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Strategic Research and Engineering Roadmap

in the domain of Multi-Modal Traffic Control

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Executive Summary

Transportation is an interesting example of a natural System of Systems (SoS). Indeed, the administrative organisation in this domain has led transportation networks to be operated by a patchwork of operators, even in limited geographical areas as around large cities, freeways, urban roads, arterial roads, subway, bus, tramway, trains, taxis, or airports. Theses operators have different levels of technical and financial means and a panel of legacy systems that were not necessarily designed to be operated together (different communication protocols, different standards, different maintenance procedures). Systems are often rather closed with little information shared between operators, both for technical reasons and due to a lack of motivation to share strategic information. New SoS architectures and software are needed to increase collaboration among operators in order to manage the transportation resource as a whole in a safe and secure way.

Coordination among road operators is very likely to lead to interesting synergies (load balancing, energy efficiency, continuity of service across different operators, mobility optimization) that are not possible in the current systems. Furthermore, some favourable emergent behaviour is expected which could yield unplanned, yet desirable, features.

Transportation systems are naturally evolutionary in the sense that sensors, communication networks and operation rules are constantly evolving, sometimes even without notice. The rapid evolution of enabling technologies in the transportation industry, e.g. sensor networks and vehicle-to-infrastructure communication, has led to more and more complex systems that are difficult to maintain using traditional techniques. Modelling and adaptability should be developed further to be able to help automate certain routine maintenance tasks.

Data sharing through standardised models is at the core of the development of multimodal transportation systems. Transportation network operation requires real-time data that goes beyond what is available today in traditional open data spaces such as low frequency traffic information or public transportation timetables, and maps. The dynamics involved in such data requires robust protocols and software implementations to make data sources reliable. Developing this reliability is necessary for operators to be confident in the data they broadcast and receive from other operators. Moreover, extensive data sharing architectures should preserve privacy through secured information exchange systems.

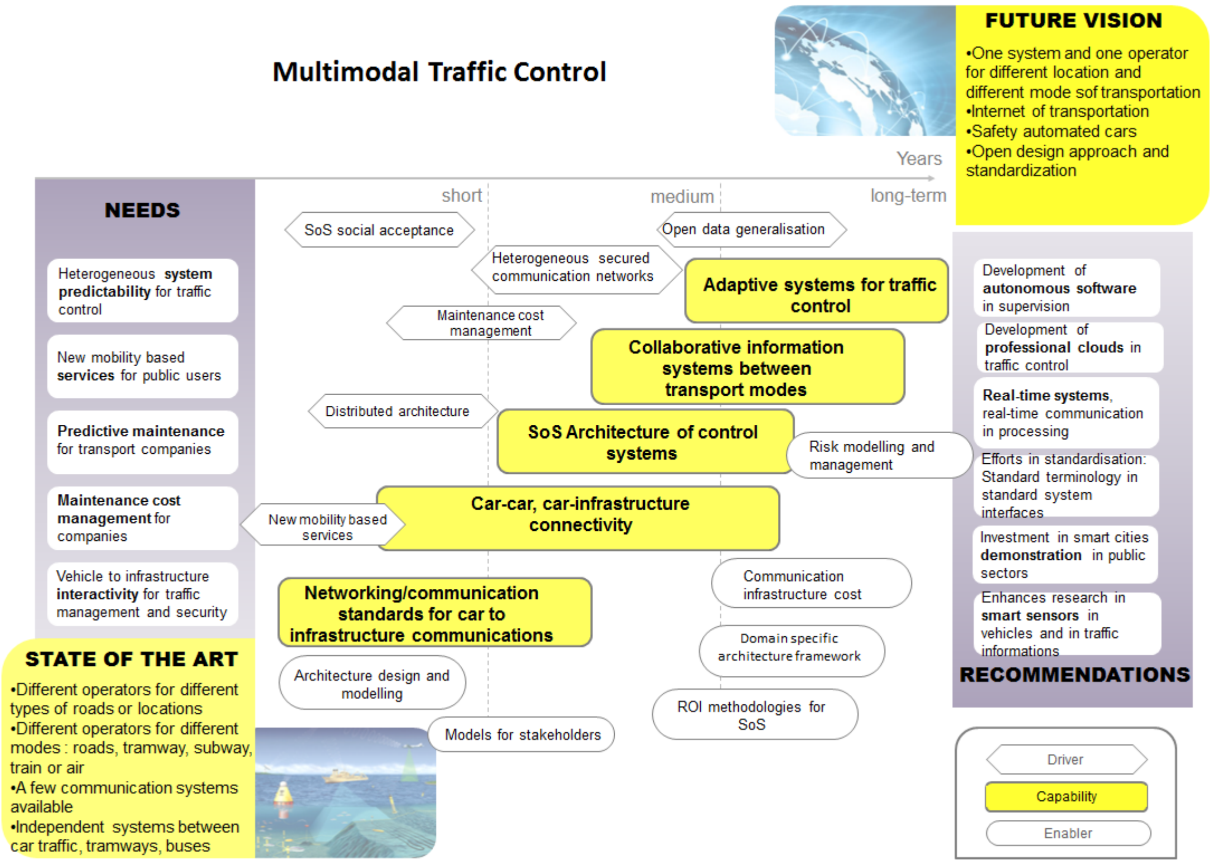

Figure 1 – Simplified SoS roadmap for the domain of Multi-modal traffic control

1. Introduction

The trend of an increasing interconnection of formerly self-contained systems into Systems of Systems (SoS) is expected to yield – by synergy and emergence – unprecedented capabilities in many domains. SoS approaches can be expected to improve the competitive position of companies, especially SMEs, and help tackle a range of societal challenges.

To effectively design, develop, run, and maintain SoS, a range of technologies and capabilities are necessary. To provide a clear view of the required technologies/capabilities but also barriers and enabler relevant with regards to SoS, the Road2SoS project develops research and engineering roadmaps in four selected application domains: (1) integrated multi-site manufacturing, (2) multimodal traffic control, (3) smart grid and distributed energy generation, and (4) emergency and crisis management. The identification of common strands arising independently in several application domains leads to recommendations for research priorities and shall inform future SoS-related R&D in Europe.

This report provides an overview of the roadmap developed in the domain of multimodal traffic control. Following a description of the roadmapping methodology, the roadmap's main aspects will be presented, covering the range of socio-economic trends, drivers and needs, along with the technological challenges and the enablers that are facilitating SoS-approaches modes.

2. Methodology

There are two contrasting approaches to creating roadmaps. The first approach, a technology-push prospective roadmap, starts with existing research projects and fills in the remainder of the roadmap to identify the diversity of capabilities to which this research could lead. In contrast, the second approach, a requirements-pull prospective roadmap, begins by envisioning the desired technology, system or other end products, before working backwards to identify the critical research and development required to fill in the remainder of the roadmap to arrive at these products.

In the Road2SoS project, roadmaps have been created by combining the technology-push and requirements-pull perspectives. Starting with existing science and technology development programs which are more technology- or requirements-driven, research gaps were identified that obstruct forward progress and the diversity of end products to which successful development could lead (Figure 2).

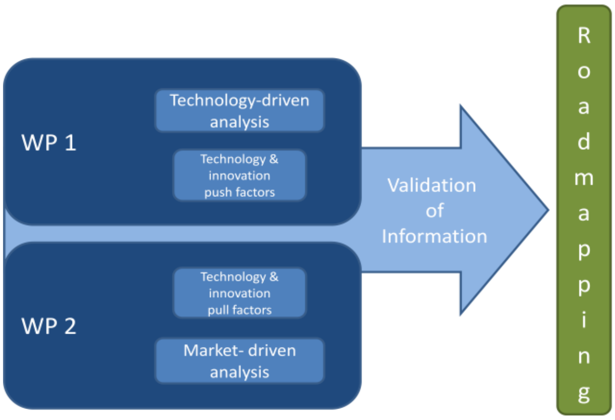

Figure 2 - Representation of the integration of the results coming from the technology-driven/push and the market-driven/pull analyses

Prospective analyses cover time frames from the present to typically a decade or more into the future. A time frame of 15 years into the future was selected due to the EC's planning horizons and objectives and the need to include SME participation. The roadmaps developed present information at a medium aggregation level.

2.1 Common roadmap architecture and workshop process

A common roadmap architecture and workshop process was developed and adopted in order to facilitate the collection and analysis of similar data across the four domains examined in Road2SoS, enabling the identification of key drivers, technologies and enablers that are relevant to make SoS approaches work in the selected application domains.

This common roadmap architecture (Figure) considers three time periods on its horizontal axis: the short-term (+5 years), the medium-term (+10 years), and the long-term (+15 years). On the vertical axis, four layers, each comprising a number of sub-layers, are included.

2.2 Phases of development

The roadmaps were developed through the following three phases.

Phase 1: Data collection and analysis
During this phase, the collection and analysis of RTD and innovation results (push perspective), domain needs and relevant trends/drivers (pull perspective) took place. This was conducted through literature review, interviews and surveys with stakeholders from research institutions, companies and governmental organisations.

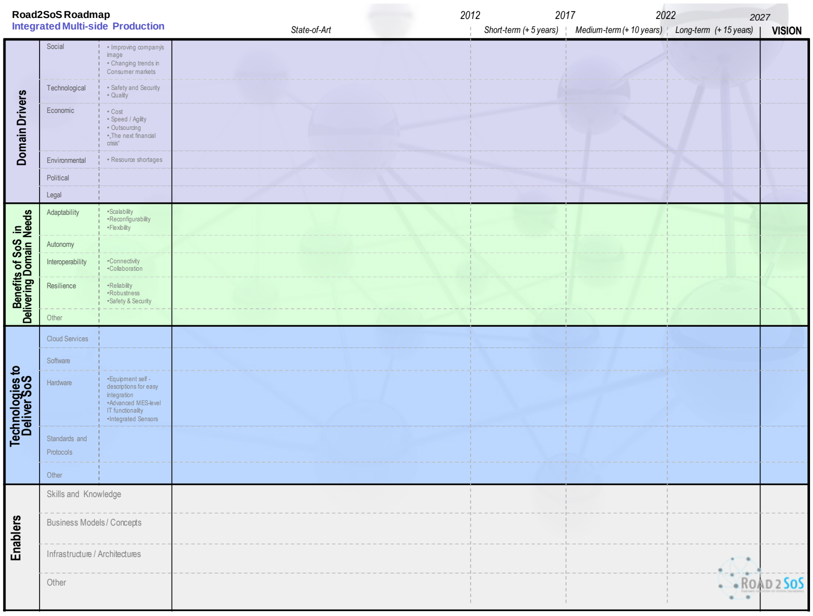

Figure 3 - Common roadmap architecture

Phase 2: Development of technology roadmaps

In this phase, a roadmapping workshop was used to validate the Phase 1 findings, complement them, and analyze them for mutual implications of push and pull perspective. Aspects captured in the roadmap furthermore underwent prioritization and in-depth discussions were devoted to top-priority aspects.

The full-day roadmapping workshop, held on 25th September 2012 in Paris, involved a group of selected experts from industry, academia and governmental organisations.

Phase 3: Cross-sectoral approach

In this final phase of development of the roadmaps, cross-domain analysis for common drivers, technologies and enablers arising independently in two or more application domains was conducted. The results were validated by means of several case studies in each of the four domains.

3. Roadmap

The result of the roadmapping process is shown in Figure . Each item is colour-coded to show its relative priority against other items within its layer. In the following sections, the highest priority items are explained in turn, beginning with the domain vision that was presented to participants at the roadmapping workshop.

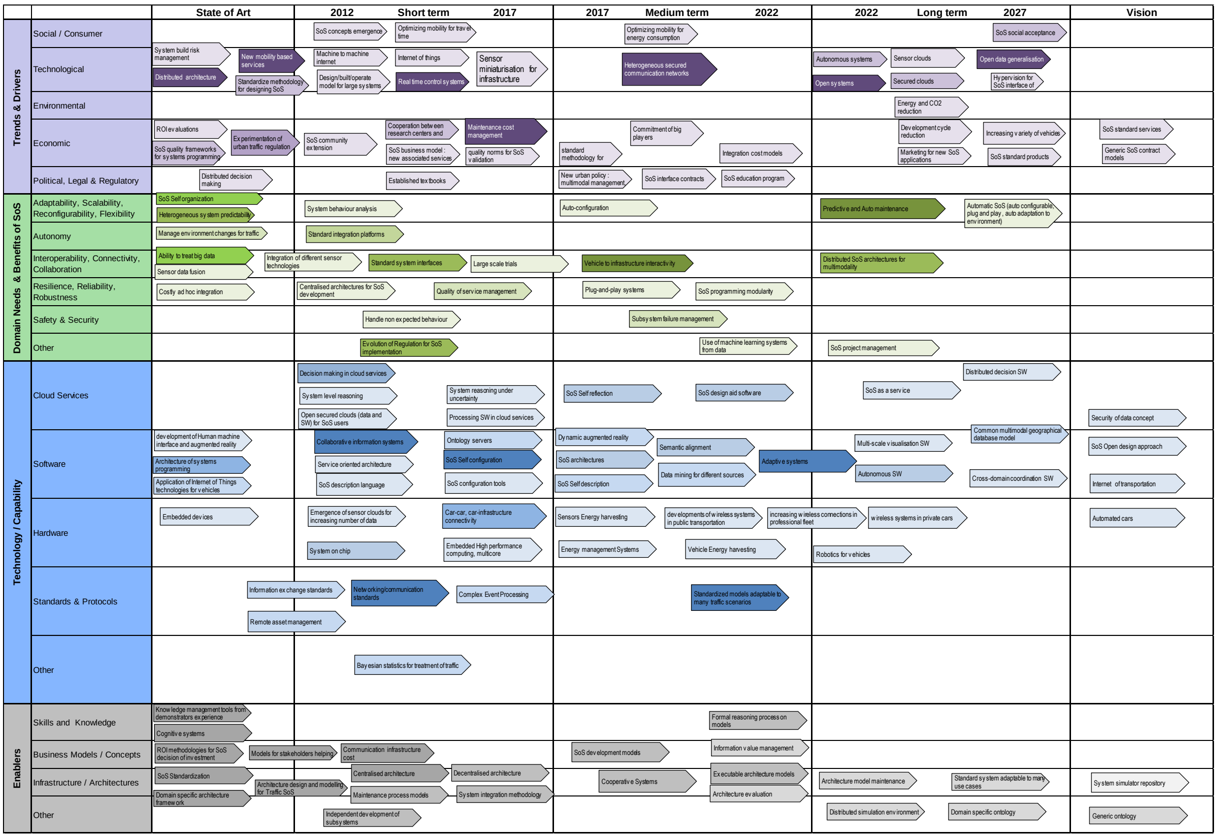

Figure 4 - Roadmap Landscape

3.1 Possible future vision for the domain

Today, transportation systems such as road networks, public transportation, trains or airplanes, are not sufficiently interconnected to ensure an optimal usage of the infrastructures and natural resources. A closer interconnection can now be envisioned thanks to the advance of networking and information technologies. This interconnection of systems gives rise to what can be treated as Systems of Systems (SoS).

The vision for multimodal traffic control is a global transportation infrastructure, operated as a whole without administrative and technological boundaries. On top of this physical layer would be a service layer, providing transportation services to end-users, making the transportation system much more easily and flexibly usable than it is today. This requires the integration of state of the art and emerging technologies like sensors, telecommunication networks and embedded systems. It also requires the integration of new systems and legacy systems that cannot be renewed on a short notice because of complexity or cost. The field of multimodal traffic control will also have to integrate innovative means of transportation such as on-demand car rental – electric or conventional –, dynamic car pooling and communicating vehicles: C2C, C2I, C2X.

Communication is a crucial for future multimodal traffic control. On the one hand, transportation network are critical infrastructures that should be operated in a secure and safe way. On the other hand, collaboration between operators that manage different means of transportation or different regions requires the opening of their information systems, at least partially. The development of frameworks that allow this feature, such as secured clouds, is critical to the development of SoS in multimodal traffic control.

The emergence of collaborative road operations is a necessary step toward a better operation of the existing transportation networks and the integration of new means of transportation in a seamless global transportation infrastructure. This step, that can greatly benefit from an SoS approach, will allow transportation to become an integral part of the smart city revolution that is currently taking place.

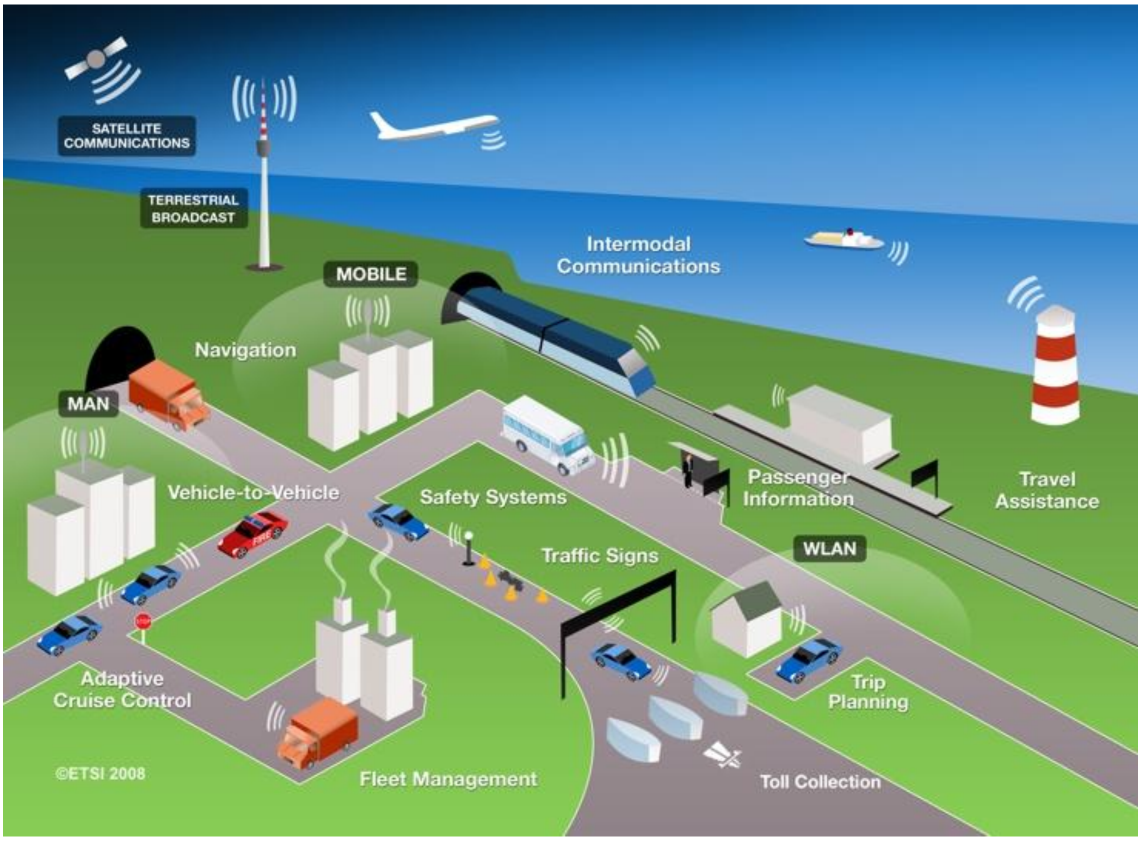

Figure 5 - Future vision of Multimodal Traffic Control

The key benefits that are expected are the following:

- For operators:
    - To know continuously the system state of each transportation mode.
    - To know the health of the system, e.g. the state of sensors, servers or signals
- For users:
    - To know continuously what the best option for a trip is
- For the community:
    - less wasted natural resources.

From our analysis, the challenges are multi-dimensional:

Technology: Even if networking and information technologies are globally available today, there are domains that will have to become more mature and industrialised on the way to a fully implemented SoS concept such as complex real-time control systems, distributed architectures, secured clouds, self-configurable systems or complex event processing for instance. For several decades, most of the research and development activities in transportation have been focused on equipment to increase performance, electric or intelligent vehicles or communication in relation to vehicle-to-infrastructure communication or the internet of things. On a system level, which addresses the interconnection of systems, a certain need for technologies can be found, threatening the emergence of SoS approaches in the domain. Standardisation of protocols and system interfaces is a fundamental step for companies to be able to implement SoS in transportation networks. Public authorities have a key role in this standardisation process. The definition of quality norms specific to SoS in transportation is also necessary given the strategic assets that are affected.

Methodologies: SoS is an emerging engineering practice and the associated concepts and tools need to be more developed and endorsed by the different stakeholders.

Politics and organisations: Today, transportation systems are operated by multiple independent institutions. An SoS scenario would require these institutions to work together, share information and decision processes. From our analysis, this is among the most important challenge for SoS to become reality. At a transnational level, as countries still have a lot of authority in the transportation domain, policies will have to be implemented to promote the emergence of SoS in this domain. The promotion of SoS practices from public authorities can be initiated by the European Commission through supporting use cases.

3.2 Trends and drivers

The top layer of the roadmap pertains to the wider social, technological, environmental, economic and political trends (STEEP), changes that are envisioned to affect the multimodal traffic control domain. A detailed view of this layer is depicted in Figure .

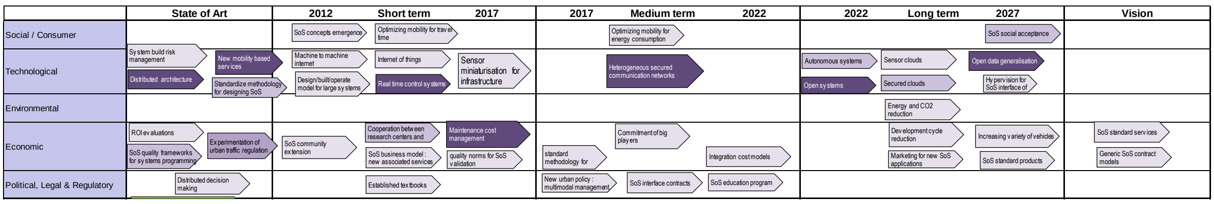

Figure 6 - Trends and drivers

As in Figure , the darker shades indicate those items that were identified by roadmapping workshop participants as being of higher significance. The ten most important trends and drivers are:

- Heterogeneously secured communication networks
- Distributed architecture
- New mobility-based services
- Maintenance cost management
- Real-time control systems
- Open systems
- Open data generalisation
- Experimentation of urban traffic regulation
- Secured clouds
- Sensor miniaturisation

The ranking of the most relevant items is distributed as follows:

Sub-layer	Ranking
Technological	8
Economic	1
Social	1
Environmental	0

This reflects the technology-dominated focus of the multi-modal transportation domain. Contrary to what could be expected, the environmental factor is not present, probably due to the technological challenges that should be overcome before focussing on environmental factors.

From this ranking, the following analysis can be performed:

- **Management of heterogeneity and security** is ranked as a top driver since these are inherent issues of the transportation industry by default to ensure safe travels.

- Technical aspects such as **distributed architectures** and **real-time control systems** are drivers that exist independently from the SoS topic as well as transportation is distributed by nature and real time control systems are deployed to manage the transportation infrastructures.

- **New mobility based services** and **maintenance cost management** are related to business drivers. SoS is seen as a way to better manage maintenance in transportation systems, which is related to the highest operational costs of the industry. Mobility based services are currently thrive due to the rapid spread of smart phones and embedded devices.

- **Open systems and open data** is a topic clearly related to SoS. It is a necessary step to achieve collaborative management in multimodal transportation systems.

- SoS implementation issues are addressed through the development of **secured clouds** and be able to realise **experiments**. Clouds are perceived as a potential solution to make subsystems more open and ease the communication of data. Involving critical transportation network infrastructure in experiments is clearly a difficult task, however, there should be mechanism to do so in order to ease the implementation and field testing of SoS in transportations.

These aspects are further described in the following sections.

3.2.1 Heterogeneous secured communication networks

Transportation systems are heterogeneous by construction such that there are multiple means of transportation or several legacy systems in each control centre. Being able to communicate data and value added information across these heterogeneous systems is necessary to benefit from synergies among systems. To the extent that critical transportation infrastructures are involved, communication networks should be adequately secured to withstand malicious attacks.

3.2.2 Distributed architecture

A goal of the SoS approach in multi-modal transportation is to allow coordinated operation of the transportation subsystems such as different regions and roads or different means of transportation. Distributed architectures are required to enable coordination as the transportation networks are operated through geographically distributed control centres. Distributed architectures also ease the operation of transportation networks that extend across very large areas.

3.2.3 New mobility based services

To globalise the flow of information in multi-modal transportation systems, each collection of systems should be aggregated in a shared data infrastructure that enables all operators to share the same knowledge about the current situation. Doing so, new multi-modal traveller services can be developed in collaborative projects or an operator can take the initiative to develop such services.

3.2.4 Maintenance cost management

Technological impediments like different sensor networks, multiple communication protocols or non-compatible / non-interoperable software complicate the interconnection of transportation systems and have a direct impact on the maintenance cost of the transportation system as a whole. The transportation domain is known to heavily rely on integration due to the complexity of the technological system that frames transportation systems. SoS should be more than another integration framework and take into account maintenance and evolution from the very beginning. SoS methodologies should lead to a better management of integration and maintenance tasks in terms of cost, timing and maintainability.

SEVENTH FRAMEWORK PROGRAMME

3.2.5 Real-time control systems

To further develop the SoS approach and particularly control structures for SoS in multi-modal transportation systems, each transportation system that constitutes an SoS should be appropriately modelled and monitored through the use of sensor networks. Sensor technologies has been developing very rapidly during the last decade. The offer of affordable and easily deployable wireless sensor networks is increasing rapidly and many solutions are now proven and industrialised.

3.3 Domain needs

The second layer of the roadmap addresses the needs of the multi-modal traffic control domain that are related to SoS. These needs are classified as: resilience, safety and security, adaptability, autonomy and interoperability. A detailed view of this layer is depicted in Figure 7.

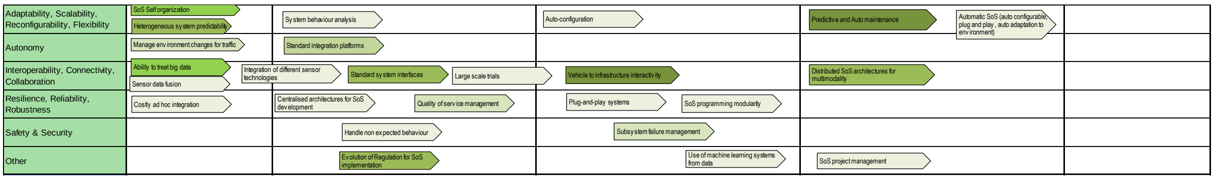

Figure 7 - Domain needs

The darker shades indicate those items that were identified by roadmapping workshop participants as being of higher significance. The ten most important needs and benefits are:

- Predictive maintenance
- Vehicle-to-infrastructure interactivity
- Heterogeneous system predictability
- Standard system interfaces
- Auto-maintenance
- Ability to treat big data
- Sensor data fusion
- Regulation
- Distributed architectures
- Scalability

The most relevant items are distributed as follows.

Sub-layer	Ranking
Safety & security	3
Resilience	3

Autonomy	2
Adaptability	1
Interoperability	1

This reflects the importance of safety, security and resilience for transportation system operators. Autonomy, adaptability and interoperability relate directly to the SoS approach.

From this ranking, the following analysis can be done:

- The high ranking of **Predictive maintenance**, **Heterogeneous system predictability** and **Auto-maintenance** in the needs and benefits is well aligned with the **Maintenance cost management** driver seen in the trends and drivers section.

- The **Standard system interfaces** need is well aligned with the **Open data generalisation** and **Open systems** driver seen in the trends and drivers section.

- The **Ability to treat big data**, **Sensor data fusion**, **Regulation** and **Scalability** are needs necessary to be able to control large SoS in the multi-modal traffic control domain.

- **Distributed architectures** highlights the distributed nature of SoS and transportations systems in general.

These aspects are further described in the following sections.

3.3.1 Predictive maintenance

Connected to the "Maintenance cost management" driver mentioned above, predictive maintenance is an important topic to ease the maintenance of transportation systems and other complex systems. Predictive maintenance enables operators to perform maintenance tasks at just the right point in time, avoiding unnecessary maintenance on the one hand, and belated maintenance on the other hand. Thus, predictive maintenance plays an important role in ensuring high quality transportation service at all times, in a cost-effective way. More and more devices involve predictive maintenance features by providing diagnostic information that can be processed automatically by software.

3.3.2 Vehicle-to-infrastructure interactivity

Vehicle-to-infrastructure interactivity is still at the R&D stage with several prototypes already available. The domain has been and is still addressed in several EU projects. Given the financial effort already invested in communicating vehicles (C2C, C2I, C2X), this is a positive feedback that it is still perceived as a need. Vehicle-to-infrastructure interactivity can revolutionise the way transportation infrastructures are operated by developing more direct and user-centric information with travellers instead of classic information panels.

3.3.3 Heterogeneous system predictability

This topic is connected to "Predictive maintenance" (see section 3.3.1), though more general. If advances were to be achieved in the predictability of each subsystem – though it is still complex and far from being completely solved –, predictability of the whole heterogeneous system will still be a challenge. This field requires more research in the dynamic modelling of complex systems.

3.3.4 Standard system interfaces

Collaborative operation of transportation networks requires the interconnection of systems and the sharing of information among operators. This interconnection of systems that were not designed to work together requires the definition of standard interfaces. These interface standards should be general enough to handle the variety of situations while being tractable and easy enough to be widely adopted. Corresponding testing procedures for such interfaces should be provided to ease the implementation.

3.3.5 Auto-maintenance

Transportation SoS are large-scale, heterogeneous, complex and geographically distributed. In order to make them also durable, they should have some features of auto-maintenance as it cannot be maintained through manual operations on a daily basis. Auto-maintenance is a software issue but the hardware components should have diagnostic features that make auto-maintenance possible.

3.4 Key innovation opportunities identified in the domain

In order to address the drivers and needs described in sections 3.2 and 3.3, technologies and enablers were identified and assigned. In the following subsections, it is explained why and how those technologies and enablers help to support the drivers and needs by means of the four priority innovation opportunities (Figure 8).

Trends & Drivers

Priority Technologies	1 Heterogeneous secured communication networks	2 Distributed architecture	3 New mobility based services	4 Maintenance cost management	5 Real time control systems	6 Open systems	7 Open data generalisation	8 Experimentation of urban traffic regulation	9 Secured clouds	10 Standardize methodology	11 Cooperation with industry	12 Sensor miniaturisation
Adaptive systems		1			1	1						
Standardized models	1	1	1	1	1	1	1	1	1	1	1	1
Collaborative information systems	1	1			1		1					

Domain Needs

Priority Technologies	1 Predictive maintenance	2 Veh. to infrastructure interactivity	3 Heterogeneous system predictability	4 Standard system interfaces	5 Auto-maintenance	6 Ability to treat big data	7 Sensor data fusion	8 Regulation	9 Distributed architectures	10 Scalability	11 Distributed SoS	12 Self organization
Adaptive systems	1				1			1				
Standardized models	1		1	1		1	1	1	1	1		
Collaborative information systems		1	1	1						1	1	

Related Technologies

Priority Technologies	1 Adaptive systems	2 Standardized models	3 Collaborative information systems	4 Networking/communication standards	5 Self configuration	6 Car-car, car-infrastructure connectivity	7 Architecture of systems	8 Decision making in cloud services	9 Dynamic augmented reality	10 Semantic alignment	11 Common multimodal geographical database model	12 Complex Event Processing	13 Connectivity in private cars	14 Distributed decision S!!	15 Information exchange standards	16 Internet of transportation Automated cars	17 Internet of Things technologies	18 Ontology servers	19 Open design approach	20 Remote asset management
Adaptive systems	1				1							1							1	
Standardized models		1								1					1	1	1			
Collaborative information systems			1			1	1	1			1			1						

Enablers

Priority Technologies	1 Knowledge management tools	2 ROI methodologies for SoS	3 Architecture design and modelling	4 Standardization	5 Cognitive systems	6 Models for stakeholders	7 Domain specific architecture framework	8 Risk modelling and management	9 Communication infrastructure cost	10 Centralised architecture	11 Independent development of subsystems	12 System integration
Adaptive systems										1		1
Standardized models		1		1								
Collaborative information systems					1							

Figure 8 – Priority Technologies

3.4.1 Adaptive systems

Transportation systems are more and more complex and should still be reactive in order to control their behaviour and provide up-to-date control strategies and information to travellers. These systems should be sufficiently reactive to adapt to changing conditions in terms of traffic as well as available data because failures in sensors or communication infrastructures may and will happen whatever quality system components are of. To match this need for reactivity, automatic adaptation mechanisms should be available. The requirement for adaptability and agility needs to be reflected in SoS system architecture and software. Developing more autonomous and adaptive transportation systems is a challenge for the next decade.

3.4.2 Standardised models

Developing the SoS approach further in transportation becomes more relevant when generic methods that are transferable to different actors of the domain can be developed. Today, each operator develops his or her own model with state of the art knowledge for a specific infrastructure (road traffic flow model, train models, air traffic models). To be relevant in SoS, these models should be representative enough for subsystem dynamics while being simple and generic enough to integrate them in larger multi-modal strategies.

3.4.3 Collaborative information systems

The challenge of making transportation systems more collaborative while providing managerial and operational independence needs to be suitably addressed by SoS engineering methods. Today, transportation network operators are often competing with each other in the sense that they want either to avoid congestions on their respective network, e.g. crowded road networks in metropolitan areas or increase the number of users, e.g. rail operators want to have as much clients as the trains can handle. Sometimes, conflicting decisions may be taken due to the lack of knowledge of other operator decisions. To make transportation operators collaborate, incentives should be provided so that these operators prefer cooperation over competition to make better use of the infrastructure they are responsible for. Transportation systems being inherently distributed and interconnected, collaboration is required to reach global operational efficiency while avoiding conflicting decisions.

3.5 Technologies and capabilities

Figure 9 shows the technologies and capabilities layer of the roadmap, including sub-layers for hardware, software, standards and protocols and cloud services. These technologies are necessary to apply SoS approaches in the multimodal traffic control domain.

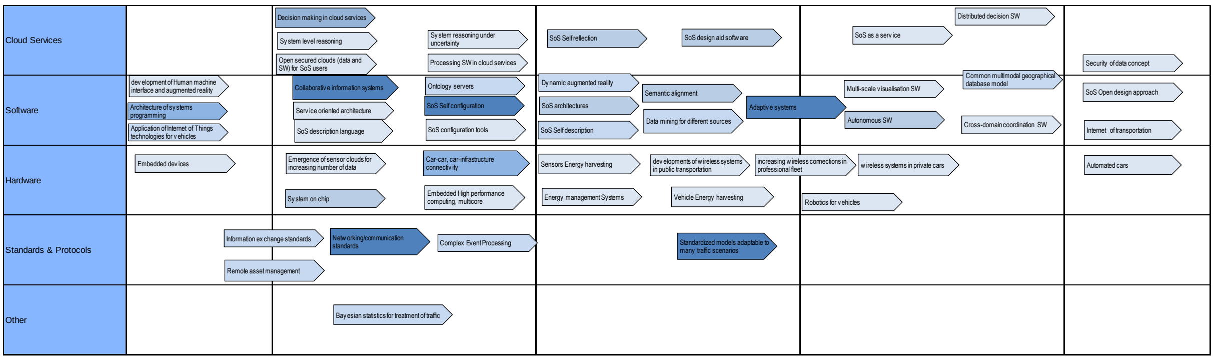

Figure 9 - Technologies and capabilities

The ten most important technologies are:

- Networking and communication standards
- Collaborative information systems
- Self-configuration
- Car-car, car-infrastructure connectivity
- Decision making in cloud services
- Architecture of systems
- Semantic alignment
- Dynamic augmented reality
- Common multi-modal geographical database model
- Information exchange standards

The most relevant items are distributed as follows.

Sub-layer	Ranking
Software	5
Standards and protocols	4
Cloud services	1
Hardware	0

This reflects the importance of software, standards and protocols in the development of SoS in general. Cloud services are not ranked very high. This might be because cloud services are only seen as a potential option among others that may come in the future. Interestingly, however in line with trends in many other technology-intensive domains, hardware is not seen as technological priority. This is due to the fact that there are plenty of hardware solutions available in the transportation domain today. The challenge is thus not to develop new hardware but being able to use existing hardware technologies in SoS transportation systems.

From this ranking, the following analysis can be done:

- The idea for **self-configured, emergent, interconnected and collaborative systems** is seen as the top priority for the development of SoS.

- **Car-car, car-infrastructure connectivity** is mentioned again. **Decision making, cloud services, system architecture and semantic alignment** are enabling technologies and methodologies needed for the development of SoS.

- **Dynamic augmented reality** and **common multi-modal geographical database models** are very specific for the transportation industry and seem less important in other industry branches.

The five most relevant technologies are detailed below.

3.5.1 Networking and communication standards

This is connected to the need for "standard system interfaces" mentioned above. The interconnection of subsystems relies on communication protocols. If standard networking protocols are available today (like TCP-IP), some legacy systems may be out of these standards and require some adaptation or going through an intermediary middleware. Besides networking protocols, communication protocols and data exchange languages may not be compatible. For different operators corresponding protocol translations may be necessary as it is not the public opinion today that all operators may comply with a global standard that would have to be defined first.

3.5.2 Collaborative information systems

Collaborative information systems are becoming increasingly important in the field of surveillance and control, mostly due to the dynamic nature of the exchanged data. Though collaboration among transportation operators is seen as the best way to better operate existing infrastructure without building new ones, there is no clear understanding of how such collaboration should be implemented and governed. Collaborative control is an integral part of this challenge, where each subsystem is modelled differently with different scales, accuracy and semantics.

3.5.3 Self-configuration

Self-configuration is related to the need for "auto-maintenance" discussed in the section above. SoS transportation systems should be able to configure themselves automatically, at least partially. The classic way of configuration by human intervention will reach its boundaries as systems become larger and more complex. Moreover, it is worth noting that self-configuration is a necessary capability in order for SoS to develop in a truly evolutionary way. If configuration of systems were only to be done by humans, true evolution would be impeded or at least disturbed.

3.5.4 Car-car, car-infrastructure connectivity

This is related to the "vehicle-to-infrastructure interactivity" need. Car-to-car (C2C) and car-to-infrastructure (C2I) are both perceived as a technology and a need because, if the technologies are mature enough, these systems are not yet spread in consumer vehicles. The spread of C2C, C2I and C2X technologies depends on their adaption by the automotive industry, which is obligatory today.

3.5.5 Decision making in cloud services

Today, decision making in transportation is done in control centres that are independent and rather self-contained, with a clearly defined scope of action. The evolution of transportation management towards SoS requires collaborative decision making and broadcasting of the supporting data. Cloud services are seen as a potential tool to implement collaborative decision making so that control centres can exchange information more easily and make decisions more globally.

3.6 Enablers

Certain enablers for SoS in multi-modal traffic control have been identified in the roadmapping process and are depicted in Figure . They are non-technical and include the sublayers: “skills and knowledge”, “business models and concepts” and “infrastructures and architectures”.

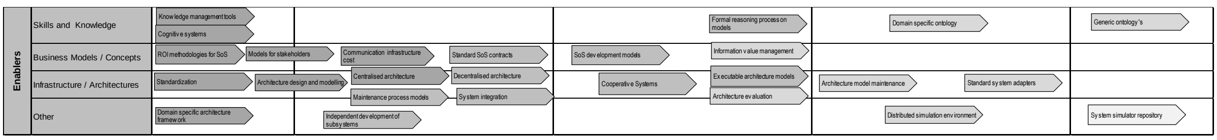

Figure 10 – Enablers

The darker shades indicate those items that were identified by roadmapping workshop participants as being of higher significance. The ten most important enablers are:

- Knowledge management tools
- ROI methodologies for SoS
- Architecture design and modelling
- Standardisation
- Models for stakeholders
- Cognitive systems
- System integration
- Standard SoS contracts
- Decentralised architecture
- Cooperative Systems

The most relevant items are distributed as follows.

Sub-layer	Ranking
Infrastructures and architectures	7
Business models and concepts	2
Skills and knowledge	1

Not unexpectedly, “Infrastructures and architectures” is the sub-layer of highest importance since ”infrastructures and architectures” are largely missing for SoS approaches in the multi-modal traffic control domain. “Business models and concepts” is not very present in the transportation industry as it is mainly operated by public bodies or affiliated companies.

The five most relevant enablers are detailed below.

3.6.1 Knowledge management tools

Knowledge management is a way to capture, maintain, and exchange knowledge across different operators with different traditions related to the infrastructure they were operating before SoS integration. Knowledge management tools also enable to keep track of the SoS evolution without having to rely on the few persons that may have a clear understanding of a transportation SoS at a given time.

3.6.2 ROI methodologies for SoS

ROI methodologies for SoS are expected to provide an incentive by showing the benefit (monetary or non-monetary) provided by SoS in transportation. It should be noted that classic ROI methods cannot be used directly in transportation as many of the operators are public bodies that are not ruled by profits. Safety and traveller satisfaction should be part of the ROI methodologies.

3.6.3 Architecture design and modelling

Some of the SoS implementation issues in transportation are depending on architecture design and modelling as there are none available today to build SoS. Modelling is at the core of the architecture design that should be developed.

3.6.4 Standardisation

Standardisation is a necessary step to develop SoS and make transportation operators confident in their involvement in SoS. Standardisation should at least take into account telecommunication, modelling, control and architecture. There should be a first common ground for the development of SoS in transportation before increasing in complexity for standardisation is a long process. Standardisation can and should be shared between several industrial domains.

3.6.5 Models for stakeholders

Operators will have to share models of their own infrastructure and use models from other stakeholders. A model for SoS stakeholders does not necessarily need to be as accurate as physical models that provide deep understanding of an infrastructure. Its goal is to allow for SoS applications and thus they should only model the shared features. Different API (Application Programming Interface) levels can be developed depending on the required accuracy of the different stakeholders.

4. Recommendations

Transportation networks are key assets for economic development. Multi-modal transportation systems naturally give rise to Systems of Systems (SoS). We have analysed the opportunities and challenges in this field to make SoS approaches work in the domain of multi-modal traffic control. We propose the following set of recommendations based on interviews with experts, state of the art analyses and roadmap development.

The administrative organisation of transportation worldwide has led to a state where all the modes of transportation are operated by a patchwork of operators (different operators for different types of roads or locations, different operators for different modes of transportations such as roads, tramway, subway, train or air). These operators have different legacy systems and standards. They have different management habits and are often competing with each other to avoid congestions on their respective network or to have more customers. These transportation systems are rather self-contained, with little information shared between them, both for technical reasons and lack of motivation to share information. Because of their inherent interconnection, transportation systems are expected to be better operated if managed as a whole though there is no initiative in this direction yet, due to the many technological and organisational challenges that have to be solved in this field. Because of the lack of collaboration between each transportation mode, several deadlocks such as management of congestions and continuity of traveller information have been reached.

We have defined certain generic enablers that could help SoS to emerge as an engineering practice. These enablers are discussed in the following.

Identify sectors where SoS can bring value and focus on them. The risk with emerging technologies and engineering practices such as SoSE is to develop them in too many sectors. Though the four Road2SoS domains are good candidates, there should be a deeper analysis to establish the priorities between subtopics for each sector.

Involve public authorities. As new business models are emerging, public authorities should be involved for creating value in this activity. Smart city demonstrators will provide a possibility for public authorities to assess, the economic benefit of SoS on real implementations.

Reference documentation with clear terminology and concrete examples. With SoS being an emerging an increasingly relevant topic, terminologies are sometimes misused. Moreover, reference textbooks are lacking to spread SoSE as an engineering practice. The description of concrete examples may serve more general purposes and help newcomers to get more insight about how to deal with SoS along their life-cycles.

R&D in sensor technologies:

- **Continue to support research and development activities in sensors, embedded systems and telecommunications.** Technologies like sensor networks and autonomous system are enabling technologies for SoS. If substantial efforts are done on the technological side, the application to real life projects will still be necessary.

- **Smart sensors.** Sensing plays a role for many SoS. Substantial innovationoccurred in this field in the last decade and the amount of sensors is growing vigorously. Smart sensors are extensively using wireless technologies, so power management is needed to fuel the development of large SoS such as smart cities. These sensors should provide enough features and be robust enough to avoid heavy maintenance costs given the large amount of smart sensors that will be deployed during the upcoming years.

R&D in software technologies:

- **Stimulate the emergence of professional clouds.** It seems difficult to deploy large scale SoS that concern strategic assets by using the current offer of cloud services on the market. Each organisation may implement its own cloud but it would require technical and financial efforts and lead to antiquated architecture not necessary related to cloud computing. Large integrators should lead the development and spreading of professional clouds tailored to their industry.

- **New research and development activities should be launched in the field of autonomous software.** The management of changes, device ortelecommunication failures and legal changes is not sufficiently taken into account to develop SoS in strategic sectors. Still in the software industry, distributed architectures should be proposed for SoS.

- **Real-time systems, real-time communication.** One of the potential benefits of SoS is the possibility to monitor and control in real-time large complex systems. Real-time operation is present in most industrial domains, including transportation networks. Nonetheless, real-time implementations like control loops, most of the time are specifically developed for each subsystem. There is a need to have standardised interfaces to be able to interconnect real-time control and communication systems in order to manage the SoS as a whole at the upper level. This would be a tedious task given the strategic operation of real-time systems in each sub-system.

Standardisation:

- **Standardisation is one of the most important aspects to be developed.** The development of standard terminology and standard system interfaces are necessary steps to further develop SoS in the industry. This standardisation process can be done partially in the industry and partially by authorities such as the European Union. Standardisation is a long and tedious process but it is necessary to make big industrial companies commit to SoS technologies. The development of standards will naturally lead to multiple implementations that will stimulate the community in systems engineering and specific sectors where SoS is naturally arising.

Demonstration. In public applications like smart cities and smart transportations, there is a need to build realistic demonstrators. This task should be led by public authorities, as they manage these assets, with or without the help of the European Union. Smart Santander and the city of Nice are good examples of such demonstrators. Contrary to other industrial domains, only public authorities can initiate such demonstrators. These demonstrators will provide a way for public authorities to assess the economic benefit of SoS on real implementations and analyse the risk-benefit ratio in terms specific to public authorities such as level of services provided to users, security or monetised benefits for transportations.

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This deliverable is based on inputs from Road2SoS deliverables D1.1 (Report on data collection and analysis of relevant European and international RTD projects/ initiatives), D1.2 (Interviews summary report), D2.2 (Market survey summary report) and D2.3 (Socio-economic summary report), which built the basis for the "pre-populated" roadmap (see 2.2 Phase 1: Data collection and analysis). References can be found in the respective deliverables.

To build the roadmaps, various Road2SoS workshops have been held, namely the "Road2SoS Expert Panel" May 22nd 2012 in Karlsruhe, "Road2SoS-Roadmapping Workshops" September 2012 – October 2012 in Paris, Brussels, Madrid. More information on these workshops can be found in the deliverables D1.3 (Expert Panel meeting minutes) and D3.2 (Minutes of the Roadmapping Workshops).

To mature and validate the roadmaps, 12 "case studies in industry" and 8 "dissemination workshops" have been conducted. Detailed information can be found in the deliverables D4.1 (Case Studies) and D6.2 (Dissemination Workshops Report).

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