have to be creative and look for non-traditional sources of funding.

Such new approaches are already happening with public authorities looking to maximise the financial potential of their assets. Examples include income generation from land assets, examining scope for redevelopment and regeneration and how this could create new funding streams.

Of course, there will be wide ranging calls on any additional new revenue generated by the public sector. Funding for transport related projects is likely to be in competition with other, sometimes ostensibly more socially relevant services such as health, social services and education. If public sector finances and funding do evolve in this way, it is vital that the 'public traffic and transport sector' do present a robust argument as to why transport projects should receive an equitable share of any available funding.

The public traffic and transport sector will need to take a radical approach in meeting this ever emerging funding challenge. It will need to focus not just on its revenue generating potential and how this potential can be realised, but also on how the revenue generated can be channelled as effectively as possible.

A major asset that the public traffic and transport sector has to this time not utilised to any great extent is the levying of a charge for usage of infrastructure. Drivers of vehicles on the public highway have, by and large, not paid the economic price that their usage warrants. For traffic management purposes, in the optimal situation all users should pay a price for their travel, reflecting also the external costs that they are causing to other travellers and those transporting goods, as well as to society (and the environment) as a whole. This should certainly result in changes in mobility, supporting traffic management objectives.

Naturally, public acceptance will be important in a widespread advocacy and uptake of road pricing. To date, the approach has been quite piecemeal - some autonomous cities - London, Stockholm, Milan, etc. - have introduced pricing schemes predicated on access control. Some countries have introduced national schemes for Heavy Goods Vehicles such as Germany and Belgium; other countries have networks of motorway standard roads, usage of which is subject to payment of a charge. As public sector finances come under greater scrutiny and pressure, it will be necessary for the sector to remake and reiterate the arguments for its introduction, emphasising the economic and equity arguments.

A more co-ordinated and comprehensive approach to road pricing is likely to be a feature of future traffic and transport policy, but it is important that revenue generated by road pricing is hypothecated so its usage is ring-fenced to traffic and transport projects, including NTM systems, which, in themselves, will be vital not only for road pricing to develop in this way, but for the NTM vision to be fully realised.

Funding for European research and innovation should be stimulated in the direction of better understanding how, where and when to invest in improving the existing infrastructures and facilities, introducing new generation vehicles and developing new technological systems to deliver safer and less congested movement of people and transport of goods across and outside Europe.

Research and innovation should be focused to offer new types of passenger and freight services. Addressing safety, security, system transformation and performance requirements will play a crucial part of the process to develop new multimodal transport services, with the aim of generating new profits, respect the environment and increase the competitiveness of European industries in the global market.

As a result, while R&I at "local"/National level will continue to have an important role in moving towards a pan-European NTM model, EU R&I should particularly encourage testing the new organisational, managerial and technological solutions across the multimodal European network, on sufficiently large scale environments, in order to fully demonstrate the potential to improve the overall network and traffic management. Large projects involving safety, security, connectivity, interoperability, multimodality, sustainability, accessibility issues between various transport modes and from different countries should get priority of EU funding, complementing past projects that were mostly focused on a National perspective and were not addressing the cross-border dimension of NTM in a co-ordinated way. Priority should be given to projects addressing the removal of nodes/hubs congestion and the removal of traffic flow bottlenecks in larger areas (especially in border areas between two or more European countries), either in normal or disrupted traffic conditions. For instance: pilot projects validating the positive impact of an international large-scale application of ERTMS (supported also by smaller-scale projects and applying multi-modal validation methods); addressing collaborative decision making for European and Intercontinental flights between aviation hubs; connecting complex logistics chains with multiple actors; successfully applying the same safety requirements in tunnels and roads; using the same types of electric vehicles and related clean fuel infrastructure charging facilities. These examples should be reference points to speed-up public and private investments, to stimulate similar investments on less developed areas (such as East-West connections), as well as to promote growth, job creation and competitiveness everywhere in Europe.

8. Conclusions and recommendations

8.1 Modal-specific findings

Aviation

The aviation sector will face a network, organisational and technical evolution, including essential operational changes (e.g. 4D trajectory management, flexible airspace management and routing, collaborative decision making across the Single European Sky and locally through Total Airport Management (TAM). The R&I ambition is to enable a much more efficient airport and airspace operations management, in order to accommodate the expected traffic growth (over 50% by 2050). The concept of the airport as the sole hub for the aviation mode is likely to evolve, so that other hubs are created that can be used by new aviation modes (e.g. UAVs, helicopters), as these modes become more prominent in a future multi-modal transport scenario. Furthermore, an efficient NTM solution for key bottlenecks (e.g. aviation hubs) requires improvement of TAM reliability, to provide a sufficient scalability of the ground and air resources, and to reduce the air traffic flow management delays (en-route, terminal manoeuvring and airport ground traffic). Implementing the TAM concept will enable the capabilities of airports to be inter-modal hubs, interfacing air and ground transport. This ambition must meet the EU policy objectives on Energy and Climate, such as the use of more fuel efficient trajectories, a seriously reduced fuel burn (at least 5-10% less fuel burn per flight) and an overall reduced (at least 10%) environmental impact.

Rail

The rail sector has the strategic plan to move towards a fully interoperable Single European Railway Area, in which the European rail industry will play a strong and globally competitive role. The challenge will be to develop traffic management and control solutions to run high capacity/speed passenger/freight trains in a sustainable and reliable infrastructure, with the support of customer-oriented IT services. The R&I ambition is to offer better NTM services to passengers and freight customers in terms of improved safety, security, reliability, quality, competitiveness and attractiveness. Quantitatively, next generation rail operations and services are expected to achieve a 50% increase in the reliability and punctuality, a 100% capacity increase, and a 50% reduction of the life-cycle cost via simplified business processes. To achieve the EU policy objectives on Energy and Climate, the expected contribution is to reduce traffic congestion (especially in highly used lines and large stations), to limit CO_2 emissions and noise pollution, and to favour the modal shift from less eco-friendly modes to rail.

Road

There has been much recent publicity about the advent of (semi) automatic vehicles and how their development may impact on both individual and public transport. The need to achieve the EU policy objectives on Energy and Climate and for developing safe and reliable NTM systems will underpin the technological development of road based vehicles and will determine the form and the nature that the development could take. It will be essential to devise systems that not only meet the needs and requirements of individuals, but also evolve in such a way that enhance the safe and efficient operation of the network which is being managed.

The manner in which NTM systems use data will be a key factor in determining how the systems evolve to meet needs of individuals and the network alike. As always, the task will be to access data, then determine which of that data can be used productively, to formulate a sustainable and viable NTM system.

Another key feature that pertains specifically to road transport is segregation. A range of different road based modes co-exist side by side with one another on road infrastructure, in a manner that does not generally happen with other modes. Cars, bicycles, motorcycles, buses, Heavy Goods Vehicles and most noticeably pedestrians often share the same space and same infrastructure, with little or no segregation. The differential speeds, passenger carrying capability and levels of vulnerability have traditionally made this a potentially volatile mixture.

Greater segregation for more vulnerable road users such as cyclists has been achieved in many areas. There is, though, of course, only finite public highway space available, and there may well be a limit to the amount of segregation that can be achieved, particularly in dense urban areas. Given the overriding priority of safety, it may well be beneficial to look at how greater segregation can be achieved, e.g. temporally, rather than physically.

Connected and automated driving requires that connectivity-wise, none of the road users including vulnerable ones are segregated – all need to be connected and cooperative. A key aspect of NTM is to integrate all road users in the system, enabling proactive dynamic network operation, where all road users are well informed and able to meet their mobility expectations. Ultimately, the efficiency and an important element of the acceptability of NTM systems dealing with road based modes will be the quantified accident reduction record that the NTM system helps to deliver.

"Last-Mile" modal transfer for freight is also becoming increasingly common in urban areas. NTM will have to be refined to accommodate this practice and ensure that such modal transfer takes place as seamlessly as possible. NTM systems will be able to play a key role in reducing the large number of freight vehicles currently making abortive journeys, whilst attempting delivery of goods ordered on-line (often these journeys end in failure due to nobody being at the destination to receive the delivery). This is becoming a major source of congestion in urban areas and rationalisation of such journeys should be a goal for an effective NTM system.

Another source of urban congestion which could be alleviated through the implementation of a comprehensive NTM system would be the elimination, or at least significant reduction of vehicles cruising on city streets searching for an on-street or off-street parking space. Software programmes/apps already exist in directing drivers to the nearest parking space. The challenge will be to integrate these into a wider NTM system.

Waterborne

European port, maritime, inland waterway activity operations play a key role for the long-distance transportation of goods, since a very large percentage of global merchandise trade is carried by sea and handled by ports worldwide. The R&I ambition in the waterborne sector is to promote global sustainable shipping concepts; to provide seamless door-to-door inter-modal transport services for the customers; to improve inter-modal freight transport, port operations, shipping competition, environmental performance in shipping operations. The achievement of EU policy objectives on Energy and Climate requires the deployment of an alternative clean fuels infrastructure and developing environmentally sustainable shipping (e.g. operational measures and existing technologies reducing up to 75% GHG, CO2 and NOx emissions, facilities for clean fuels in ports and aboard vessels), increase the environmental performance of ships. All this will only be achieved by developing technological and organisational NTM systems for shipping, ports and maritime logistics.

8.2 Common themes across modes

Safety and security are ubiquitous considerations across all modes and their necessity is taken as given. Concepts such as connectivity, interoperability, sustainability, flexibility, spontaneity, transparency and accessibility will always be common across modes. They really represent the building blocks of the structure that a high quality NTM system should contain. It is, of course, obligatory that these concepts should be incorporated into any NTM system and they are prerequisites for successful deployment and operation.

The issue of **intelligent data usage** is a common theme across all modes. Technological advances are such that they have created vast amounts of data. The challenge, as is being increasingly recognised by all parties, is to use this data in a way which optimises performance within mono-modal and multimodal NTM systems. The initial challenge is to identify, fuse and manage the generated data in a co-ordinated and efficient manner, while protecting the privacy and security of travellers and goods, contributing to creating enhanced NTM systems.

Access to data is an obvious prerequisite: it is essential that data is made readily available by those agencies which generate it, to those stakeholders who have a legitimate interest in acquiring it, to develop NTM systems.

There is a need to produce a system that can target known problem areas e.g. **cross-border locations** and known **traffic congestion locations**. Data input into the systems architecture of an effective NTM system will need to accurately reflect the nature and degree of the problem to be addressed. Similarly a NTM system must be streamlined enough to be able to **function efficiently across administrative regional boundaries and national borders**, which has so often to date been the Achilles' heel of efficient network operation.

Tracking systems are presently vital components of a NTM system. The information that they provide is critical in building a composite real time picture of movement of individual people and all transport modes. It is safe to assume that the criticality of tracking systems will remain central to the formulation of effective and efficient

NTM systems. People can be tracked via their mobile devices and this information is crucial in the formulation of a robust NTM system. Issues such as privacy will need to be addressed, with anonymity preserved if particular individuals maintain that this is an overriding factor. The EU's and European Space Agency's Galileo GNSS constellation continues to grow and its accuracy and potential usage continues to increase. By 2050, it is not unreasonable to assume that Galileo's degree of coverage in Europe will be comprehensive enough to provide extremely precise location fixes, with the consequent degree of data accuracy feeding into NTM systems.

Flexibility, resilience and the ability to recover from disruptions are another group of key factors within a NTM system, irrespective of whether it is mono-modal or multimodal. Any viable system should be sufficiently flexible to respond in a coherent way to unforeseen incidents or perturbations. Examples include terrorist attacks, weather-related incidents, accidents, breakdowns, collisions, etc. The system architecture should be constructed in such a way to incorporate the necessary flexibility, to ensure that the NTM system can continue to operate effectively in the event of an emergency situation and to be able regain full system performance in case of disruptions in due time. Key to this will be the facility to give accurate and timely information to individual travellers, should such a situation arise. Research indicates that people are much more accepting of disruption due to unplanned incidents/emergency situations, provided they are informed about the cause of disruption and the action that is being taken to rectify it. Flexibility is supported by incorporating self-learning and self-healing capabilities to the NTM systems and their components, as well as by integrating simulation tools to semi-automatically select the optical NTM actions in each situation, by on-line prediction of the consequences of different NTM measures and actions for the case in question.

Pre-tactical planning and management in order to "act" instead of "react". Based on the travel plans available for the individual travellers or goods, as well as information and forecasts based on historic (i.e. by data mining) or predicted (i.e. weather now/forecasting) data, the intentions and the resources available can be estimated. Knowing these shortcomings, such as over-demands, can be foreseen and counter-measures can be initiated.

8.3 Multimodal considerations

The examples cited under "Common themes across modes" do, of course, similarly apply to multimodal systems, functions and applications. The essential factor is to be able to provide a high quality traffic management service and high quality customer service throughout a multimodal journey, with key focus on interchange hubs / nodes.

There is a natural juxtaposition between certain transport modes, with interchange taking place relatively frequently (e.g. bus/rail stations). Often in urban areas a major bus station will be sited adjacent to a railway station. This encourages smooth and efficient modal interchange. Key essentials include accurate real time information, which should be provided at all critical points along the journey path (e.g. not just within the bus station itself, but also within the railway station within the ticket hall / main circulating area), but also at platform level in the station, so passengers can make informed decisions at key points within their journey chain. This particular multi-modal facility is already quite well developed, though certainly more work needs to be done to ensure that timetable information is shared more freely between different modal operators and incident management is better co-ordinated across modes.

Other bi-modal interfaces are less well developed (e.g. air/road). This interface will become more and more relevant, particularly in urban areas, as airspace usage (e.g. for UAVs and helicopters) becomes increasingly utilised and the interaction between road-space and air-space becomes a management challenge. Similarly, the interface between other modes that traditionally had little interaction, e.g. waterborne/road, waterborne/air will need to be examined to establish the potential for their inclusion within a truly multi-modal NTM system. Some would argue that there is less direct necessity for these bi-modal interfaces to be as well developed as rail / bus for instance, as the numbers of interchanging users are relatively small compared to an urban rail / bus interchange. Whilst in strict numerical terms this is correct, there is scope at this time to examine the potential of developing a multi modal NTM system, which will be sophisticated and mature enough to encompass all modes.

Already steps have been taken to enhance multi modal interchanges between those modes that traditionally operate in relatively standalone environments (e.g. at airports information is available to passengers interchanging to rail or metro). Often the real time status of the rail or metro mode is available at key locations within the airport buildings, as well as on individuals' mobile devices. It would be desirable to make this more of an equal bi-lateral arrangement with, for example, real time aviation information widely available across feeder modes and vice versa. A comprehensive NTM system should be able to deliver this goal.

As automatic/semi-automatic vehicle usage continues to rise, there is a need to develop and give further consideration to those elements of a future NTM system that can help not just to promote this mode, but also how this mode interfaces with other transport modes. (Semi) automatic car usage will need to be promoted quite carefully in a focused fashion. The inter-relationship of (semi) automatic cars, or even by 2050 (or already 2030) pod usage, with the traditional urban forms of road based public transport (e.g. bus, tram) needs careful management. Policies should be formulated that give direction on preferred transport choice in different situations. For instance, it will probably not always be the case that an individual should take an automatic car/pod and there would be wider societal benefits for that person to take a bus or tram for their travel.

Whilst journey modal choice will fundamentally be policy driven, it is highly desirable that the NTM system that develops between now and 2050, from the perspective of public acceptability, has the capacity to be able to allocate a preferred modal choice in any given situation.

Annexes

Annex 1: International experience: selected examples

United States

In the US, ownership of traffic management related data rests with the various State Departments of Transport (DOTs); private service providers; City authorities and traffic operator authorities. Federal and state laws recognise a certain degree of privacy with respect to driver information, but a consistent approach to anonymising probe data by public and private sector data providers is still missing. Network and traffic management operations are closer to the system used in the EU. Traffic management centres use the services of data providers in balancing traffic and optimising the traffic network. Nonetheless, aspects related to IT-Security, and data protection and privacy are more prominent in traffic management policies in the EU28, as the protection of privacy has given rise to the concept of privacy by design. Each EU Member State has its Data Protection Authority to monitor corporate behaviour, as Privacy is a Human Right, while U.S. federal agencies have been given little power to limit the potentially privacy-invading behaviours of private companies.

Japan

In Japan, "Smartway" is the latest traffic management system, whereby people, vehicles and the road network are connected based on ITS technologies. Road safety and the mitigation of congestion, along with environmental policy are the priorities dictating traffic management policy. "Smartway" deploys ITS Spots, a high speed, large capacity V2V and I2V communication, shares and exchanges information with the aim to give advice, to facilitate actions or to control vehicles, with the objective of improving safety, sustainability, efficiency and comfort beyond the scope of stand-alone systems. It is controlled by the Ministry of Land, Infrastructure, transport and Tourism (MLIT). Various ITS services, such as the electronic toll collection (ETC), car-navigation and vehicle information and communication system (VICS), can be provided with a single on-board unit. ITS Spot Services are provided by ITS Spot equipment, installed on the roadside by the State and an ITS Spot-compatible car navigation system installed in vehicles. ITS Spot services include currently three basic services, namely “dynamic route guidance”, “safe driving assistance” and “electronic toll collection (ETC)”. In the future, additional services will include internet access at expressway’s service areas (already available by some model of car navigation systems), cashless payments, tourist information and logistics operation support. ITS Spot is a system developed as a platform for various ITS services. ITS Spot enables not only road infrastructure to provide vehicles with traffic information, but also enables vehicles to transmit their probe information to the road infrastructure. All of this enables ITS Spot to function as a probe system. The MLIT has been conducting research and development on utilising this ITS Spot probe system for driver’s services, such as traffic information and safe driving assistance, study and research on road traffic, and road management.

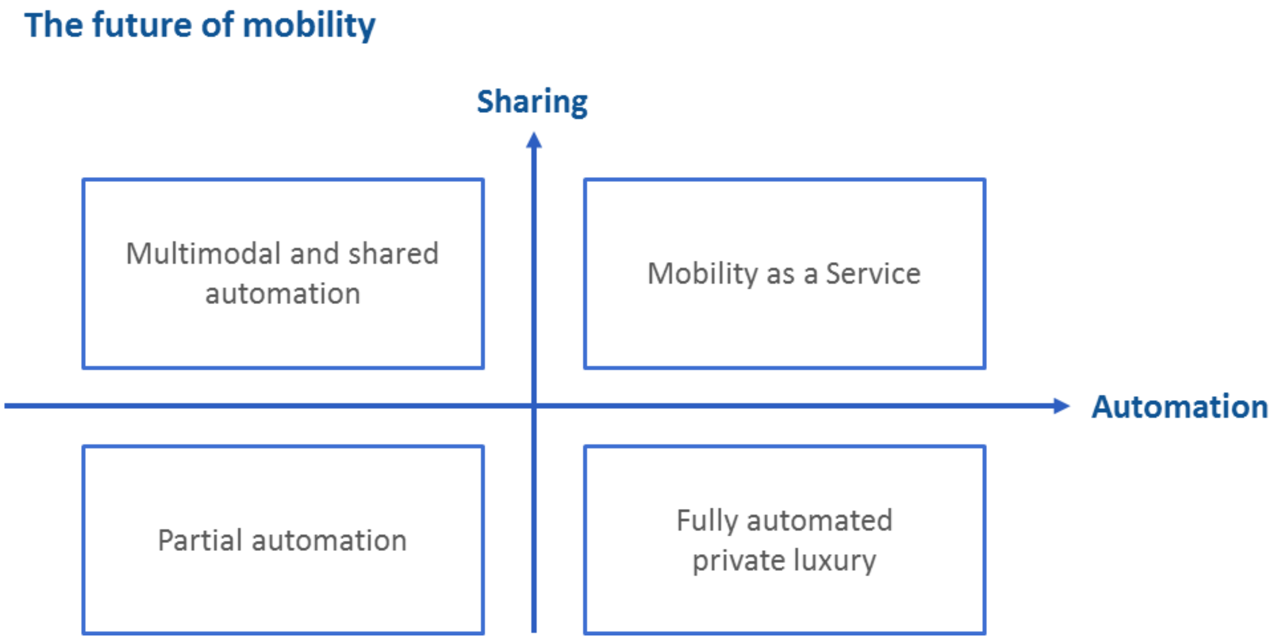
Public sector probe systems in Japan comprise the ITS Spot and a National Police Agency’s system. Ownership of probe (vehicle) data lies with the MLIT and the respective expressway companies, while users own the ITS Spot-compatible car navigation systems they purchase and install in their vehicle. That makes network and traffic management a publicly controlled operational environment.

Annex 2: Some guidelines towards possible win-win schemes within NTM

For network traffic management business architectures to be both functional and successful for all modes, new possible private-public cooperation models are needed. As already discussed in the main NTM Roadmap, alignment of the different stakeholder priorities can create the 'win-win' model sought for the collaboration between the private sector and public authorities, while safety is one of the factors that will play a pivotal role on the new understanding of cooperation schemes among stakeholders coming from the public and private domain.

Projecting today how the future will be is inevitably based on what is today known and expected. Currently, two parameters that are among those currently seen as steering the future of transport in Europe are: **automation and multimodality**. What is more, two of the (currently) known (and expected to be) dominant trends of **shared economy** and **connectivity** can add to the identification of possible guidelines that would bring forward new schemes of private-public cooperation along all transport modes within the NTM.

As seen in the scheme below, the evolution of Automation and the Shared economy can result in, among others, two different possibilities with regards to the parameter of Automation, while Multi-Modality deserves to be given attention as a separate possible scheme:



The parameter of Automation

Possible Guidelines for Scheme 1: Automation in private use

As Automation is currently evolving, it will transform the transport infrastructure into a highly automated and modernised one (NTM Roadmap milestone set for 2025), which will then eventually become part of a highly automated, coordinated and harmonised EU NTM system (NTM Roadmap milestone set for 2035). Automation sets in motion the public and private sectors' exploration of new forms of partnership. With regards to road transport for example, the passage of mobility from the stage of "partial automation" to the stage of "fully automated vehicles" will necessitate a change in both the allocation of liability and that of customer satisfaction in private-public (PP) cooperation schemes.

Public authorities will have to send traffic management information to the car during both of the automation levels described above. This information will either be sent to the car via service providers and/on vehicle manufactures. Nonetheless, when this information is safety related (and as already discussed, in full automation very little information *is not* safety related anymore), **the vehicle and/or the service provider have to send back to the public authorities an acknowledgement message/signal that: a) the safety related information was received and b) the advice is being duly followed.** The private sector in this scenario is thus becoming more and more liable for the safety of the user and the entire traffic management network will have to increasingly depend on the private sector's ability to successfully comply with the system requirements.

Possible guidelines for Scheme 2: Automation in shared economy

In the second possible scheme examined in this Annex, automation is set as going beyond private ownership, thus entering the realm of shared economy. As is also the case in the possible guidelines for scheme 1, in scheme 2 the milestone dates are the same. Nonetheless, the system as such does not support private ownership and use of self-driving vehicles. Transport by automated vehicles/transport modes is offered in the first phase (until the 2035 milestone) as an additional option to multi-modality and eventually, upon the attainment of the 2050 target, as MaaS in the entire NTM.

According to that scenario, the roles of private-public interact accordingly. Both public / private sectors enter into a variety of partnerships to build a system of service provision, where all partners collectively work for the public benefit, regardless of the fact that the profit of each partner comes from only one or more 'legs' (or services) of the MaaS system. The combination of multi-modality and automation in the first phase (until 2035 milestone), may seem to leave public safety responsibility entirely to the public sector, but in reality the dominant presence of **automation will very soon change the paradigm into one of shared responsibility for the collective safety**, as has been also described in the case of scheme 1 above.

The parameter of Multimodality

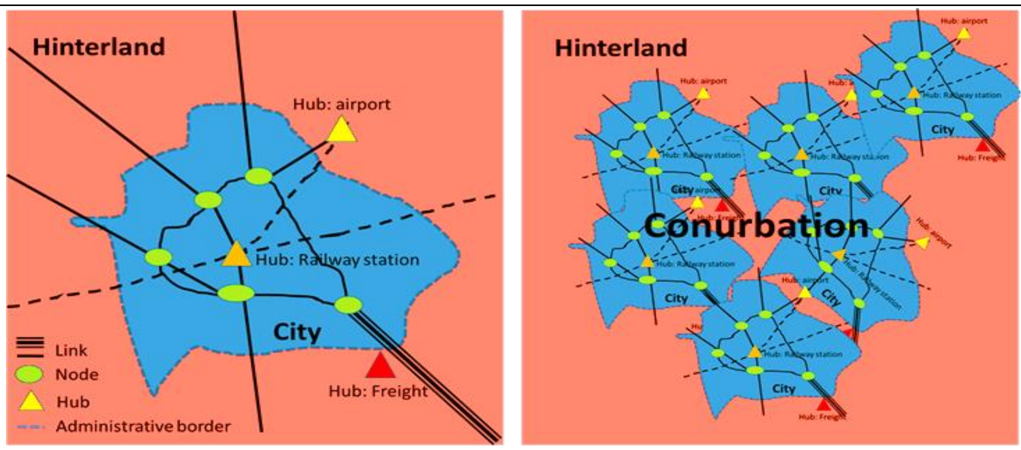
Possible guidelines for Scheme 3: Multimodality

In a multimodal mobility scheme, all transport nodes will progress towards the set milestones of 2025, 2035 and finally 2050 when they will become part of a fully interconnected, intermodal EU transport system. Fully **interconnected intermodality** means that airport authorities will be able to know how many people are using this transport mode real-time and how many people are expected at any given time (or moment). Connectivity based on Big Data and ITS will be the basis of new services and products with regards to traffic service provision. That development will prove positive for not only safety, but also programming and planning of a variety of other activities and actions by public and private sectors alike. For instance, ports will be able to know real-time how many vehicles/freight/people are expected to arrive at any given time, or how many of them are using the port services at any given time. Better traffic management within the port, on its portals and access arteries and their vicinity (all aspects of freight logistics) is expected to be the positive outcome of NTM and this will affect the roles of public and private stakeholders accordingly.

The authorities that control transport hubs, such as airports and ports, for example, will be in full contact with those that will be controlling the road network. All will interact in a web of exchange of traffic information, with the aim to attain sufficient and effective operations for the benefit of their users. The benefits, regardless of whether these authorities are public or private, will not be limited to the users of the narrow transport network of port and trucks for freight, for example, but they will inevitably have a much wider effect, impacting the entire chain of traffic information, freight logistics and traffic management. In multi-modal systems, people, freight and services are inevitably interconnected, while fully automated environments will prove able to guarantee functional and efficient services. As a result, 2050 is to be seen as the milestone date when both private and public stakeholders will aim for that same target of ensuring full efficiency in the NTM, while at the same time being fully liable for their service's mishaps in the system.

All in all, the above public-private partnership schemes will be the inevitable result of progressive transformation, from several isolated traffic management systems into a unique NTM. Increasing connectivity of transport goods and modes within a NTM system is key in overcoming cross-border barriers for both people and freight in the EU.

Annex 3: Glossary

Term	Definition
Transport	The movement of people and goods from one place to another.
Traffic	The flux or passage of motorised vehicles, non-motorised vehicles and pedestrians.
Traffic Management	The task to optimise the traffic flow in terms of given performance indicators under the given conditions of the existing transport infrastructure and the current traffic situation.
Network management	The task to optimise the entire transport network (incl. ITS-infrastructure) in terms of given performance indicators to guarantee the coverage of mobility demand of persons and goods.
Journey management	The task to accommodate and support optimised execution of the stated mobility needs of passengers and goods (‘journey’) in all phases (from pre-planning to commencement), in terms of given performance indicators under the forecasted / given conditions of the available transport infrastructure (expected / current traffic situation) and customers' preferences (e.g. travel time, cost, duration, comfort, special needs, environmental impact, predictability etc.) Passenger and goods flow-management considering individual requirements and wishes.
Transportation management	All activities of a transport company related to the transportation process itself (different from marketing, accounting, personnel management, etc.). Several temporal views of transportation processes exist: strategic planning (long term), tactical planning (mid-term), operations control (short term and real time) and statistics of transportation.
Traffic Management system	An integrated collection of subsystems for the management, the control and the guidance of traffic flows, which supports the traffic manager in his/her traffic management task.
Network (of transport)	Transport infrastructure (network consisting of links and nodes and ITS-infrastructure) for the movement of persons and goods.
Link / Node / Hub	
Mode (of transport)	A term used to distinguish substantially different ways to perform transport.
Mono-modal	Involves the use of only one mode of transport for a journey.
Inter-modal (transport)	Involves the use of more than one mode of transport for a journey.
Cross-modal (traffic management)	Manages traffic across the borders of two or more modes of transport.
Multi-modal (journey)	Involves the use of multiple modes of transport for one journey.
Synchro-modal (traffic management)	Manages traffic across the borders of two or more modes of transport in a synchronised way.
Mobility (of persons and goods)	The basic need of people to be able to move themselves or their goods from A to B.
Mobility as a service	A shift away from personally owned modes of transport and towards mobility solutions that are consumed as a service.
Sectors (in transport)	Distinguish the kind of legal and economic background of actors, acting in the transport domain.
Capability	A characteristic which enables an actor to execute an activity.
Safety (to traffic)	The state of being "safe”, the condition of being protected from harm or other non-desirable outcomes during a journey.
Efficiency (of transport)	An index which expresses the degree of utilisation of the capacity of the transport infrastructure.
Decarbonisation (of transport)	Transport based on low carbon power sources that have minimal output of greenhouse gas (GHG) emissions into the environment biosphere; specifically refers to the GHG carbon dioxide (CO_2).