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Abstract :

This document describes the state-of-the-art in the automotive, rail, aerospace, maritime and logistics sectors considering implementation of Cyber Physical Systems of Systems. In all areas there is increased connectivity of systems and use of ICT allowing improved capability, capacity, performance and safety. Additionally, in all areas there is a move towards more autonomy. Many of the challenges within Europe arise from the fragmented infrastructure that has evolved requiring the need for cross border, cross-organisation, co-operation. There is thus a natural need for Systems of Systems approaches in order to meet the pan-European transport flow of goods and people presenting technical, political, standardization and legislative challenges. Here the European Commission has a significant role to play.

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Table of Contents

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement No 611115.

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 611115.

List of Figures

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Acronyms and Definitions

Acronym	Defined as
ACARE	Advisory Council for Aviation Research and Innovation in Europe
ADAC	Allgemeiner Deutscher Automobil-Club
ADS-B	Automatic Dependent Surveillance - Broadcast
ANPR	Automatic Number Plate Recognition
ANWB	Algemene Nederlandse Wielrijdersbond
ASTRAEA	Autonomous Systems Technology Related Airborne Evaluation and Assessment
ATM	Air Traffic Management
ATOC	Association of Train Operating Companies
ATP	Automatic Train Protection system
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
CISE	Common Information Sharing Environment
CO_2	Carbon Dioxide
CP	Control Period
CPS	Cyber Physical Systems
CPSoS	Cyber Physical Systems of Systems
C2C	Car to Car
C2I	Car to Infrastructure
C2X	Car to Anything
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V
EASA	European Aviation Safety Agency
EEA	European Economic Area
EMSA	European Maritime Safety Agency
EPA	Environmental Protection Agency
ERA	European Railway Agency
ERRAC	European Rail Research Advisory Council
ERTICO	European Road Transport Telematics Implementation Coordination Organsation
ERTMS	European Railway Traffic Management System
ERTRAC	European Road Transport Research Advisory Council
ETCS	European Train Control System
ETP	European Technology Platform
EU	European Union
FuTRO	Future Traffic Regulation and Optimisation programme
FAA	Federal Aviation Authority
GDP	Gross Domestic Product
GEO	Group on Earth Observations
GEOSS	Group on Earth Observations Systems of Systems
GPS	Global Positioning System
GSM	Global System for Mobile Communications (originally Groupe Spécial Mobile)
GSM-R	Global System for Mobile Communications – Railway
HGV	Heavy Goods Vehicle
ICT	Information and Communication Technologies
IED	Improvised Explosive Device

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IMO	International Maritime Association
ISIS	Lockheed Martin UAV Platform
ITS	Intelligent Traffic Systems
I4D	Latitude, Longitude, Altitude + Time Information
MAC	Media Access Control
MIF	Maritime Industries Forum
MoD	Ministry of Defence
MOU	Memorandum of Understanding
NOx	Nitrous Oxide
OEM	Original Equipment Manufacturer
PI	Physical Internet
PM	Particulate Matter
PM10	Particles 10 micrometers in diameter (resulting in major risk of lung cancer)
PTDS	Lockheed Martin UAV platform
RFID	Radio Frequency Identification
RTA	Required Time to Arrival
SESAR	Single European Sky ATM Research programme
SERA	Single European Railway Area
SMART	Sustainable Modelling and Accessibility Research and Transformation
SOx	Sulphur Dioxide
TEN	Trans European Transport Network
TP	Technology Platform
TRKC	Transport Research Knowledge Centre
UAS	Unmanned Air System
UAV	Unmanned Aerial Vehicle
US	United States (of America)
VOC	Volatile Organic Compounds
VSAT	Very Small Aperture Terminal
VSL	Variable Speed Limit
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
WAVE	Wireless Access in Vehicular Environments

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1 Executive Summary

The objective of this deliverable is to present and analyse the current state-of-the-art in Cyber Physical Systems of Systems within the automotive, rail, aerospace, marine and logistics domains. The report is a result of consultation with around 100 practitioners around the world from key companies and organisations identifying the key issues and needs. In producing the report it was clear that Cyber Physical Systems of Systems was a major topic in the transport sector and numerous examples of applications could be found. In the report key examples across Europe and beyond are presented along with commercial drivers. Drivers include demands for 24/7 operation, higher availability, improved safety, reduction in cost, reduction in emissions, pressure from competition on the world stage and government regulations. The increased integration of systems using ICT is seen as an opportunity to optimise operation providing potential monetary savings, improve capacity, improve safety and reduce emissions. The use of ICT is seen as critical in achieving industry targets and visions set out for the future for an integrated transport system.

Across domains there are differences in the views in the readiness levels for development of CPSoS. In the aerospace sector the view is that engineers already have the capability to think and develop systems in a Systems of Systems way. In the automotive sector planned implementations of Systems of Systems technologies are currently underway but much of the concentration is on technical innovation at the hardware level and cost reduction rather than the issues of systems operation. Although in the rail sector Systems of Systems are the norm, engineers are not thought to think in a Systems of Systems way presently. In the marine sector Systems of Systems have evolved over the years but the concept of Systems of Systems is not a known term. In the area of logistics Systems of Systems is a very well-known concept.

A key issue that was highlighted across a number of sectors was the need to provide convincing evidence that a new Systems of Systems approach will deliver the benefits expected. This is needed for investment and to convince companies to engage in Systems of System activities. Proving that a Systems of Systems solution is "better" is challenging when the modelling of the systems is not possible and so the return on investment is difficult to justify. In many cases industry is funding Systems of Systems research activities because it is thought to be the "right thing to do". Other challenges for industry are in coordinating implementation, rolling out a Systems of Systems, Validation & Verification, and operating and maintaining a Systems of Systems.

A number of barriers to implementation were identified. These included difficulty/cost to implement**,** difficulty to justify investment**,** and the problems of decision making across entities/borders. User/public acceptance and trust is also a key issue and it is noted that attitudes to security and privacy differ in EU member states. The top issues highlighted were:

Support for Development

- Requirements engineering, model-based systems engineering and validation and verification that support "systems that are never finished" and legacy integration
- Modelling (interdisciplinary) and large-scale simulation of heterogeneous Systems of Systems
    - Multi-objective optimisation of Systems of Systems
    - Proving (economic) benefits of increased integration/system-wide control
    - Giving confidence in safety
    - Identifying any emergent behaviors

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Autonomy and Increased Interconnectivity

- Autonomous decision making, system-wide control and coordination
- Socio technical issues of humans interacting with "autonomous" Systems of Systems (noting that not everything will be autonomous)
- Interoperability between systems and development of data exchange standards
- Trust – which becomes more of an issue as systems become more autonomous and highly interconnected (considering security, privacy, and designing to fail safe or operate in presence of security breaches)

Resilience and Monitoring (Situational Awareness)

- Condition monitoring, fault detection and reconfiguration strategies to provide resilience
- Low cost (self-powered) sensor technologies to provide data
- Management of data deluge via large-scale online data analysis to extract information and visualization tools to provide a view of the "real-world in real-time"

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2 Introduction

2.1 Purpose and Intent

In order to gain an overview of the state-of-the-art in Cyber Physical Systems of Systems in the automotive, aerospace, rail, marine and logistics sectors a comprehensive data gathering exercise was performed.

2.2 Data Collection

Fig. 1 – Data Gathering

Data has been gathered by a number of means as shown in Fig. 1. A key aim was to engage strongly with industry to understand the industry pull for Cyber Physical Systems of Systems [1] and also the state-of-the-art in the area. Many industry sectors already build and operate Cyber Physical Systems of Systems and so there is considerable practical knowledge of the challenges that need addressing. To this end around 100 industry practitioners from large companies and SMEs have been contacted.

Airbus France and UK	Emirates Airlines	Martek Marine	SESAR – Air Traffic Control Org
Altran	ERRAC	Mitre Corp.	Sillitto Enterprises
BAe Systems	ESA	NASA	Thales France, UK and Australia
Boeing	Esterel	Network Rail	THHINK Japan Ltd
Car2Car Consortium	FastWave Austrialia	Peugeot (PSA)	Toyota
Cassidian	FMV	Pratt and Whitney	UPS
CEA-LETI	GE	Rail Infrastructure Technology Ltd.	Vector
Cummins	IBM	Renault	Volvo Trucks
DHL	Jaguar Land Rover	Rolls-Royce Aerospace and Marine	Wartsila
EADS	Lockheed Martin	Safran	Waterborne Technology Platform

Fig. 2 - Examples of Companies/Organisations Who Have Contributed to this Report

There was a high response rate from industry indicating that there was real interest in the topic and the author thanks the many people who have contributed to this report. Questionnaires have been collected from over 50 companies and telephone and face-to-face interviews have been performed with 12 key actors. Input from academics who have a strong relationship with industry has also been collected. This gives a view

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of the longer term research issues that need addressing. Already a cluster of EU projects is addressing Systems of Systems issues and input from these projects has been gathered. A questionnaire was also placed on the CPSoS website [2] and information has been gathered from the Internet to get as broad a picture as possible of activities going on around the world. Finally, the input and feedback from the eleven cross-sectorial members of the Working Group on Transport and Logistics has also been added.

2.3 Transport Infrastructure Innovation at the European Level

The European Commission supports a number of transport Technology Platforms that includes ERRAC[3], ERTRAC[4], ACARE[5] and WATERBORNE[6]. In 2001 the Commission issued a White Paper [7] setting a 10 year agenda for the European transport policy which was updated in the mid-term review of 2006 [8]. This highlighted that transport is a complex Systems of Systems that depend on multiple factors, including the pattern of human settlements, the organisation of production and the availability of infrastructure. Transport is an essential component of the European economy accounting for about 7 % of GDP and for over 5 % of total employment in the EU. Although the European transport system compares well in terms of efficiency and effectiveness with most advanced regions of the world, it is still not on a sustainable path. The open markets in Europe have led to more efficiency and lower costs which can be particularly seen in air transport, however, in other transportation areas there is a need to harmonise differences in taxation and subsidies. To coordinate the planning of infrastructure projects across Europe the Trans-European transport networks (TEN-T) policy has provided many benefits with an investment program of EUR 400 billion.

The TEN-T Guidelines [9] are the European Community’s instrument for policy definition and network planning. Adopted in 1996 and amended in 2004, the guidelines include two planning layers: a comprehensive network layer including outline plans for rail, road, inland waterway, combined transport, airport and port networks and a second layer of 30 priority projects. The TENs have already gone a long way in linking EU markets and peoples. Progress has been achieved in reducing air pollution and road accidents. Air quality in European cities has significantly improved through the application of stricter Euro emission standards addressing fine particles (PM10) which are particularly damaging for human health. The guidelines are also addressing expansion of transport infrastructure which result in habitat loss and landscape fragmentation.

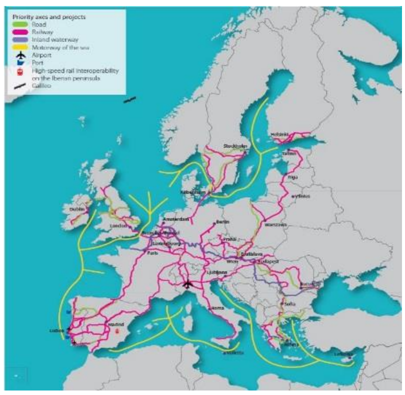

Fig. 3 - Cross-Modal Transport Infrastructure Innovation Roadmap [10] and Key Routes Identified [11]

Key transportation routes have been identified across Europe covering road, rail and marine transport [10, 11] (See Fig. 3). Sustainability is a key issue and there has been a dramatic increase in both freight (35%) and passenger transport (20%) between 1995 and 2006. Along with this increase in traffic there has been an increase in emissions and within Europe transport accounts for a quarter of all emissions. The expectation is that traffic will increase

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further in all sectors and the infrastructure needs to support continuing increase in demand. Linked with this is a drive to improve safety. There is an objective in the 2001 White Paper to halve casualties with respect to 2001 levels in road transport. Although not achieved in practice significant progress has been made. With still over 39 000 deaths in the EU in 2008, transport by road is still costly in terms of human lives. In the maritime sector, marine pollution and maritime accidents were considerably reduced and the EU has established one of the most advanced regulatory frameworks for safety and for pollution prevention (most recently with the third maritime safety package). In aviation, a comprehensive set of common, uniform and mandatory legislation has been adopted covering all the key elements affecting safety (aircraft, maintenance, airports, air traffic management systems, etc.). Safety agencies have been set up for aviation (EASA), maritime affairs (EMSA) and rail transport (ERA).

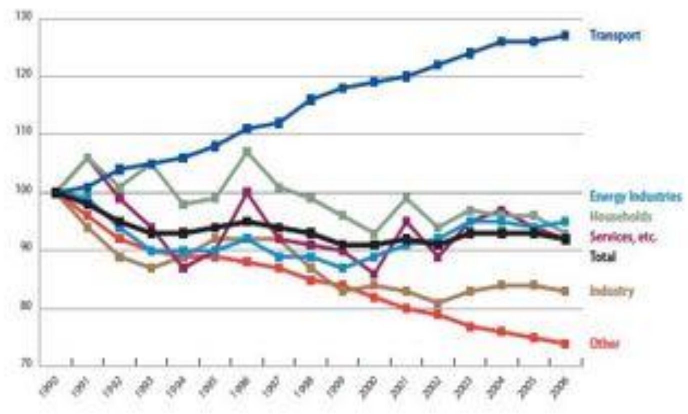

Fig. 4 - Cross-Modal Transport Infrastructure Innovation Roadmap [10] and Key Routes Identified [11]

The growth of transport activity raises concerns for its environmental sustainability. According to data from the European Environment Agency [11], transport accounted for close to a quarter (23.8%) of total greenhouse gas emissions and slightly more than a quarter (27.9%) of total CO_2 emissions in the EU-27 in 2006. No other sector has the growth rate of greenhouse gas emissions as high as in transport (See Fig. 4). As the transport sector relies on fossil fuels for 97% of its needs, the fight against climate change in this sector is also synergistic with energy security of supply. Europe's roads have become safer in recent years: the number of road accidents involving personal injury fell by some 12% between 1991 and 2007. More importantly, the number of road fatalities dropped by more than 44% over the same period.

Freight transport follows trade activity and in recent years this has grown more than GDP. Passenger transport, excepting aviation, has undergone a less dramatic rise. These trends can only be sustained, however, if transport radically improves its energy efficiency and reduces its greenhouse gas emissions.

3 STATE-OF-THE-ART IN THE AUTOMOTIVE SECTOR

Traffic management represents a highly complex System of Systems coming under increasing demands for additional capacity, greater safety and lower costs while meeting strict environmental regulations. At the same time the global car fleet is predicted to double from currently 800 million vehicles to over 1.6 billion vehicles by 2030. Without innovative thinking, integration of information and flow control systems severe congestion will be a major concern for mobility with long commutes and dramatic implications for road haulage of freight leading to logistical problems of late deliveries within highly complex scheduled systems. Already embedded intelligence, mobile phone, car-to-car and car-to-infrastructure communication are offering the opportunity for increased awareness, more efficient mobility and automated driver safety systems

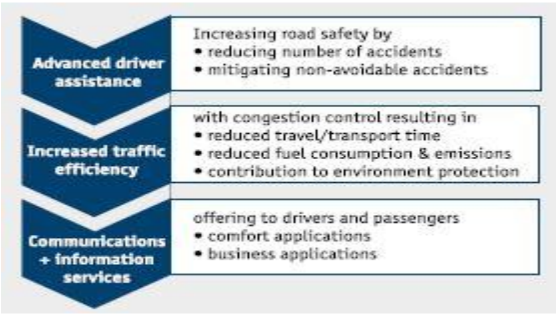

Fig. 5 - Intelligent Transport Systems [12]

In the automotive sector Intelligent Transport Systems (ITS) [13] are being developed to provide innovative services relating to different modes of transport and traffic management (See Fig. 5). These will enable various users to be better informed and make safer, more coordinated, and 'smarter' use of transport networks. The aims are to increase journey efficiency, reduce congestion, improve road safety and reduce air pollution. An EU Directive (2010/40/EU) was issued on the 7 July 2010 [14] defining the framework for deployment of intelligent transport systems in the field of road transport. Here ITS are defined as “systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport”. Air pollution and congestion are issues in areas of high population density and integrated approaches exploiting combinations of walking, bicycle, buses and trains are advocated.

In the US similar ITS activities are being proposed, however, here a key driver is homeland security. There is a desire to provide surveillance of roadways and also a means for mass evacuation of people in urban areas as a result of natural disaster or threat. Among the technologies being explored under ITS are car navigation, traffic signal control systems, vehicle message signs, automatic number plate recognition and speed cameras. Opportunities to link with parking guidance and with weather systems are also being considered. For congestion avoidance advanced modelling techniques are being explored against historical baselines to predict and redirect traffic.

Another trend which is enabling ITS is a fundamental change in vehicle control systems. A typical vehicle in the early 2000s had between 20 and 100 individual networked microcontrollers using non real-time operating systems. The current trend is towards fewer, more capable microprocessor modules with hardware memory management and Real Time Operating Systems. This increased capability allows potential for more sophisticated software applications to be implemented based on model-based control and artificial intelligence.

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Already a lot of work is being performed on "floating car" or "probe" data collection for obtaining travel time and speed data for vehicles traveling along streets and motorways [13]. This can be done from triangulation from mobile phones (which periodically transmit their presence to the mobile phone network), vehicle re-identification using sets of detectors mounted along the road to track a unique vehicle serial number (provided by Bluetooth MAC addresses or RFID serial numbers, e.g. from toll tags) as it travels down a road to give travel times and speed, or from in-vehicle GPS (satellite navigation) systems that have two-way communication with a traffic data provider. A key advantage of floating car data technology is that it less expensive than sensors or cameras, it provides greater coverage, is faster to set up and maintain and works in all weather conditions including heavy rain.

Cameras are a common sight on today’s roads and have been used for many years for traffic enforcement to detect and identify vehicles disobeying a speed limit (normally combined with radar detection), detect vehicles that cross red traffic lights, identify vehicles traveling in bus lanes, vehicles crossing railways, crossing double white lines or incorrectly utilising high occupancy vehicle lanes (reserved for car pooling). Number plate recognition systems can be used to automatically issue tickets to offenders. However, more recently cameras are also being used for traffic flow measurement and automatic incident detection.

Cameras are considered to be "non-intrusive" as there is no need to install components into the road surface but they do require some configuration, e.g. input of known measurements such as the distance between lane or the height of the camera above the roadway. The typical outputs from a video detection system are lane-by-lane vehicle speeds, counts, and lane occupancy readings. Some systems provide additional outputs including gap, headway, stopped-vehicle detection, and wrong-way vehicle alarms. These systems have been successfully combined with variable speed limits that change with road congestion and other factors such as weather conditions. One example is the M25 Motorway that circumnavigates London. On the most heavily travelled 14-mile (23 km) section (junction 10 to 16) of the M25 variable speed limits combined with automated enforcement have been in force since 1995 [13]. The results indicated savings in journey times, smoother-flowing traffic, and a fall in the number of accidents, so the implementation was made permanent in 1997.

Inside of the car emergency vehicle notification systems (eCall) [15] are becoming more common driven by EU regulation and also insurance companies who are interested in driver behaviour tracking functionalities. In an emergency the vehicle occupants can manually eCall or the vehicle can automatically call via activation of in-vehicle sensors after an accident. The eCall device establishes an emergency call carrying both voice and data directly to the nearest emergency point. The voice call enables the vehicle occupant to communicate with the eCall operator. At the same time, data is sent containing information about the incident, including time, precise location, the direction the vehicle was traveling, and vehicle identification. The pan-European eCall system aims to be operative for all new type-approved vehicles as a standard option. Depending on the manufacturer of the eCall system, it could be mobile phone based (Bluetooth connection to an in-vehicle interface), an integrated eCall device, or a functionality of a broader system like navigation, telematics device, or tolling device. Going one stage further the EC funded project SafeTRIP [16] is developing an open ITS system that will improve road safety and provide resilient communication through the use of S-band satellite communication. This would allow greater coverage of the Emergency Call Service within the EU.

Work on the eCall standard has been ongoing for a number of years and currently it is targeted for implementation in 2017. This has been slowed by lack of support for it from some member states and currently other technologies are overtaking it combining the same functionality with congestion and traffic management information. In general telematics in the automotive sector, even for fleet and insurance operations, has a low uptake because of the cost of retrofitting it to vehicles which is far higher than for factory installed equipment. Customers are not currently asking for connectivity. The younger generation who are more interested in connectivity tend to live in big cities and have children later in life. The car sales to younger people are thus decreasing. Presently the interest is in providing in-car WiFi so that passengers can connect to services such as Apple CarPlay [17] and those being

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provided by the Android Open Automotive Alliance [18]. Going one step further Apple is producing wearable computing that connects with cars. The future could well be a “Google Dashboard” and Google are very interested in the automotive industry as collecting information from cars gives them free mapping information.

With the rise of communication technologies there is interest in “communication cooperation”: car-to-car, car-to-infrastructure, and infrastructure-to-car. This can be used for warning drivers of upcoming hazards. An example of this is in Japan where installed sensors on highways are used to notify motorists that a car is stalled ahead. Transmission of car data to infrastructure opens up the opportunities to centrally fuse and process data to detect events such as rain (wiper activity), congestion (frequent braking activities) and ice detection (from ABS activations). Transmission from infrastructure to car can be used to provide driver recommendations to avoid traffic or warn of hazards increasing road safety. The European Commission defines communication cooperation as

> "Road operators, infrastructure, vehicles, their drivers and other road users will cooperate to deliver the most efficient, safe, secure and comfortable journey. The vehicle-vehicle and vehicle-infrastructure co-operative systems will contribute to these objectives beyond the improvements achievable with stand-alone systems."

A Network of National ITS Associations was officially launched on 7 October 2004 in London [19]. This Network is a grouping of national ITS interests formed in order to ensure that ITS knowledge and information is transmitted to all actors at the local and national level. The Network currently consists of 27 member organisations. The Network Secretariat is at ERTICO-ITS Europe and is a multi-sector, public/private partnership pursuing the development and deployment of Intelligent Transport Systems and Services. It connects public authorities, industry players, infrastructure operators, users, national ITS associations and other organisations together and works to bring “Intelligence into Mobility”. The ERTICO work programme [20] focuses on initiatives to improve transport safety, security and network efficiency whilst taking into account measures to reduce environmental impact. The vision is of a future transport system working towards zero accidents, zero delays with fully informed people, where services are affordable and seamless, the environment is protected, privacy is respected and security is provided.

In the United States, a similar activity is being pursued but here each state has an Intelligent Transportation Systems chapter that holds a yearly conference to promote and showcase ITS technologies and ideas. Representatives from each Department of Transportation (state, cities, towns, and counties) within the state attend this conference. At a worldwide level the ITS World Congress [21] is an annual event to promote and showcase ITS technologies organised by ERTICO – ITS Europe, ITS America and ITS Japan. This event attracts over 8,000 people.

MIRA in the UK operates Europe’s most advanced ITS test track, innovITS-Advance [22] dedicated to research and development of intelligent transportation systems (ITS). This utilises modern communication technologies, private GSM and cellular networks, fully configurable wireless networks and state-of-the-art vehicle-to-vehicle communications based on the draft 802.11p WAVE standard [23]. Work is investigating transport information, intelligent vehicles, and intelligent infrastructure, looking at a range of topics including OEM/aftermarket applications for congestion, hazards, tracking and fleet management, data management and modelling, real-time data sharing, integrated in-vehicle multimedia applications, aftermarket and integrated HMI solutions, secure communication networks, pedestrian safety, vehicle positioning and sensor systems, co-operative control systems and autonomous systems.

3.1 ERTRAC Strategic Research Agenda for Road Transport

In Europe the ERTRAC Strategic Research Agenda [24] covers mobility, transport and infrastructure, safety and security, environment, energy and resources, design and production. It highlights a number of key research topics including traffic management, integration of vehicle and infrastructure systems, traffic

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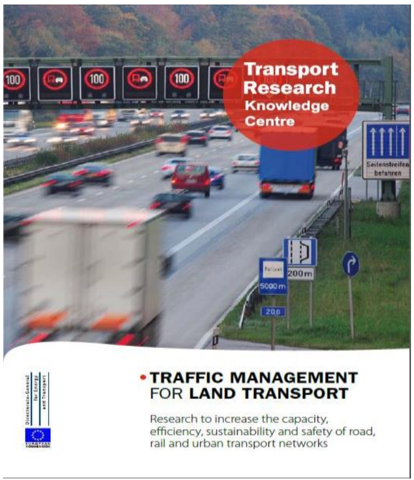
management using ITS, data collection and processing, business models, optimisation of road space to ensure that vehicles (particularly HGVs) adopt routing systems that minimise adverse impacts, systems for segregating traffic with dedicated infrastructure and prioritised traffic management and methods to assist the booking of optimised slots for freight vehicles. The White Paper produced by ERTRAC [25] highlights a number of ongoing projects around Europe and also highlights the key role that exploitation of new ICT functionality will have on the future of ITS. In order to fulfil the aspirations of the Transport White Paper there is a need to coordinate the development of Systems of Systems for surface transport at an EU level with strong political commitment.

3.2 Traffic Flow and Integration with Infrastructure



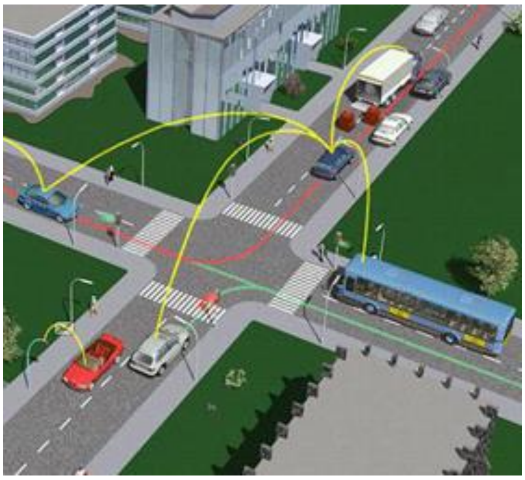


Fig. 6 - Policy Brochure on Traffic Management [9] and Intelligent Transport Systems [12]

The Transport Research Knowledge Centre (TRKC) consortium produced a Policy Brochure on “Traffic Management for Land Transport” [9] covering both road and rail on behalf of the European Commission’s Directorate-General for Energy and Transport (See Fig. 6). Although the use of railway signalling and traffic lights in cities have long been used for traffic management a key tenet of this brochure is the need for sophisticated integrated applications based on Intelligent Transport Systems. This is driven by realisation of the need to manage transport networks more effectively in order to maximise the use of existing infrastructure, provide a reliable service to the end user and increase safety, while reducing negative environmental effects. Urban and inter-urban traffic management research and applications are covered in this publication, including aspects such as network management, public transport priority, safety, punctuality and international traffic. Safety related to traffic management, e.g. speed management is also covered. The aim of traffic planning is to plan, monitor, control and influence traffic to maximise the effectiveness of the use of existing infrastructure, provide reliable and safe operation and address environmental goals. A further aim is to ensure fair allocation of infrastructure space (road space, rail slots, etc.) among competing users.

For road or rail transport the scope includes fleet management and timetabling, matching services and vehicles to meet demand and providing essential services while also fitting in with (or finding ways to improve) constraints caused by network capacity, driver shift patterns and technical aspects. For rail traffic the scope includes the bottom operational level of signalling systems and systems for train location; the intermediate level, consisting of the management of rail operations to enhance both the level of service to users and safety; and the higher strategic level, dealing with network access terms and capacity allocation. European policy has long promoted the use of rail in order to rebalance modal shift and encourage the use of this more environmentally friendly and safer transport mode. European rail policy has been developed in the last twenty years to open the competitive market for rail services, first in freight, then in passenger transport and to provide greater interoperability. This is expected to transfer more goods and passengers to rail, at a lower price and with better quality.

In the automotive domain the report highlights that research and deployment of ITS at the EU level is a key tool for traffic management and control to improve safety and user services and reduce the environmental impact of traffic, particularly at infrastructure bottlenecks. ITS applications for traffic management and control include rerouting, Variable Speed Limits (VSL) with automated enforcement, lane control, dynamic use of the hard shoulder on motorways or access control measures such as ramp metering, as well as specific measures for freight such as information on Heavy Goods Vehicle (HGV) parking and “stacking” of lorries in the case of disruption. Cooperative systems, whether vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I,) will play an increased role in traffic management and control in the future. To achieve this coordination across countries and regions, as well as with vehicle and equipment manufacturers, is required. Automatic Vehicle Identification and Location (AVI/AVL) and Automatic Number-plate Recognition (ANPR) is a prerequisite in order to ensure full use can be made of traffic management and enforcement strategies. Existing Automatic Incident Detection (AID) measures can be supplemented by linkage with “probe” (or “floating“) vehicle systems.

Traffic control is not a new concept and inductive loops that detect magnetic field changes have been placed in road networks for many years to perform ramp metering in order to manage traffic congestion [13]. The simplest detectors simply count the number of vehicles during a unit of time that pass over the loop, while more sophisticated sensors estimate the speed, length, and weight of vehicles and the distance between them. Loops can be placed in a single lane or across multiple lanes, and they work with very slow or stopped vehicles as well as vehicles moving at high-speed. However, more recently advances in telecommunications and information technology, coupled with state-of-the-art microchip, (RFID Radio Frequency Identification), and inexpensive intelligent beacon sensing technologies, have enhanced the technical capabilities opening up new opportunities for more global control of traffic. Vehicle and infrastructure-based networked systems using infrastructure sensors installed or injected into the road or attached to buildings, posts, and signs, can be placed permanently or during road maintenance to provide better monitoring of vehicles operating in critical zones.

3.3 INRIX

Founded in 2005 in Kirkland, Washington and with offices in the UK and Germany INRIX [26] combines data from 1 million miles of roads in North America and 1 million kilometres in 28 European countries to provide services in the car, online and on mobile devices for personal navigation, mapping, telematics and other location-based services. The company has 200 customers and industry partners worldwide including the Ford Motor Company, MapQuest, Microsoft, NAVIGON AG, TeleNav, I-95 Corridor Coalition, Tele Atlas, deCarta, TCS, Telmap, ANWB and ADAC.

Using the services drivers get information on the fastest routes and travel journey times that save time, money and reduce fuel consumption. The traffic data services include accurate real-time and predictive information, real-time incident and weather safety alerts, personalized traffic reports and route advice as well as historical traffic information. For fleet operators the company provides traffic congestion information which can be used to reduce fuel costs and optimise schedule planning. The company also provides information to media broadcasters on traffic congestion and estate agents on actual drive time to and from home and work based on traffic conditions.

3.4 CAR 2 CAR

The CAR 2 CAR Communication Consortium (C2C-CC) [12, 27] is a non-profit, industry driven organisation initiated by European vehicle manufacturers and supported by equipment suppliers, research organisations and other partners.

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement No 611115.

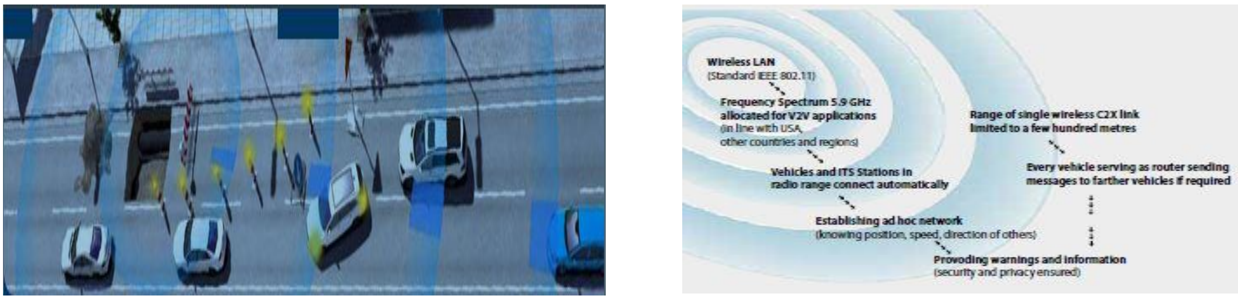


Fig. 7 - Car2car Communication consortium [27]

The C2C-CC (See Fig. 7) [27] is dedicated to the objective of further increasing road traffic safety and efficiency by means of cooperative Intelligent Transport Systems (C-ITS) with Vehicle-to-Vehicle Communication (V2V) supported by Vehicle-to-Infrastructure Communication (V2I). It supports the creation of European standards for communicating vehicles spanning all brands. As a key contributor the C2C-CC works in close cooperation with European and international standardisation organisations. In cooperation with infrastructure stakeholders the C2C-CC promotes the joint deployment of cooperative ITS. The European Commission forecasts a heavy increase of vehicle kilometres. To improve mobility on the roads it has adopted the ITS Action Plan [28] indicating 24 concrete measures in 6 priority areas, with target dates spanning from 2009 to 2014.

An iMobility Forum has been created and a number of R&D programs including large scale field operational tests are being performed. These are expected to contribute to the reduction of road fatalities, improve efficiency and reduce the environmental impact of road traffic in all areas including smart cities.

Fig. 8 - Partners in CAR 2 CAR

The C-ITS will provide new active safety measures to enhance the existing passive safety systems preventing or mitigating traffic accidents. As energy consumption and emissions need to be reduced and road traffic needs to exploit road capacities, new driving measures are required to support sustainability, e.g. green driving. The aim is to develop an open European standard for C-ITS with an associated validation process focusing on V2V Systems. This is to be supported with realistic deployment strategies and business models to speed up the market penetration and a roadmap for deployment of C-ITS (for V2V and V2I). A key aim is to also provide a validation route for these technologies. Specifications will be provided to the standardisation organisations, in particular ETSI TC ITS, in order to achieve common European standards for ITS. There is also an aim to push for the harmonisation of C2C Communication Standards world-wide such as 802.11.P and promote the allocation of a royalty free European wide frequency band for V2V Applications and joint deployment of C-ITS by all stakeholders.

The mandate M/453 of the European Commission [29] paved the way for the development of the minimum set of standards by the European standardisation organisations ETSI, TC, ITS, and CEN in 2012, ensuring the interoperability of C-ITS**.** Deployment will rely on these standards covering the whole communication chain, including security and privacy issues and starting with day-one applications based on selected common message sets. The project will demonstrate the C2C-System as proof of technical and commercial feasibility.

The standard is close to finalisation and a MOU exists between the major OEMs (See Fig. 8) who have a plan to put various vehicles on the roads in 2015 (although this may be delayed and it is more likely that manufacturers will deploy cars in 2016). Critically day-one applications will reveal if the standards are sufficient and whether further work is required. The initial applications are concentrated on providing all the information in the car rather than having centralised information being sent to the car so cars will also utilise sensing radar, laser scanners and image detection. Importantly cars must be able to understand each other and not be dependent on the OEM.

3.5 DRIVE C2X

The DRIVE C2X project [30] has 34 partners, 13 support partners and an 18.6 million Euro budget. It aims to provide the foundations for cooperative systems in Europe with the aims of safer, more economical and more ecological driving. The project will carry out field tests of systems leading on from the PRE-DRIVE C2X which implemented technologies in European test sites in Finland, France, Germany, Italy, Netherlands, Spain and Sweden. An aim is to raise public awareness, provide feedback for standard organizations and support for initiating public-private ventures. The work focuses on communication between vehicles (C2C) and the roadside and backend infrastructure system (C2I). Previous projects such as PReVENT [31], CVIS [32], SAFESPOT [33], COOPERS [34], and PRE-DRIVE C2X [35] have proven the feasibility of safety and traffic efficiency applications based on C2X communication. DRIVE C2X goes beyond the proof of concept and addresses large-scale field trials under real-world conditions at multiple national test sites across Europe.

The systems to be tested are built according to the common European architecture for cooperative driving systems defined by COMeSafety [36]. This guarantees compliance with the upcoming European ITS standards. This approach also ensures that the results of DRIVE C2X have long-term validity at a European level, giving system developers as well as decision makers confidence.

To gather correct results from the field operational tests for cooperative systems, a technological basis is a fundamental prerequisite. DRIVE C2X relies on results from the PRE-DRIVE C2X [35] project in terms of specification, hardware and software prototypes, test environment and integrated simulation tool set developed. The basis comprises different technological components, namely the communication system (radio, communication protocols), facilities, human machine interface, applications and management.

DRIVE C2X is also implementing and testing a concept for the integration of a data backend, enabling commercial services based on C2X communication data to be developed for private and commercial customers. Such services are expected to become a major revenue source for cooperative driving systems and are key for successful implementation of this technology on European roads.

3.6 Mobile Millennium

Mobile Millennium [37] was developed by the California Center for Innovative Transportation (CCIT), the Nokia Research Center (NRC), and the University of California (UC) at Berkeley. The partnership began in 2006 when the National Science Foundation co-funded a joint US/European Union workshop in Helsinki. The aim of the work is to use mobile phone and navigation technologies to monitor real-time traffic flow.

In 2008 the Mobile Century project performed proof of concept work to test traffic data collection from GPS-equipped cell phones in one hundred vehicles driven on a 10-mile stretch of a highway located in the San Francisco

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 611115.

Bay Area. The phones, which effectively served as vehicle probes, stored vehicle speed and position information every three seconds. These measurements were sent wirelessly to a server for real-time processing. The Mobile Century experiment enabled the design and development of algorithms and data collection systems to assemble traffic data from GPS-equipped mobile phones.

The aim of the Mobile Millennium project was to demonstrate the potential of GPS in cell phones to alter the way traffic data is collected, by using the existing cell phone infrastructure to collect data and transmit it directly back to drivers as a 24/7 consumer service. This was demonstrated in the Bay Area and New York City in November 2008 and remained operational until June 2010 with 2000 registered users. Mobile Millennium highlighted some future challenges that need to be addressed by transportation agencies and businesses before similar systems become more commonplace. These challenges include new procurement approaches that are focused on purchasing information rather than equipment, defining the respective roles (and business models) of the public and private sectors in provided traffic information to consumers, and trade-offs between individualized information delivered to a smart phone and distracted driving.

3.7 SMART – US Project

SMART (Sustainable Mobility & Accessibility Research & Transformation) [38], is a project of UMTRI, the University of Michigan Transportation Research Institute and TCAUP, the Taubman College of Architecture and Urban Planning, in Ann Arbor. The US SMART programme is working with Ford to undertake research and demonstration projects related to the sustainable future of transportation in an urbanizing world. This is driven by the need for sustainable transportation to cope with accelerating urbanization, population growth, globalization, and demographic shifts. Key issues are the environment, energy security, social equity, productivity, urban economies and livability. Recognizing the complexity of the challenge and the sophistication of the innovation required, SMART takes a systems approach to urban mobility. It is a university-wide initiative, working on new theoretical perspectives and practical, innovative, systems solutions.

3.8 US ITS Deployment – Sensys Networks

Sensys Networks is an American SME developing wireless sensor technologies for ITS. They are working on control of intersections and within the PATH project [39] on “connected corridors” which is concerned with coordinated control of freeways and adjacent urban streets. The timeline for implantation of these systems is 2-3 years with drivers for 24/7 operation, low cost, safety and mobility. A key aim is to provide the ability to get a layered view of operations from network level to individual intersections and compare real time and historical performance of road networks. The expectations are that this will reduce traffic congestion and the associated costs and emissions.

3.9 Autonomous Cars - HAVEit – Highly Automated Vehicles for Intelligent Transport

There is great interest in the automotive industry in introducing autonomous driving features to improve safety. The EU funded HAVEit project [40] has developed concepts and technologies for highly automated driving (See Fig. 9). The key drivers for automated driving are increasing traffic density, the growing flood of information available to drivers and the rising average age of the population. In Europe 1 in 3 people will be

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over the age of 60 in 10 years time. Automation is needed to relieve drivers of some of the stress of driving guiding them through traffic more efficiently with a consequent environmental benefit.

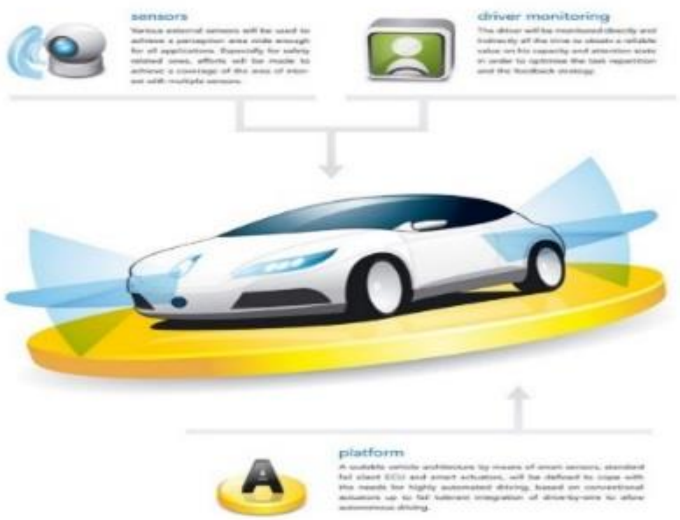

Fig. 9 - HAVE-it Autonomous Car

This will help reduce driver workload, prevent accidents, reduce environmental impact and make traffic safer. The HAVEit consortium (17 partners) consisted of vehicle manufacturers, Continental, Volvo Technology AB, Volkswagen AG, automotive suppliers and scientific institutes from Germany, Sweden, France, Austria, Switzerland, Greece and Hungary. In total, investments of 28 million Euro were made into HAVEit, 17 million Euro of which were EU grants and 11 million Euro were contributed by the 17 partners. Seven demonstration vehicles were produced. HAVEit also aimed to bring together research and development resources across Europe and strengthen Europe's international competitive position in a market full of technical challenges.

Highly automated vehicles can take over three main driving functions: steering (lateral automation), path planning (longitudinal automation) and navigation. These make driving easier for people and create highly automated systems which can be used intuitively. As part of the HAVEit project, three automation modes which can be selected and activated by drivers were developed and implemented in all demonstration vehicles.

- Normal - Lane keep assist and emergency brake assist
- Longitudinal automation - no need to accelerate or brake
- Lateral automation - no need to steer

In the first mode, the driver steers the vehicle alone, assisted by already-available standard driver assistance systems, such as lane keep assist or an emergency brake assist. In partly or semi-automated mode, the vehicle drives with longitudinal automation, so drivers no longer have to accelerate or brake. At the level of high automation, lateral automation comes into play, meaning the driver no longer has to steer. Despite the level of automation selected, the driver is always fully responsible for manoeuvring the vehicle and can take control in place of the system at any time. The driver also has to monitor the vehicle's driving manoeuvers. In the partially and highly automated modes, the system observes the driver with the help of a camera located inside the vehicle. The moment the driver stops paying attention to the road, the assistant prompts them to take control of the wheel.

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The German Aerospace Centre (DLR) and the Wuerzburg Institute of Traffic Sciences (WIVW) developed the concepts of adaptive communication between the driver and the automated vehicle.

3.10 Drive Me

The Swedish Drive Me project [41] is a joint autonomous driving pilot project between the Volvo Car Group, the Swedish Transport Administration, the Swedish Transport Agency, Lindholmen Science Park and the City of Gothenburg with a vision for zero traffic fatalities. 100 self-driving Volvo cars will use 50 Km of selected public roads in everyday driving conditions around the Swedish city of Gothenburg to identify:

- How autonomous vehicles bring societal and economic benefits by improving traffic efficiency, the traffic environment and road safety
- Infrastructure requirements for autonomous driving
- Typical traffic situations suitable for autonomous vehicles
- Customers’ confidence in autonomous vehicles
- How surrounding drivers interact smoothly with a self-driving car

The roads to be used are typical commuter arteries and include motorway conditions and frequent queues. The project started in 2014 with work on customer research and technology development, as well as the development of a user interface and cloud functionality. The first cars are expected to be on the roads in Gothenburg by 2017. An aim is that the Drive Me project will help define the role of self-driving vehicles in future city planning reducing infrastructure investments, lowering emissions and improving traffic safety. The driver will hand over responsibility to the vehicle, which can handle all driving functions at the driver's discretion, however, the driver is expected to be available for occasional control with a sufficiently comfortable transition time. For drivers autonomous driving is expected to provide more efficient time-management behind the wheel with the ability to interact safely via phone or tablets. The project will also investigate fully automated parking, without a driver in the car, such that the driver can walk away from the car at the parking entrance while the vehicle finds a vacant spot and parks by itself.

3.11Google Car

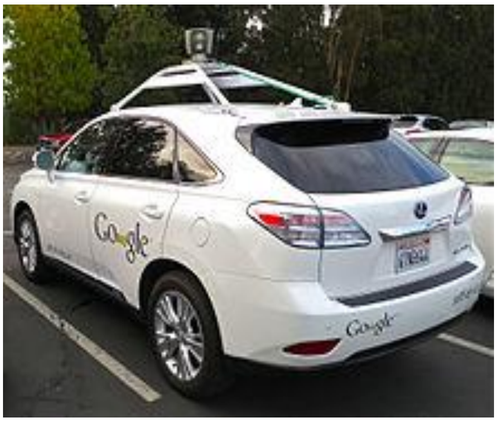


Fig. 10 - Google Equipped Lexus Autonomous Car and Google Prototype Driverless Car

Google has been working on a Self-Driving Car project [42] for several years to develop autonomous car technologies. This has resulted in the Google Chauffeur software. The company has equipped 6 Toyota PRIUS, 3 Lexus RX450h (as shown in Fig. 10) and an Audi TT with $150,000 of equipment to allow autonomous operation.

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Google has also been active lobbying American states to allow operation of autonomous cars and has been successful in Nevada, Florida and California. By April 2014, the 10 cars had logged nearly 700,000 autonomous miles (1.1 million km). Google have also announced their own driverless car that has no steering wheel or pedals (See Fig. 10). Google is not planning on commercial development of the system but they are interested in selling the system and the data behind it to automobile manufacturers.

3.12 Comments and Discussion

Individual vehicles could already be viewed as Systems of Systems if the requirements for physical separation of systems were relaxed. Given that at present cars have a driver then they could also be considered to be a CPSoS. Traditionally vehicle development is very component oriented and this has worked because the components had functionality produced by purely mechanical means and the majority of interactions between them was mediated by mechanical transmission of energy. In a modern vehicle the majority of the functionality is produced under software control and the interactions are mediated by information transmission. This has led to components having interactions with other components that they could never have had before. Also, because such interactions are now easy to set up the growth of such interactions has been exponential. This means that the traditional component based development is no longer suitable and OEMs are finding it very difficult to move to a more systems engineering approach. This involves major organisational changes, which can get very political and there are also issues with getting different engineering disciplines to work together, e.g. mechanical engineers need to understand the software/information based view of the system. There is thus already a need for research into organisation structures appropriate for systems engineering of large complex mechatronic systems and issues associated with organisation change. There are also needs for methods/notations/tools for the large representation of mechatronic systems.

The industry has been working for 10-15 years already on car-to-infrastructure and car-to-car communications. The key need here is a world-wide standard that covers Europe, American, Japan and China. Although a common standard is being agreed the software being used to implement the standard is different. Toyota and Denso for instance are developing their own version of the standard and Japan is some way ahead in terms of the technology as it is already used for communication between cars and tolls.

There is good progress on developing a standard for short-range communications using IEEE 802.11 protocols, e.g. WAVE or the Dedicated Short Range Communications standard being promoted by the Intelligent Transportation Society of America and the United States Department of Transportation. Longer range communications in the past have typically used UHF and VHF frequencies but the use of WiMAX and GSM/3G has also been proposed. This would require extensive and very expensive infrastructure deployment. It should be noted that a key requirement in any infrastructure implementation is the ability to be future proof and allow for future likely innovations. This is challenging as electronics typically becomes obsolescent in 18 months and a car in 10 years. An infrastructure investment needs to last 30 years or more and to operate the system requires built-in functionality for remote monitoring to allow for maintenance. Any widespread deployment of wireless sensors or communication nodes within infrastructure would preferably need to be self-powered to avoid the need to change batteries. There are a number of barriers to adoption including the difficulty of integrating with legacy equipment, justifying the need for investment to government and the slow and bureaucratic decision making process of government.

The industry view is that communication between cars and infrastructure is the future but there is a need for experience from day-one applications. A critical issue is the quality of the standard and this needs to work in all the member states. It is expected that deployment of day-one applications in 2015-2016 will reveal new problems which will identify new areas for research. It should be noted that the technology is expected to enhance safety, efficiency and emissions via enabling a better traffic flow. Even if only a few cars are equipped with the technology,

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e.g. 2-3%, then their modified behaviour will affect all other cars. Even staged roll-out of Systems of Systems resulting in incremental changes are likely to have a large impact. Cars that operate in stop and go traffic produce 30% more emissions and congestion tends to occur in urban areas.

The technology itself is quite mature and it is thought by the industry that suitable systems engineers exist to support development of ITS Systems of Systems but a challenge is to convince companies and government bodies to invest in the technology. As traffic congestion and delays are measureable and it is possible to prove that a new approach is better via modelling there is a means to justify investment. Modelling is thus thought to be a key issue, however, the experience is that this is difficult in practice. Modelling needs to show the benefits in terms of monetary savings through improved operations, lower maintenance costs and also improved capacity. A reduction in emissions is achieved through mobility improvements which can be measured by various metrics, e.g. delay, throughput, and emissions. These can be converted into monetary savings using established practice.

Car manufacturers believe that autonomous driving is an important technology to make road traffic more secure and more efficient but tools are needed to support development. The move to greater automation and eventually driverless vehicles is very much the current Zeitgeist and the whole industry is trying to move in this direction. A good overview of the various approaches has been produced by the EU funded TRAMAN21 project [43]. The majority of the work is on quite low level technical solutions, e.g. processor architectures, sensor technologies, data processing algorithms, but little is being done about how a population of such vehicles, mixed with more traditional vehicles, will actually behave, especially under fault conditions. It is unrealistic to assume that the designers will be able to anticipate all possible eventualities and put in place necessary and sufficient mitigations. This is because the scope of the system is effectively unbounded and therefore the number of eventualities is very large but also because no one will feel responsible for all aspects of the whole population, rather they will limit their scope to their own commercial interests. Emergence will thus be a key issue.

Although increased autonomy is the future there are still technical and legislative hurdles that need to be addressed before a 100% autonomous car is possible. An example of this is that in some European Countries communication between traffic lights and cars is not allowed by law. There are fewer barriers to implementation in the USA.

There is a need for intensive real time monitoring of the performance of the systems to spot potential issues arising before they develop into accidents. This raises concerns over privacy. There are needs for protection from unscrupulous companies and state surveillance, and also security to provide protection from criminals and terrorists.

An example of the privacy problem has already been highlighted by an add-on GSM dongle that fits to the diagnostic port on a car from Delphi. Garages can retrofit these to customer's cars for free to let them know when something is wrong with the car by automatically transmitting the fault codes as they appear. The garage receives alerts from Delphi and can use these to contact a customer to bring a car in and fix it before it breaks down providing a service. An issue with the roll-out of this system in Europe was that the data was to be sent to a Data Centre in America. In order to operate in Europe, due to sensitivities over privacy, another European Data Centre is now being used and currently the system is only being rolled out in two member states because it also has the facility to track cars.

The issue of data privacy is something that needs to be addressed at the European level as different countries have different views on privacy with different regulatory and political interests. For instance, at a political level in Germany privacy is a very important topic and technology cannot be used for tracking cars. In France there is a different point of view and so car tracking is also possible.

Another key issue for autonomous cars is risk. Accidents are inevitable and what process is adopted when accidents happen is important. Here there are issues of how is responsibility apportioned among a myriad of suppliers and

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sub-suppliers and what do victims have to do to get support for their loss and/or recovery , i.e. they should not need to battle through the courts for 10 years. Some research in this area is needed.

The key enablers for the successful development of Systems of Systems in the automotive sector are thought to be advances in **s**ensors, wireless communications and much better theory/algorithms/data. Little work is being done on the Systems of Systems issues apart from notably the Local4Global project addressing traffic management [44]. From a research perspective there is a need to fuse disparate sensor data. Here there are control/communication/computing trade-offs. A key issue is that there is no Systems of Systems theoretical framework at present. There is also a need for tools to support quick prototyping of heterogeneous hardware and software for deployment.

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4 STATE-OF-THE-ART IN THE RAIL SECTOR

The European rail infrastructure, a highly complex Systems of Systems, is facing increasing congestion due to unprecedented numbers of passengers requiring innovative ways to increase capacity on existing infrastructure (faster scheduling of passengers through stations and shorter stopping times at stations) and demanding levels of punctuality never before seen with more people and improved journey times. Here the Systems of Systems management, control and sociological aspects need to be considered in unison.

The interoperability regulations and the 2011 Transport White Paper [45] require that the European railway system behaves as a single Systems of Systems. The commercial drivers in the industry are for 24/7 operation, high availability, low cost, safety, increased capacity, recovery from disturbance, low carbon emissions and customer satisfaction. Already trains are operating across the European continent and the Commission requires a level playing field without barriers to competition. The main competitors to the rail network are other modes of transport and in order for the railway to be the preferred transport mode, the industry must offer a guaranteed door-to-door or factory-to-point-of-sale service 24/7. To achieve this there is a drive towards Automatic Train Control and automated maintenance to increase capacity and reduce costs to the point where rail operations do not require subsidy from government. Capacity is currently severely restricted due to controlling train movement through a system of blocks (sections of “reserved” track that no two trains can operate on). Moving blocks improve this but autonomous train-to-train communications and new infrastructure components could increase capacity by more than 100% with an asset value of billions. The 2011 Transport White Paper [45] requires the majority of medium to long distance journeys (freight and passenger) to be by rail. This is driven by congestion costs (1.5% of EU GDP) and the need for greatly reduced transport emissions. Priorities are set at national levels and within the UK for instance the funding for Network Rail is allocated using five year Control Periods that set specific targets in terms of infrastructure condition, renewals and customer satisfaction. Network Rail currently face an estimated £70M fine for failing to meet the 92.5% on time target so there are great incentives to improve. The EU is driving the railway industry towards a single system through interoperability requirements.

The industry also aims for a more resilient infrastructure and some of this resilience can be obtained by a better Systems of Systems to route traffic in an optimal manner responding to an incident. Systems of Systems should have a better overview of the whole system rather than the more localised view of the individual control centres or signal boxes. This would improve capacity and operations reducing fuel costs while increasing revenue by carrying more passengers and freight on the same or reduced infrastructure. Key improvements expected from a Systems of Systems approach are:

- Improved capacity
  - Improved planning and operation with potentially more flexible timetables could deliver improvements in capacity, by optimising the timetables at peak periods to maximise traffic flow.
- Reduced Emissions
  - Improved timetable planning and operation, can lead to optimised driving to reduce stopping and starting to reduce emissions. A Systems of Systems approach may also provide the necessary planning that would allow hybrid rail vehicles to just run the combustion engine away from stations and urban areas, reducing noise and urban pollution.

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4.1 ERRAC Strategic research agenda 2020 for rail

ERRAC [3] was set up in 2001 with the goal of creating a single European body with both the competence and capability to help revitalise the European rail sector and make it more competitive, by fostering increased innovation and guiding research efforts at a European level. Within ERRAC, all major rail stakeholders are gathered, including 45 representatives from each of the major European rail research stakeholders: manufacturers, operators, infrastructure managers, the European Commission, EU Member States, academics and users' groups. ERRAC covers all forms of rail transport from conventional, high speed and freight applications, to urban and regional services. Since its launch in 2001, ERRAC has produced a number of important and influential documents, such as the Joint Strategy for European Rail Research – Vision 2020 [46], the SRRA – Strategic Rail Research Agenda [47] and its 2007 updated version, Suburban and Regional Railways Landscape in Europe [48], Light Rail and Metro Systems in Europe [49], Rail Research in Europe [50] and a comparison of the Member States public research programmes.

A set of roadmaps were developed in the EU funded (FP7) project ERRAC ROADMAP (2009-2012) and in 2012, an initial update of the ERRAC vision for the future of rail to support H2020 was released. This vision "Railroute 2050" [51], highlights the European effort required for research and innovation especially to meet the objectives of the European Commission 2011 Transport White paper "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system". RailRoute 2050 offers a range of research opportunities for a competitive, resource-efficient and intelligent rail transport system that meets the future demands of European citizens, stipulates economic growth, creates European jobs, and strengthens the position of the European rail sector in global competition. The European vision for railway research and innovation outlined in RailRoute 2050 illustrates the research pillars that need to be supplemented by the corresponding investment pillar.

Additionally, ERRAC launched FOSTER RAIL (2013-2016) [52] which will support development of a new full and complete vision, including the Rail Business Scenario and the Strategic Rail Research and Innovation Agenda.

4.2 European Rail Roadmap

Rail infrastructure management
Business Process Reengineering (BPR) for railway infrastructure managers was addressed in the **IMPROVERAIL** project. It provided a roadmap for BPR which takes a holistic approach to the management of infrastructure. It covers functional and technical issues as well as the institutional issues between the infrastructure manager and other agents. The tool has identified representative processes in three areas: operational, commercial and managerial. The framework includes prospective network capacity management, short and long-term planning, life-cycle cost assessment for infrastructure investment evaluation, and railway infrastructure benchmarking.

In France, research by SNCF has developed several software tools for rail traffic management, including **Exalibur**, which is a prototype decision-support system to monitor and manage traffic in the event of disruption, **Lipari**, which is a simulation system to help manage networks nearing saturation, and **Demiurge**, a program designed to assist in making rail network capacity studies.

Research has also addressed the enhancement of interactions between terminals and the network. A demonstration was carried out in the Novara Intermodal Goods Centre at the border between Italy and Switzerland within the **INTERFACE** project in order to reduce train delays from the terminal to the rail network. It consisted of harmonising the interface of the information systems of CEMAT (the main intermodal operator at Novara terminal) and train operator Trenitalia, and creating a common wagon database. This measure, together with Integrated Timetable Planning (ITP), has produced positive impacts on train punctuality along the transport chain, capacity increase for intermodal transport on the line and at the terminal, and optimisation of transhipment movements at the terminal.

In another demonstration (**PROMIT** project) at the Bologna Interporto freight terminal, the implementation of an Intelligent Automation System (IAS) has permitted improvements to the management of traffic in the existing shunting system by minimising the number of wagon movements and maximising the number of trains operated within the terminal.

Safety management
The development of a Safety Management System (SMS) for European railways was the aim of the **SAMRAIL** project. The structure and requirements of the different elements of the SMS, such as safety policy, risk management and incident/accident reporting, have been specified and guidelines provided. The steps which could be taken by the European Commission and by the European Railway Agency to develop a SMS certification standard have been identified. A risk management approach has been proposed. The project also proposed the adoption of two types of safety targets: global targets for measuring performance of Member States and specific targets for measuring performance of individual railway functions.

Managing international road and rail traffic: Strategies and solutions

Trans-European Road Network (TERN)
On the TERN, a series of "Euro-Regional" projects have developed coordinated traffic management, in particular in cross-border areas. This includes the **CENTRICO** project, which studied and implemented cross-border Traffic Management Plans (TMP) over major interurban routes between Belgium and the Netherlands, Germany, Luxembourg and France, and the **SERTI** project which researched and implemented trans-Alpine cooperation and traffic management between road and motorway operators in France, Italy and Switzerland. Data exchange between regions and countries has been a key element in international road traffic management, and standard language-independent protocols have been developed by all Euro-Regional projects using the DATEX II standard. Although the Euro-Regional projects, which are now part of the Europe-wide **EasyWay** project, are mainly focused on ITS deployment, a significant part of their work has been applied research and studies of systems and operational techniques.

Trans-European Network – Rail (TEN-Rail)
Solutions for efficient management of rail services on international corridors have been dealt with in the **NEW OPERA** project. The first concern was the increase in network capacity. The project also addressed the signalling and rail operation management systems needed to achieve a more homogeneous speed of trains as well as longer and heavier trains. The utilisation of new infrastructure for High Speed Trains (HST) together with former railway lines was considered as a means to remove existing bottlenecks and increase speed on the main European corridors. The project identified a range of management and bureaucratic barriers which interfere with optimisation and prevent the rail system from becoming one uniform rail space in Europe. Harmonisation in operating rules and in training was also tackled. Specifically on interoperability the project provided a cost-effectiveness assessment of ERTMS levels 1, 2 and 3.

The allocation of rail capacity on international routes, in particular for freight corridors, was the focus of the **PARTNER** project. First, state of the art European timetable planning together with the identification of user requirements and technical specifications were provided. A prototype, the PARTNER demonstrator, has been developed which includes a conflict detection module and a conflict solving part, with a capacity allocation module and a user interface using data standards according to RailML open formats. The project has shown that it is possible to achieve a better support in Infrastructure Manager (IM)-to-IM cooperative planning by use of more advanced methods for capacity allocation and consequent reformulation of track access fees, based on standardised European methods.

Fig. 11 - European Rail Roadmap

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 611115.

Between 2009 and 2012, ERRAC carried out a 3 year rail research roadmapping project called ERRAC ROADMAP (See Fig. 13) [53]. This highlights the needs for intelligent mobility, competitiveness and enabling technologies and infrastructure as priority research areas related to traffic management (See Fig. 11).

- In the area of intelligent mobility, the main issues deal with the definition of new management techniques to enhance infrastructure use. These include timetable optimisation, new fleet management tools, and development of information systems, as well as harmonised information exchange between stakeholders in cross-border traffic.
- In the area of competitiveness and enabling technologies, priorities include the compatibility of on-board data collection systems and their integration with communication networks, as well as the analysis of passengers and traffic flows in order to reach a more efficient Europe-wide train path allocation.
- Finally, in the infrastructure area, priorities include the development of train control systems and new operational rules in order to optimise both capacity and service interchange.

The roadmap indicates many technology advances are dependent upon utilisation of ICT. Here there are opportunities for use in infrastructure management and optimization across Europe and in safety management. Identified projects which address potential Cyber Physical Systems of Systems issues are IMPROVERAIL, Excalibur, Lipari, Demiurge, INTERFACE, PROMIT, SAMRAIL, CENTRICO, SERTI, EasyWay, NEW OPERA, PARTNER, BRAVO, InteGRail, INESS and KOMODA.

4.3 UK Sustainable Rail and FuTRO Initiatives

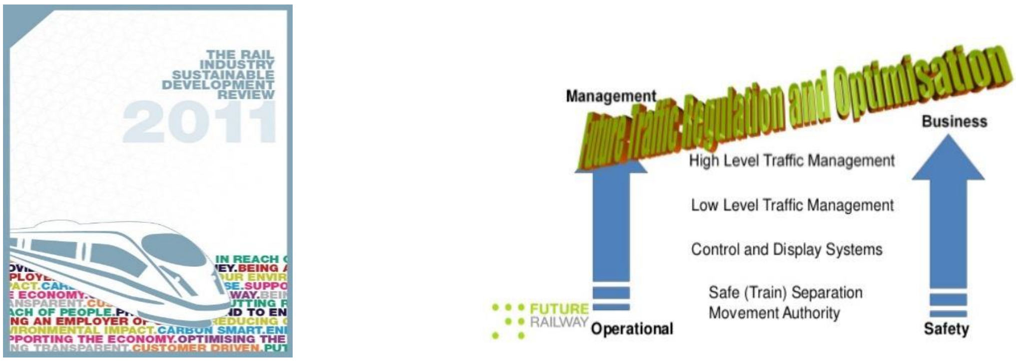

Fig. 12 - UK Sustainable Rail Programme [54] and FuTRO [56]

The UK's Sustainable Rail Programme (SRP) (See Fig. 12) [54] supports the industry in meeting the challenges and opportunities of sustainable development. It is a cross-industry programme facilitated by the Rail Safety & Standards Board (RSSB). This body focusses on policy, strategy, and research for the rail industry in the UK. The Programme's early work focused on agreeing key strategic cross-industry issues and reviewing cross-modal performance. Resulting from this the industry performed a sustainability review called "The case for rail". In 2009, the programme published the Rail Industry Sustainable Development Principles (SD Principles) that covered social, economic and environmental issues. The intention of this is to provide a platform that can be used for embedding sustainability throughout the UK Rail industry. The SRP has focussed on embedding the SD Principles into industry decision-making processes resulting in a number of activities. The SRP was used to develop the industry carbon trajectory and ambitions for CP5 (the UK rail industry investment is managed over 5 year Control Periods). To support this a railway carbon accounting tool was created. Additionally, a web-based tool was developed to help industry organisations assess their performance and strategy against the SD Principles. The tool has recently been used in planning for capacity enhancement at Waterloo station. The SRP has also provided a response to the EUs

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Environmental Noise Directive [55] in 600 areas identified in noise mapping and provided guidance for industry and partners based on the results of ATOC's (Association of Train Operating Companies) station travel plan pilot programme.

Transport integration at the Systems of Systems level is seen as fundamental to a sustainable transport system. It is acknowledged that while rail can provide the core element of many journeys there will always be a beginning and a section of travel that is not rail. In a National Passenger Survey in Spring 2011 73% of people in the UK thought that connections to other forms of transport were "satisfactory or good", however, of note is that this figure has not changed in the last 5 years. To understand why people do not use the rail system ATOC in the UK engaged with non-rail travellers. This identified that price is the biggest barrier but time and convenience for the whole journey is also a significant issue that needs to be addressed. A study was performed identifying that the best value for money to address this problem would be to improve access to stations and reduce the interchange time between modes (passengers are particularly unhappy about having to wait for connections). ATOCs Station Travel Plan pilot project is covering 31 stations in the UK. This plan identified needs for partnerships with local authorities, wide stakeholder consultation, appropriate resourcing and the need for robust data.

Another key initiative is to optimise the railway to maximise the rail systems capability and efficiency to provide good value for money. The average annual UK public investment in rail has been around £5bn. This figure is reducing as improvements are expected in efficiency and passengers are expected to bear more of the costs. In terms of benefit an audit of the UK rail spending indicated that every pound spent on the railway delivered 2 pounds of benefit. This has been achieved in a variety of ways and a major one has been through improvements in capacity. The UK rail network has been the fastest growing network in Europe over the past 10 years. Passenger numbers have increased by 43% and rail freight has increased by 60% making it one of the busiest mixed rail networks in the world. In 2010 1.3 billion passenger journeys were made over 33 billion miles. A result of this is that some sections of the network have reached their limit in terms of capacity and between 2009-2014 £12bn has been invested in projects to improve capacity such as lengthening stations and allowing more trains to run.

Systems of Systems approaches that can further improve capacity are thus of high interest. Network Rail has agreed to 23% efficiency savings for the funding period 2009-2014 following achievement of 27% savings achieved in the previous funding period. A further 30% reduction is believed possible by 2018/2019 and a challenge is to deliver this while maintaining operational performance and safety. The Technology Strategy Leadership Group in the UK is now investigating traffic management and disruption management as a means of doubling capacity. Key areas being looked at are bottlenecks, the relationship between reliability and capacity enhancement and control methods to safely reduce the distance between trains.

Looking more long term the Future Traffic Regulation Optimisation programme (FuTRO) (See Fig. 14) [56] is part of the UKs Rail Technology Strategy 2012. It is addressing how regulation of trains in the UK must change, adapt and improve looking 40 years into the future. The scope of FuTRO is very wide and includes many different aspects and systems in creating and delivering a positive end-to-end experience on the network. Innovation is expected to come from a wide range of sources including the physical and biological sciences, all types of engineering system design and the human/social sciences (considering passengers). Inspiration from outside of the rail industry is seen as a key to success and insights/technology from related and unrelated fields are being sought. The aims are to meet customer needs answering three key questions:

- How will we understand the needs of passengers and freight customers over the next 15-40 years?
- How will customers know what the railway is offering them both in advance and in real time?
- How will the system design contribute to reducing passenger stress and improving satisfaction?

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4.4 Foster Rail

FOSTER-RAIL is a European Level 1 Coordination and Support Action [52] driven by ERRAC aimed at supporting the land transport European Technology Platforms activities. The aim is to strengthen the research and innovation strategies of the transport industries in Europe. This will assist ERRAC and the other transport-related European technology platforms (ETP) in defining research needs for their strategies and programmes for H2020 in order to realise the objectives of the Europe-2020 strategy [46] and the White Paper 2011 vision for a competitive and resource-efficient future transport system [45]. Currently an updated Strategic Rail Research and Innovation Agenda is being produced under Foster Rail. It is being performed in consultation with the European Commission and Member States and Associated States. FOSTER-RAIL will integrate the work of ERRACs Working Groups and progress this building upon the ERRAC ROADMAP project and RailRoute 2050 [51]. An aim is to support and enhance cooperation between stakeholders and decision-makers to provide an enhanced definition of strategic research and innovation needs and establishment of Business Scenarios. A key area is co-modality with other transport modes. The project will support the Strategic Rail Research and Innovation Agenda as well as a Rail Business Scenario for 2050. This Railway Business Scenario shall be the reference for future research agendas and technology roadmaps to be developed until 2050. It should be noted that similar Foster Road and Foster Waterborne activities are also being pursued for the road and maritime sectors as part of a joint initiative.

4.5 SHIFT^{2}RAIL

SHIFT^{2}RAIL [57], starting summer/autumn 2014, is a H2020 supported European rail joint technology initiative seeking focused research and innovation (R&I) and market-driven solutions by accelerating the integration of new and advanced technologies into innovative rail product solutions. The integration of systems is a core objective of the programme and it applies to all segments of the rail market: High Speed/Mainline, Regional, Urban/Metro & Suburban, and Freight. SHIFT^{2}RAIL will promote the competitiveness of the European Rail Industry and create a Single European Railway Area (SERA). SHIFT^{2}RAIL aims to double the capacity of the European rail system, increase its reliability and service quality by 50% and at the same time halve lifecycle costs.

The aim is to achieve this by introduction of better trains (more comfortable, quieter and more reliable), operating on an innovative rail network infrastructure in a reliable way from the first day of service introduction. This will be done at a lower life cycle cost, with more capacity to cope with growing passenger and freight mobility demand. SHIFT^{2}RAIL also aims to attract more users to rail. For passengers there will be more travel options, more comfort, and improved punctuality. For the freight forwarder/shippers rail freight will become more cost effective, punctual and traceable as a shipment option. There is an expectation of more job creation, less pollution and more efficient and optimised public investments.

4.6 ON-TIME

The Optimal Networks for Train Integration Management across Europe (ON-TIME) project [58] aims to introduce a step-change in railway capacity by reducing delays and improving traffic flow. The project integrates railway industry experts, system integrators, small knowledge led companies and academic researchers and draws upon previous research projects and national trials. The project brings together best practice on how national railway companies have improved their own networks. Academic research on algorithm development is being used to address the nature of delay initiation and propagation with a view to implementation in commercial traffic management and traffic planning tools.

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4.7 European Rail Traffic Management System (ERTMS)

The European Railway Traffic Management System (ERTMS) [59] is a major industrial project developed by Alstom Transport, Ansaldo STS, AZD Praha, Bombardier Transportation, CAF, Mermec, Siemens Mobility and Thales in close cooperation with the European Union Railway stakeholders and the GSM-R industry. Currently there are more than 20 train control systems across the European Union. Each train used by a national railway company has to be equipped with at least one system but sometimes more are required to be able to run safely within one country. A problem is that each system is stand alone and non-interoperable. If traffic is cross border this leads to extensive integration and engineering effort with high associated costs. This restricts competition and also hampers competitiveness of the European rail sector versus road transport. As an example the Thalys trains running between Paris-Brussels-Cologne and Amsterdam have to be equipped with 7 different types of train control systems.

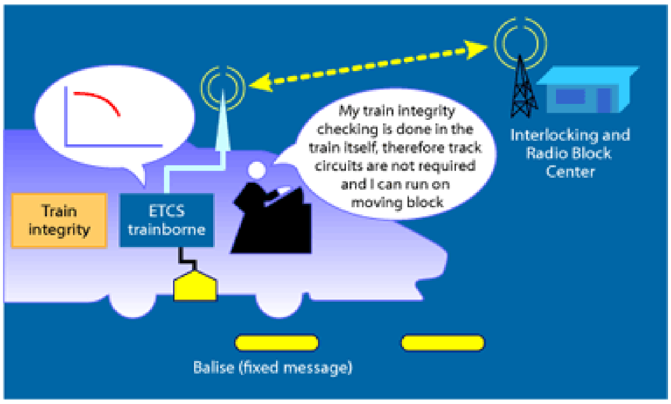

Fig. 13 - ERTMS Level 3 and Balise

To address this ERTMS aims to gradually replace the different national train control and command systems across Europe to create a seamless European railway system. Instead of lineside signals, a computer in the driver's cab controls the speed and movement of the train, whilst taking account of other trains on the railway (See Fig. 13). Bringing the control system inside the train will allow more autonomous operation, so that drivers can always run at the optimum safe speed helping more trains run faster and recover from delays quicker. Each train will run at an appropriate safe speed, allowing more trains onto the tracks. This will increase passenger and freight capacity, reliability, reduce maintenance costs, improve punctuality and lead to safer trains and greater competitiveness for the supply market. By moving more people and freight onto trains and reducing delays there is also an expected reduction in pollution.

ERTMS has two basic components, the ETCS, the European Train Control System, which is an Automatic Train Protection system (ATP) to replace the existing national ATP-systems, and GSM-R, a radio system for providing voice and data communication between the track and the train. This uses standard GSM but on a reserved rail frequency. It should be noted that ERTMS is not a new concept and it has been successful outside Europe in countries such as China, India, Taiwan, South Korea and Saudi Arabia. The ERTMS/ETCS is split into a number of application “levels” which range from track to train communications (Level 1) to continuous communications between the train and the radio block centre (Level 2). Level 3, which is in a conceptual phase, will further increase ERTMS potential by introducing a “moving block” technology to increase capacity.

- ERTMS level 1 is used as an add-on to conventional lineside signals and train detectors. Communication between balises (See Fig. 13) and the train ensures that it automatically brakes if exceeding maximum allowed speed.

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- ERTMS level 2 does not use lineside signals (reducing maintenance costs by their removal). The movement authority is communicated directly from a Radio Block Centre (RBC) to the onboard unit using GSM-R. Balises are used to transmit “fix messages” such as location, gradient, speed limit, etc.
- ERTMS Level 3 is still in its conceptual phase but allows introduction of “moving block” technology. Removal of fixed blocks (sections of tracks where two trains cannot run at the same time) increases capacity greatly. The train itself becomes a “moving block” communicating accurate position data.

4.8 Comments and Discussion

Existing railway control centres act as a type of Systems of Systems, where the individual railway sections are subsystems controlled by signalling interlocks utilising information from track circuits or axle counter methods of train detection. Control centres act as higher level systems that plan traffic routes and respond to delays and incidents. Each control centre covers a regional area and therefore the intercommunication between control centres is vital. ERTMS is aiming to become a much more centralised traffic management system which will remove many of the operational problems of running trains between countries. The system is being trialled currently at different levels in different countries, with full roll out expected by 2024. There are also a number of national initiatives such as FuTRO in the UK. The rail industry is being driven by targets to reduce cost, increase passenger and freight bearing capacity and reduce CO_2 emissions. There is also a drive to attract more customers and to achieve this there is a need to improve customer satisfaction and customer service. In terms of a competitive environment the European railway infrastructure managers and train operations face little genuine competition with most customers having little choice in whether to change operators, however, there is competition amongst the supply industry.

There is confidence that suitable systems engineers exist in the rail industry to meet future needs and also strong confidence that a Systems of Systems approach will be better with metrics already being gathered to support this argument. The rail industry have many years of experience of rolling out Systems of Systems and also of maintaining networks. An issue is that traditionally railway infrastructure maintenance and operations have been subject to a “silo mentality” with just a few engineers having the job title of “railway systems engineer” and with comparatively little budget. To convince management that there is a need to invest in Systems of Systems research requires effort and there is a need for leadership to achieve more than incremental change. There is, however, general industry support for change – if there is no investment in modernisation the railway will become obsolete. With investment capital limited, investment decisions must be weighed against the benefits of other schemes. At a European level there needs to be the strongest possible leadership between national entities. Leadership capable of planning the execution (beyond incremental steps) and convincing government are seen as essential ingredients for rollout.

Within the industry anything new that operates at a low level is difficult to implement on the railways due to the scale of the infrastructure, however, to build a new higher level Systems of Systems on top of the existing control and command systems is not thought to be as difficult to implement, although safety and security become key issues for railway systems at this level. The migration to a new Systems of Systems approach is complex as there is a need to maintain the present level of services while the migration takes place. There are generally no public acceptance problems within the rail industry as any change that improves the rail network is welcomed by customers. Customers are, however, becoming more sophisticated and will demand a door-to-door service from public transport in the future which requires a Systems of Systems integration of different transport modes.

Key enablers are thought to be a well prepared implementation scheme with the benefits clearly mapped out. Already the initiatives identified in this report are providing supporting information for this. The key research needs

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are support for determining the design and validation of such a scheme and proving that it is secure and safe and ready to be used on the railway system. Underlying this there is a need for assessment tools and methods to prove the benefits. Modelling capability is thought to be critical here for optimising the components (operations, maintenance, etc.) within the Systems of Systems and it is felt that there is a lot of underexploited modelling capability in Universities around Europe. There is also a need for commitment from the top, i.e. from Government as there is a need for large investment. There will inevitably be some disruption to passengers and freight operations during rollout which needs to be minimised.

Three key areas where identified as being important:

1) Data gathering and management

- How is data to be sensed, collected, communicated, processed, stored and deployed?
- How are the vulnerabilities and threats to integrity and security going to be addressed?
- What standards are relevant and how are they to be managed?

2) Optimisation of systems performance

- What are the criteria of system performance that will be important?
- How will tools, algorithms, cost functions, timetables be developed?
- What are the technical and commercial constraints on performance?

3) Autonomy and sociotechnical issues

- Which things should be controlled automatically, which by humans and which in combination?
- How can technology be used to support human decision making?
- What tools and interfaces will be needed between humans and technology?

Within the industry the present levels of knowledge on each of the three topics varies greatly. There is a feeling that much of the knowledge already exists for other industries, e.g. aerospace, and requires adaption for the railway sector.

Systems for autonomous operation of close coupled trains are key for increasing capacity and automated high speed maintenance systems will keep the track open for more time further increasing capacity. There is a need for whole system data management and communications presenting Big Data issues and underlying all areas is a need for modelling at different layers of abstraction.

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5 STATE-OF-THE-ART IN THE AEROSPACE SECTOR

5.1 Passenger Routes and Traffic

In the aerospace sector air passenger volume is predicted to double air traffic density over the next two decades in an already congested airspace. Movement of increasing numbers of passengers requires a complex Systems of Systems across the world that integrates airport operations, baggage handling and air traffic control to maximise flow. Air traffic control systems by themselves integrate numerous functionalities which enable semi-automated operations in the en-route airspace. Tools and methods that partially automate some of what is manually performed by Air Traffic Controllers today is currently an active area of research. At the same time the need for unprecedented high levels of aircraft availability is driving the use of sophisticated information and communications technologies for predictive health monitoring, integrated with worldwide maintenance and logistics systems to ensure that aircraft are always fit to fly.

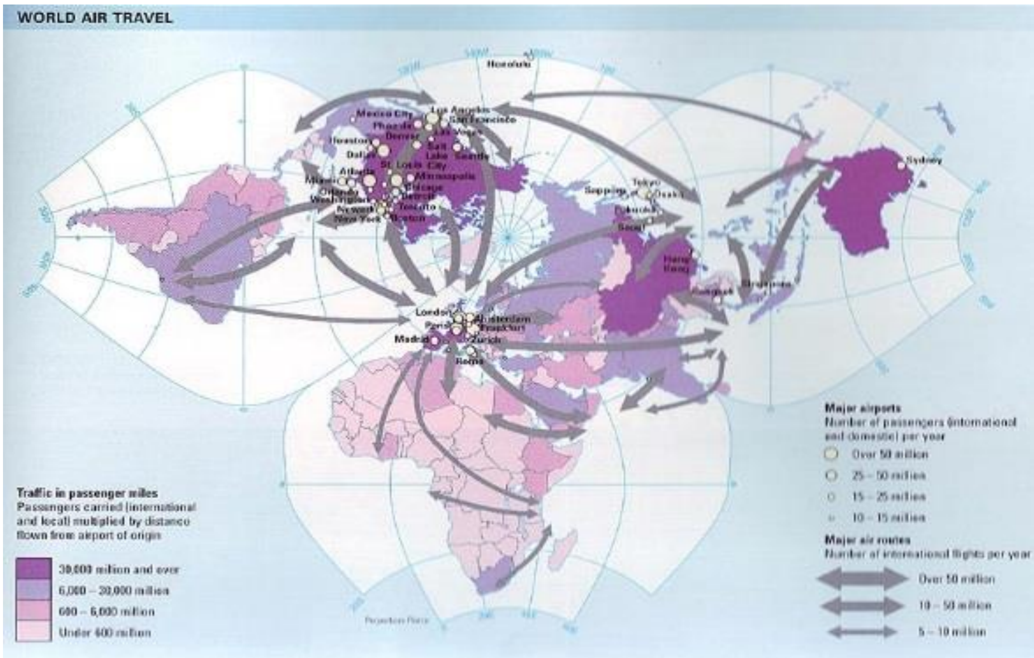

Fig. 14 - Major World Airports and Traffic Routes [60]

Fig. 14 shows a map of major air traffic routes around the world [60]. On the key routes shown there are over 50 million passengers a year and on the majority of other routes there are 10-50 million passengers. Air traffic is increasing and the number of aircraft is expected to double by 2020 to meet demand. As a global aviation industry, the biggest and most important challenge is to continue to safely accommodate ever increasing air traffic in support of global economic growth and prosperity, whilst protecting the environment.

From a Systems of Systems perspective Air Traffic Management will be a major topic in the coming years, especially in Europe where separate systems will have to be integrated. The challenges here are not only technological, but also legislative/political and need to be tackled at a European (and even world-wide level). In the future Unmanned Aerial Vehicles will also be integrated with the normal ATM network presenting further technological, legislative and political challenges. Autonomous aircraft operations are not a new concept in the aerospace domain. Partly this is due to the ability to operate in controlled military airspace and also the 3 dimensional separation of vehicles which is not available in other sectors. Aircraft already feature a number of automated features to reduce pilot

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workload and rely on very accurate navigation systems supported by a comprehensive network of ground stations and satellite systems. The sector is thus a leader in terms of implementation of autonomous vehicles. The technologies used to integrate UAVs into civil airspace may also be applicable to self-driving cars in the future.

5.2 SESAR – Air Traffic Management

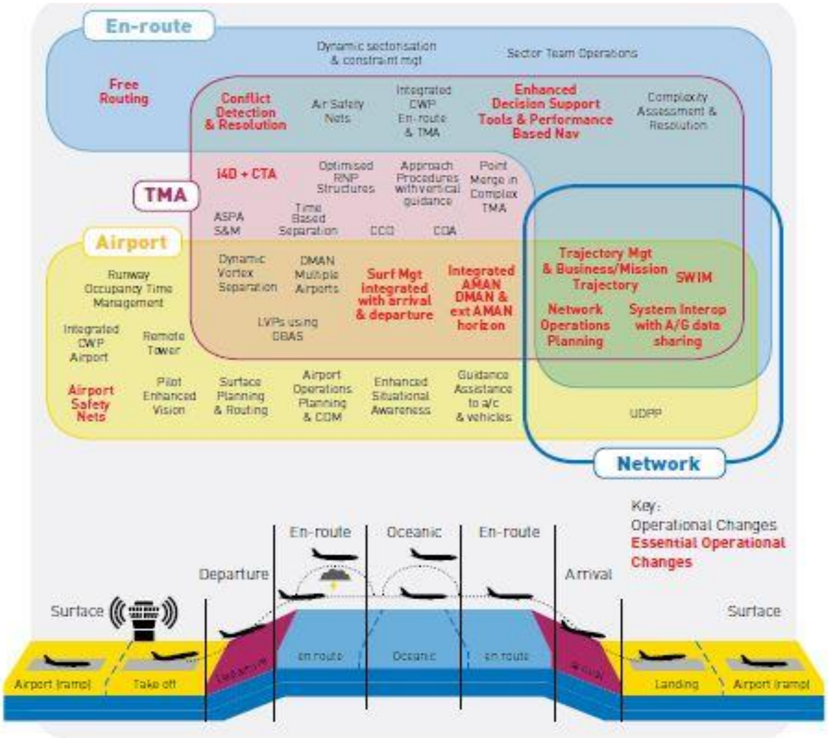

Fig. 15 - SESAR 4D Routing [61]

The Single European Sky programme [60, 61] is reforming the architecture of European Air Traffic Control to meet future capacity and safety needs. Within Europe Eurocontrol predicts 20.4 million yearly flight movements by 2030 which is twice the current figure. In order to meet this need 2.1 billion Euros is being invested in R&D to develop a new air traffic control system for Europe. This will exploit improved air traffic and aircraft positioning and communication technologies, such as GALILEO [62] to provide significant improvements in the efficiency and safety of air travel. The Single European Sky ATM Research programme (SESAR – formerly known as SESAME) is the name given to the collaborative project that will completely modernize the European Air Traffic Control infrastructure. SESAR (See Fig. 15) aims at developing the new generation air traffic management system capable of ensuring the safety and fluidity of air transport worldwide over the next 30 years.

The first definition phase of SESAR ended in 2008, delivering an ATM master plan [63, 64, 65] defining the content, the development and deployment plans of the next generation of ATM systems. This activity was led by Eurocontrol, and co-funded by the European Commission under the Trans-European Network Transport programme. Work was executed by a consortium with representatives of all air transport stakeholders and included non-European members reflecting the global nature of ATM. The development phase (2007-2013) provided a new generation of technological systems and components. For this phase the Commission created the SESAR joint undertaking, based on the GALILEO model, supported by public and private funds from the European Community, Eurocontrol, industry and third countries. The current deployment phase (2013-2020) is seeking to build the new infrastructure necessary for the future within Europe and in partner countries. This is being carried out under the

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responsibility of industry without further public funding. Additionally, there has been some activities performed under the Clean Sky EU programme [66] looking at ATM and related issues to reduce emissions and fuel cost such as work by Thales on innovative Flight Management Systems.

5.3 NEXTGEN – Air Traffic Control USA

The equivalent of SESAR in the US is NEXTGEN [67]. The National Airspace System (NAS) is the collection of all the components (airspace, facilities, equipment, services, workforce, procedures, etc.) that enable the US air transportation system. Within the United States one organization, the FAA, operates 350,000 airplanes and 18,000 landing facilities. NEXTGEN, is short for the "Next Generation Air Transportation System," and is a programme to comprehensively transform the NAS into a system to meet future needs that will be safer, more reliable, more efficient and which will reduce the impact of aviation on the environment. The system is due for implementation across the United States in stages between 2012 and 2025. Again this is a very large programme and contractors include Lockheed Martin ($500M) and NASA Ames.

There are some fundamental differences between Europe and the US. The European community is by far the most diverse community of air navigation service providers in a high-density airspace. A key issue is in achieving full consensus on modernization – it is a Systems of Systems problem – whereas in the US everything is under the control of a single body making implementation much simpler. An assessment of the SESAR and NEXTGEN programmes by the US indicated that they believe that SESAR is more advanced with respect to implementation. There is, however, a key difference between the two approaches being undertaken. SESAR's emphasis is on i4D (using aircraft RTA capabilities – the aircraft themselves calculate the Required Time for Arrival) while the FAA's emphasis is on ADS-B (Automatic Dependent Surveillance - Broadcast) for Interval Management (where aircraft positions are sent by the aircraft and are monitored and controlled centrally). This potentially may lead to a global harmonisation problem for aircraft operators and manufacturers, i.e. multiple solutions for the same operational problem in the same timeframe.

5.4 GEOSS – Earth Observation

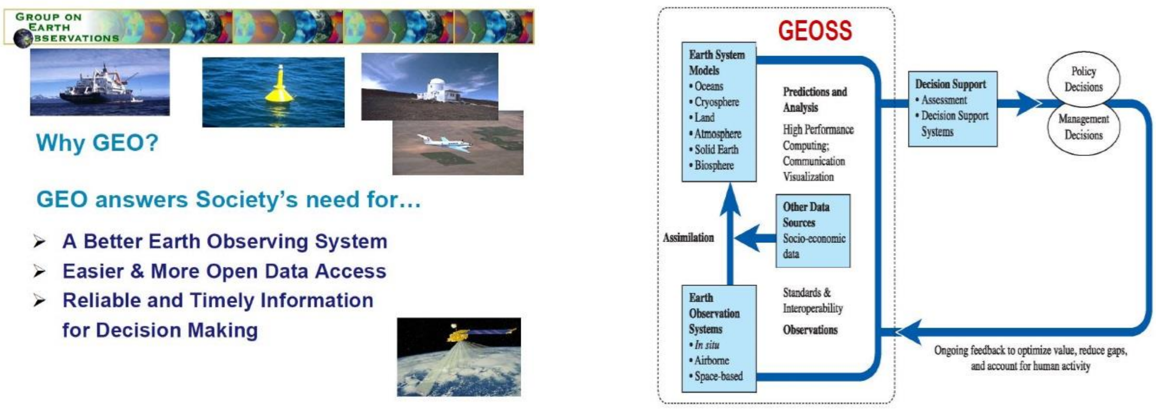

Fig. 16 - GEO Systems for Systems for Earth Observation and Decision Support Tools [69]

The GEO Systems of Systems (GEOSS) [68, 69] as shown in Fig. 16 is operated by 90 member governments, including the European Commission and 77 Participating Organizations making Earth observations. These include measurements and monitoring of the Earth from all aspects: under water, on the land surface and beneath, monitoring of air and water quality, of atmospheric conditions, and measures of the health of humans, plants and animals. Within the GEO Systems of Systems measurements can be made directly by sensors in contact with the environment or through remote sensing including a range of land, marine and space platforms. These observations support modeling or feed into tools that create information for environmental decision-making.

The societal benefits and uses of such information are in:

- Reduction and Prevention of Disasters
- Human Health
- Energy Management
- Climate Change
- Water Management
- Weather Forecasting
- Ecosystem
- Agriculture
- Biodiversity

The EPA Group on Earth Observations (EPA GEO), serves as a forum to facilitate the Agency's response and contribution to the development of GEOSS, including EPA's Advanced Monitoring Initiative program and projects. There are numerous datasets, models, decision support tools, and programs that EPA manages, oversees, supports, or uses (See Fig. 18). The GEOSS architecture integrates environmental observation, monitoring data and measurements with modeling to support and inform environmental decision-making. The ultimate goal of GEOSS is to provide decision makers with scientific information that can advance societal benefit areas including human health, ecosystems, climate change, air and water quality. On 17 January 2014, the Group on Earth Observations (GEO) agreed to continue building on the organization's first 10 years of pioneering environmental advances. Fuelled by open data, GEO's efforts are now evident in most regions of the world. Other federal agencies such as the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration work with a myriad of databases, models, and programs that also contribute to the GEOSS.

5.5 Unmanned Aerial Vehicles (UAVs)

There are numerous UAV activities being undertaken within Europe with several major large programmes and many smaller programmes investigating and developing UAV technology for military and civilian use. It is not possible to cover all of these in a report but in this section a few key large programmes are highlighted. In larger UAV programmes multiple vehicles are operated as part of Systems of Systems implementations to gather information or perform tactical missions.

Fig. 17 - Watchkeeper UAV [70]

The Thales Watchkeeper WK450 [70](see Fig. 17) is a remotely piloted air system (RPAS) for all weather, Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) which has been developed for use by the British Army, in a €1bn contract awarded to UAV Tactical Systems (U-TacS) in 2005, a joint venture between Thales UK and Israeli Elbit Systems. A UAV "system" such as Watckeeper is not a Systems of Systems in itself, it is a single

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system since it is managed and operated as a single distributed system, however, Watchkeeper detachments will be deployed and integrated into task forces and force packages so will form part of an ad-hoc contingent of Systems of Systems. Watchkeeper does have an important characteristic that is shared by some "systems" and all Systems of Systems in that the "system" dynamically reconfigures as entities leave and join the system, and external systems connect to and disconnect from it.

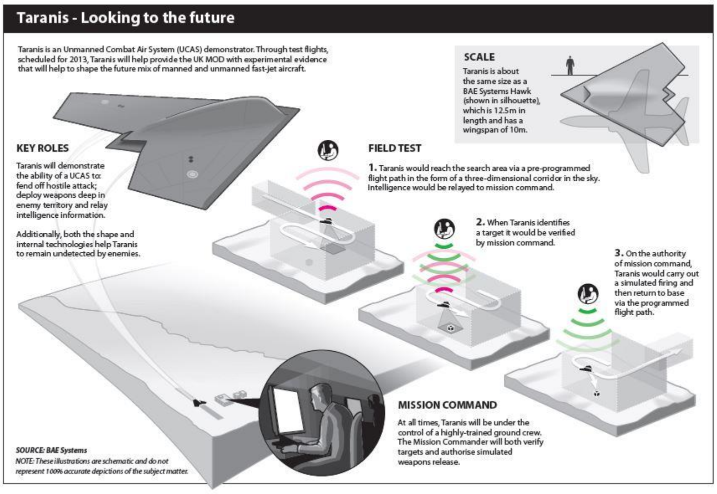

Fig. 18 - TARANIS UK Military Programme [71]

Named after the Celtic god of thunder, the £185 million Taranis concept aircraft [71] (See Fig. 18) is jointly funded by the UK MOD and UK industry. The Taranis demonstrator aircraft was formally unveiled in July 2010. It is about the size of a BAE Systems Hawk aircraft and has been built by BAE Systems, Rolls-Royce, the Systems division of GE Aviation (formerly Smiths Aerospace) and QinetiQ working alongside UK MOD military staff, scientists and other smaller companies. The Taranis demonstrator is the result of one-and-a-half-million man hours of work by scientists, aerodynamicists and systems engineers from 250 UK companies. The aircraft was designed to create an unmanned air system which is capable of undertaking sustained surveillance, marking targets, gathering intelligence, deterring adversaries and carrying out strikes in hostile territory. The aircraft has low observability, high levels of systems integration, supporting control infrastructure and full autonomy elements. The aim of TARANIS was to help the UK MOD and Royal Air Force make decisions on the future mix of manned and unmanned fast jet aircraft and how they will operate together in a Systems of Systems in a safe and effective manner.

Fig. 19 - Lockheed Martin Unmanned Aerial Vehicles [72]

Lockheed Martin are key proponents of Systems of Systems and produce a range of military autonomous vehicles for aerospace, land and underwater marine [72]. They also regularly send out press releases highlighting the

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importance of Systems of Systems to best meet future military power projection requirements. Two examples of their autonomous air vehicles are shown in Fig. 19. These are the Aerial Reconfigurable Embedded System (ARES) design concept which was developed as part of the Transformer (TX) program in 2009 [73]. Transformer aimed to develop and demonstrate a prototype system that could provide flexible, terrain-independent transportation for logistics, personnel transport and tactical support missions for small ground units. The other is the K-Max unmanned cargo helicopter which is designed to keep forward operating bases supplied, reducing the number of truck convoys, and the troops that protect them, on the dangerous roads of Afghanistan. Here difficult terrain and threats, such as ambushes and Improvised Explosive Devices (IEDs) can make ground-based transportation to and from the frontline a dangerous challenge. While manned helicopters can easily bypass those problems, they often present logistical challenges of their own and can subject flight crews to different types of threats. Additionally Lockheed Martin also make smaller Unmanned Aerial Systems such as Desert Hawk III that enables soldiers to see what is over the next hill and "persistent surveillance" platforms like PTDS, High Altitude Airships, Hybrid Air Vehicle and ISIS [73] to keep "eyes in the sky" over large areas for weeks, months and even years at a time.

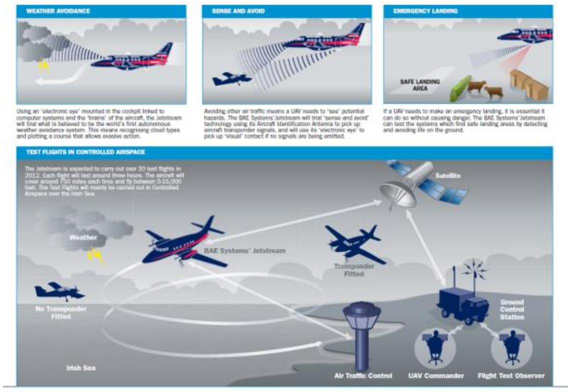

Fig. 20 - ASTRAEA UK Civil UAV Programme [74]

The ASTRAEA (Autonomous Systems Technology Related Airborne Evaluation & Assessment) programme [74] (See Fig. 20) is a UK industry-led consortium focusing on the technologies, systems, facilities, procedures and regulations that will allow autonomous vehicles to operate safely and routinely in civil airspace over the UK. The aim of the ASTRAEA programme is to enable the routine use of UAS (Unmanned Aircraft Systems) in all classes of airspace without the need for restrictive or specialised conditions of operation. This will be achieved through the coordinated development and demonstration of key technologies and operating procedures required to open up the airspace to UAS. The programme is a £62 million effort led by seven companies: Autonomous Decision Making SOftware (AOS), BAE Systems, Cassidian, Cobham, Qinetiq, Rolls-Royce and Thales. The programme consists of two separate projects:

Separation Assurance & Control – covering the particular technologies required to control the flying vehicle in the airspace considering the ground control station, the spectrum, security and integrity of the communication system and the vehicle's sense and avoid sensor system.

Autonomy & Decision Making – providing the intelligence within the vehicle through a variable autonomy system that shares decision making for the mission and contingency management with the human operator.

5.6 Comments and Discussion

Systems of Systems are not a new concept in the aerospace industry and there was considerable discussion and comment from this sector. There is a lot of military experience in the operation of aircraft and other assets within

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Systems of Systems and it is well known that military capability is enhanced through the synchronisation of force elements across time and space. Although Systems of Systems is a well-known term within military aerospace there is still a greater understanding of the concept of "combined operations". In a civilian context the same approaches can be used for more effective and focused disaster response by making best use of information and assets and indeed these are areas that are already being explored in EU funded Systems of Systems projects. With respect to civilian use for general aircraft operations the expectation is that Systems of Systems approaches to Air Traffic Management will reduce costs and delays with better integration of systems offering the opportunity to optimise gate-to-gate transits without on-the-ground delays or stacking before approach (with consequent reductions in emissions). Already air space is becoming congested and better coordination of aircraft and existing assets will allow for increases in capacity and real-time deconfliction of flight paths. This results in better performance and also monetary savings due to reduced need for capital equipment and more efficient utilisation of assets and resources.

The requirements for Systems of Systems depend on the application:

- For military and home-land security domains, the requirements are mainly performance, security, safety and human factors
- For crisis management the requirements are dynamic goal-driven
- For the civil domain, the requirements are economical, environmental, legal and social

It was noted by the industry that Systems Engineers are often stuck in a "requirements first" clean sheet design paradigm and are used to having a level of control over the system elements. This is not available to them in Systems of Systems engineering. Specification needs to be thorough in the context of real Systems of Systems use cases, which should be as simply and clearly articulated as possible. The key perception is that there is a need for a scientific foundation to handle multi-layer operations and multiple life-cycle management. Supporting this there is a need for modelling and simulation. Although modelling, optimization and simulation tools are useful in reducing the amount of investment needed for development there is also a need to link these with Validation and Verification applicability so that the modelling and simulations are also used to increase confidence in the Systems of Systems. The biggest problem in modelling is to access accurate enough "as built", "as tested" and "as configured" information. Often this information is jealously guarded by individual contractors, and not everyone who needs it can easily get access to it. Testing needs to be thorough in the context of real Systems of Systems use cases and also "mis-use cases". The relevant state space needs to be limited to contain the cost and maximise the relevance of the limited Validation and Verification resources and time available. Here the aviation industry has great experience. Any developed Validation and Verification procedures should allow Systems of Systems to be adopted in the public domain so there is a need to closely link research in this area with regulatory aspects.

A key aim in Systems of Systems engineering is to reuse existing systems, integrate them in an operational environment with new ones and obtain the benefits of the resulting synergy. Consequently, monetary savings and improved capability are drivers for Systems of Systems. However, often there is a problem putting a value on the (potentially large) marginal improvement in capability that will come from a (potentially relatively small) marginal investment in Systems of Systems capability. This results in high levels of uncertainty and over-selling of individual projects. This presents problems as projects are assessed on an individual basis in most organisations and the accountants tend not to have the tools for assessing Systems of Systems added value or if they do, they are based on a very different worldview from the engineering one. It is almost impossible to make a business case for Systems of Systems investment to create better marginal capability, because financial systems do not know how to put a value on "better capability". More usually the running costs are considered as these are more visible. As a consequence Systems of Systems activities tend to be funded when there is a consumer "pull" and the potential to create a big enough extra market that everyone believes they will benefit from (even given the level of uncertainty). Alternatively legislative and regulatory changes may drive the need for a Systems of Systems approach, e.g. reduction of greenhouse gases which, for instance, is also a target for SESAR. It was noted that often individual

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projects are underfunded and overspent. As a consequence the funding for interfacing and Systems of Systems integration are the first things to be traded out – they are seen as luxuries that might not be needed rather than as essential elements of the overall enterprise-level business case.

Decision making is also challenging due to the need to integrate decision makers of different types (e.g. autonomous vs human) and, in Europe in particular, the need to deal with different legislation. It is important to master the life-cycles of the constituents systems and resulting behaviour of the Systems of Systems. It should be noted that the aim is not to have strong integration; but to have dynamic integration along the life-cycle of the Systems of Systems in order to take into account addition and suppression of constituent systems, their evolution and the emerging effects. The challenge in rolling out a Systems of Systems are the asynchronous lifecycles of constituent parts and also the fact that many components are developed independently. The key is to make sure that the integration is loosely coupled so that integration can happen in any order, or at least such that useful capability is achieved by many different partial Systems of Systems configurations. This ensures that everyone is incentivised to join the Systems of Systems because they get benefit for each integration step. To support this the interfaces must be simple and easy to test. Another important research area is the interaction between Systems of Systems and the systems they are meant to replace as during staged roll out they need to co-exist with existing systems. Once rolled out operating and maintaining a Systems of Systems requires a good knowledge of the "as-deployed-and-configured" system physical, functional and behavioural configuration.

Considering the development of Systems of Systems, companies have to demonstrate their ability to manage huge complexity. Leading companies in the area, e.g. THALES, Cassidian, etc. have demonstrated their ability in already deployed systems, e.g. for homeland security, that indicate that there is maturity in methods, processes, skills and competencies. The actual differentiators between companies are the knowledge and the usage of Architecture Frameworks, Systems Engineering norms and standards.

Looking to the future there is a need for communication standards between systems, however it is difficult to judge at what level this should occur (e.g. is one standard for all system types viable, or are several standards for different system types a better choice). Cassidian, for instance, validate all communication protocols used in a system including those used in legacy parts of the system as there is a need to guarantee a Quality of Service to maintain operation. Again, communication between the systems is paramount, as well as an increased level of autonomy to deal with the times when communication may not be possible. For Systems of Systems that do not operate in a strictly controlled environment, dynamic reconfiguration is key.

Finally, there is a need to not only consider the technical issues but also training, equipment, people, information, doctrine and process, organisation, infrastructure and logistics. These all need to be considered and aligned to be successful in Systems of Systems development.

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6 STATE-OF-THE-ART IN THE MARITIME SECTOR

6.1 Drivers within the Maritime Sector

By far the most efficient mode of transport for the movement of goods, the shipping sector is expected to grow by 150-250% over the next 30 years. Here Systems of Systems thinking is leading to integrated world-wide ship management systems being linked with ship fouling efficiency metrics and navigation systems to optimise performance to reduce fuel consumption and emissions. The introduction of emissions monitoring [75] has led to new operational approaches such as “slow steaming” for products that are not time critical. Logistically there are complex interactions in the movements of containers around the world to ensure that shipping and handling costs are minimized with tight linkage into the appropriate rail or road haulage network to move the goods onwards as quickly and efficiently as possible.

European shipbuilders are world market leaders by turnover [6]. In particular Europe produces nearly all the high value cruise ships in the world, around 50% of all equipment suppliers’ products are exported outside Europe and almost 100% of the dredging technology and know-how is European. From a fleet management perspective around 40% of the world merchant fleet is controlled by European companies and approximately 25% are flying the European EEA flag. Of the top 5 world ports, 3 are European and the European Oil & Gas Service Industry is also a world technology leader, exporting 70% of products. The European maritime industry is spearheading environmentally friendly technologies, e.g. European equipment suppliers have provided on-board total waste management systems ahead of future environmental regulations.

A key driver in the maritime industry is improving safety of waterborne operations. This is because recent maritime disasters and accidents in inland navigation have shown that accidents come with high costs in terms of loss of life, environmental damage and with high economic impact. Additionally, high profile accidents have tarnished the overall image and public perception of the waterborne sector. With the increase in cargo traffic in busy North Sea lanes there is a need to maintain safe operations of cargo vessels. At the same time passenger cruise ships have also got bigger and are now operating in non-traditional, remote and difficult regions such as the artic with new and increasing risks. Passengers have high expectations for comfort and a wide range of on-board amenities. The current research drivers are to develop and demonstrate innovative solutions for ship design and waterborne operations to avoid and mitigate passenger risks and ensure high levels of safety.

The industry believes that new technologies for maritime traffic management will be key for safer and more secure operations. In the marine sector there is great interest in optimised shipping operations and voyage optimisation, condition based maintenance, reducing costs and reducing emissions. Local legislation has resulted in emissions monitoring being introduced in ports and local governments have introduced their own requirements. The drivers are for reduced maintenance, enhanced asset life, reduction in crewing levels through increased automation and fleet optimisation via shore based decisions. Key enablers in the industry are the introduction of VSAT systems [76] that allow much greater data rates for data transfer.

There is also a drive for a more integrated transport chain. To reduce congestion in ports and port fairways, port traffic guidance systems need to be at the same time cost efficient and easily deployable. Synergies with existing systems should be ensured, with the aim of integrating the use of port traffic guidance tools by all relevant authorities and ensuring the full interoperability between Information and Communication Technologies (ICT) systems, which monitor vessels, freight and port services.

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6.2 Waterborne

Fig. 21 - WATERBORNE European Technology Platform Research Summary [78]

In Europe the marine industry has come together with the aim of providing sustainable waterborne transport for the future. To support this the WATERBORNE European Technology Platform [77] has been created with the aims highlighted in Fig. 21 [78]. The WATERBORNE initiative was driven by the Maritime Industries Forum (MIF) and its R&D Committee in 2005. Waterborne identifies R&D requirements for European competitiveness in the industry and the innovation and research needs to meet new regulations for safety and environmental goals. The programme is very wide with stakeholder coverage from deep and short sea shipping, inland waterways, ship yards, equipment manufacturers, the marine leisure industry, research and university institutions and classification societies. In addition to a stakeholder Support Group, there is a Mirror Group of government appointed delegates. The WATERBORNE TP published a Vision 2020 paper in 2012 [79], a Strategic Research Agenda in 2011 [80] and an Implementation Plan in 2011 [81]. These documents are being used by the European Commission to direct calls under the R&D workprogrammes and also national R&D programmes. They are also being used by industry to guide research and development.

6.3 Marine Vision 2020 and Strategic Research Agenda

Although waterborne transport is the most sustainable, fuel-efficient and environmentally friendly transport mode, special consideration is required of the consequences of accidents, particularly in sensitive coastal areas. As a mode of transport ships have the capacity to transport very large quantities of cargo or large numbers of passengers, consequently there must be a strong focus on safety and also environmental protection. The development and expansion of port capacity is required but care must be taken to preserve natural habitats in surrounding areas. Additionally, security is increasingly an issue and operations must be protected against threats. The EU shipping industry working with public authorities has progressively enhanced safety at sea and introduced greater measures to protect the environment and is actively promoting this on an international basis. The Vision 2020 paper [79] produced by the industry highlights the needs for effective designs, systems, procedures and techniques to increase the level and reliability of the ship system's performance, with the goal of a "zero accident" record. To do this there is a need for research into:

- Effective means to avoid accidents
- Robust ships and reliable equipment
- Improved survival in extreme conditions (ice, freak, waves, etc.)
- Competent crew, ship management and shore operations

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Fig. 22 - Innovation Challenges: Traffic Management, Integrated Supply Chains, Port Efficiency [79]

Supporting this there is a drive to improve man-machine interfaces and decision support systems to minimize impact of human error. Ships built in Europe will be equipped with on board systems for performance monitoring (see Fig. 22) with the aim of reducing life cycle maintenance and also providing safer operation. This will include monitoring and failure prevention strategies and systems for corrosion and wear monitoring. This requires the development of predictive maintenance and inspection capabilities to support the whole life cycle. For safer operations cheap, fool-proof and safe communication and identification equipment needs to be developed to support smaller coastal craft (e.g. fishing and recreational craft, craft with amateur crew) that can be integrated within traffic management systems. This is required if a political decision driven by safety is made to include all small coastal craft in traffic management systems. Additionally, safe and efficient data models and algorithms will be required to cope with the expected huge numbers of traffic participants. If no political decision is made safety is still a concern and so alternative safe and user friendly strategies to traffic management also need to be developed.

Emissions are another key issue and a 'zero emission' approach, to SOx, NOx, CO_2, PM, VOCs presents a technological and economic challenge particularly as approaches to reducing one pollutant tend to increase the emissions of other pollutants with different options being needed for a variety of ships.

Efficient data models and algorithms are needed to manage operations in high risk / dense traffic sea ways. Additionally they are required for port approaches and port call preparation. From a human factors perspective these need to be supported by optimal and easy to handle man-machine and communication interfaces for implementation of complex integrated traffic management systems. Shipping information systems need to be integrated across inter modal boundaries. The expectation is that in 2020 the costs of waterborne transport will still be lower than other modes, however there is a need to continuously improve the efficiency of all elements in the waterborne transport chain. The aim is to maintain a cost level of approximately 20% (or less) compared to road transport through introductions of new ICT based technology and improved integration and optimisation of systems. Fully integrated European supply chain systems are to be developed and optimized with a Systems of Systems approach, addressing the combination of the different transport modes in terms of costs, reliability, safety, environmental friendliness, ease of choice, integration, security and market demand. The Waterborne Strategic Research Agenda [81] focuses on three themes:

- Safe, sustainable and efficient waterborne operations
- Maintaining a competitive European maritime industry
- Managing and facilitating growth and changing trade patterns

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These are subdivided into topic area such as short-sea shipping, inland waterways, ship design, operation, and maintenance, maritime safety and ports and port operations. Within each of these areas a number of projects have been funded. In the area of short sea shipping several projects address aspects of Systems of Systems. These include activities on regional and coastal traffic management, decision support systems and logistical integration. At the inland waterways level research is being performed into tele-maintenance, intelligent ship operations and data management. In the topic of user comfort and quality there are a number of projects addressing efficient and environmentally friendly ship operations, navigation and information management and management of hazardous goods. Within the area of ports and port operations there are a considerable number of projects investigating topics such as environmentally friendly shipping operations, efficient management of passenger terminals and support tools to help ports improve shipping operations.

6.4 Horizon 2020 Call

Under mobility for growth 2014-2015 there is a major programme [82] supporting innovation actions to develop safer and more efficient waterborne operations through new technologies and smarter traffic management. The key areas related to ICT and Systems of Systems are:

- New and improved systems for the surveillance, monitoring and integrated management of waterborne transport and other activities (commercial and non-commercial).
- New and cost effective European Global Navigation Satellite System (European GNSS)-based procedures for port approach, pilotage and guidance, ICT-enabled shipping lanes and maritime services that will reduce the risk of accidents and incidents in port approaches and dense traffic lanes, and minimise both delays and turn-around times.
- For traffic management, solutions that support the extension, integration and optimisation of waterborne transport information and communication systems with the aim of contributing to build a comprehensive "e-maritime" environment (including e-Navigation components that are compatible with existing or emerging international standards). The objective here is to build a “European Maritime Transport Space without Barriers” allowing waterborne transport (including inland navigation) to be used to the full potential within an integrated intermodal logistic chain.

Of particular note is that the call is asking for solutions that will also provide the foundation for the deployment of autonomous and actively guided ships as well as the possibility to verify all related safety certificates before a vessel enters the port. This is to support the future long term goal to reduce crew numbers still further and move towards autonomous and actively guided ships. In parallel with the research activities there is a need to also provide inputs into EU and international regulatory regimes. An aim is to promote standardisation and international research co-operation particularly in the areas of safety devices and e-Navigation solutions.

The expected impacts are to:

- Achieve significant improvements in terms of navigational safety and efficiency (in particular emission reductions) along the entire waterborne transport logistic chain, and decrease administrative burdens
- Facilitate the transfer of new safety concepts from passenger shipping to other areas of maritime operations
- Show a statistically relevant decrease in the number of fatalities caused by maritime accidents, the number of ship losses and specific incidents such as fires or black-outs accompanied, where relevant, by operational empirical evidence
- Support the upgrading of international maritime safety regimes through relevant inputs

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6.5 e-Maritime

The EU e-Maritime initiative [83] aims to foster the use of advanced information technologies for working and doing business in the maritime transport sector. Maritime transport administrative procedures are complex, time-consuming and, even today, are quite often done on paper so there is a need to embrace modern ICT technologies and ways of doing business. Major European ports have deployed advanced information systems. These deliver considerable quality and efficiency gains, however, currently there is no interoperability between port information systems. From a Systems of Systems perspective this limits the potential for new services and economies of scale. Small ports may not have any electronic data transmission capabilities at all. The usual practice is that shipping companies at each port manually enter the same data repeatedly, resulting in duplication and errors.

For the next generation of sailors (the "Internet" generation) access to cyberspace is a must. e-Maritime aims to stimulate coherent, transparent, efficient and simplified solutions in support of cooperation, interoperability and consistency between Member States and transport operators.

Going beyond e-Maritime there is also an activity to provide a mechanism for a Common Information Sharing Environment (CISE). This is currently being developed jointly by the European Commission and EU/EEA member states [84]. It will integrate existing surveillance systems and networks and give all concerned authorities access to the information they need for their missions at sea. CISE will make different systems interoperable so that data and other information can be exchanged easily.

6.6 Highly Automated Marine

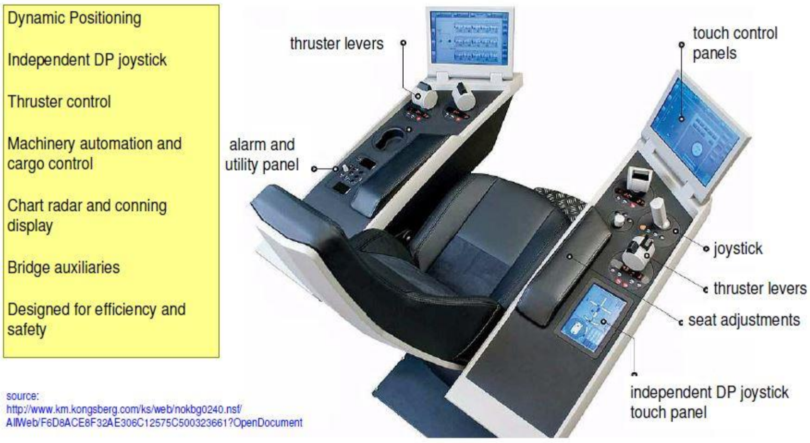

Fig. 23 - Captains Chair (Wartsila)

Modern ships are operated with much lower numbers of crew than in the past. This has been achieved by introducing much greater levels of automation and also through more advanced on-ship monitoring systems. Within a Systems of Systems interactions with users and the Human Machine Interface are highly important. New systems are providing key information directly to the captain or first officer allowing much greater situational awareness and the ability to control a myriad of systems (See Fig. 23). This not only includes the ships systems, e.g. chillers, etc., but also functionality such as deck winches, anchors and station keeping linked with GPS technologies controlling thrusters around the ship. New advanced systems are being designed to optimise operator comfort and improve ergonomics. Much work has been done for instance by

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Rolls-Royce on monitoring eye movement, if there is excessive scanning this may indicate that the operator is confused so positioning and displays are placed such that very precise eye movements are seen [85]. Reducing unnecessary scanning so that the user does not have to search for information leaves more mental capacity (less cognitive load) to handle safety critical situations, which can actually mean the difference between incident and accident in many situations. Movement of a display by a few centimetres can be the difference between operating in a relaxed position where the operator leans on the chair's backrest versus that where the operator has to lean forward numerous times to touch a display that is just out of reach. This causes annoyance and strain and increases cognitive load.

Fig. 24 - Rolls-Royce Unified Bridge [85]

With reduced crews covering more ergonomics become a much greater requirement and the Rolls-Royce unified bridge (See Fig. 24) has been designed to ensure low reflection of sunlight during day operations, and common dimming to ensure good night time vision, and clear views of the deck. The front end of the consoles has been angled so that the operator can have an even better ergonomic position during operation and the winch and anchor handling operations are specially designed to minimise strain on the operator. Levers and emergency switches have been placed in easily recognizable positions. Bridge chairs have been made flexible enough to support both seated and standing operation and are designed to better enable the operator to vary their posture.

6.7 Unmanned Ships

Fig. 25 - Rolls-Royce Unmanned Ships Concept [86]

Rolls-Royce’s Blue Ocean development team has set up a virtual-reality prototype that simulates 360-degree views from a vessel’s bridge [86]. The idea is that eventually captains on dry land will be able to use similar control centres

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to command hundreds of crewless ships. Drone ships would be safer, cheaper and less polluting for the shipping industry that carries 90 percent of world trade (See Fig. 25). The European Union is funding a 3.5 MEuro study called the “Maritime Unmanned Navigation through Intelligence in Network” project which will produce a prototype for simulated sea trials to assess costs and benefits. The Rolls-Royce design for an autonomous ship (See Fig. 26) has no bridge with just containers from front to back. By replacing the bridge and the systems that support the crew, e.g. electricity, air conditioning, water and sewage, the ships can be 5 percent lighter before loading cargo and would burn 12% to 15% less fuel. Additionally, from a financial perspective figures show that a crew costs $3,299 a day and account for about 44 percent of total operating expenses for a large container ship.

There are considerable hurdles to adoption of unmanned ships coming from regulators who are concerned about safety and unions who are concerned about job losses. In fact current regulations dictate minimum crew levels by international conventions. The country where a ship is registered is responsible for regulating vessels within its own waters and for enforcing the international rules. The international IMO regulations apply to seagoing vessels trading internationally and exceeding 500 gross tons, except warships and fishing boats. If drone ships do not comply with the IMO rules, they would be considered unseaworthy and ineligible for insurance. There is, however, interest in deployment of unmanned ships in the Baltic Sea. The expectation is that computers will gradually increase their role in navigation and operations reducing crew levels further. Container ships and dry-bulk carriers are the most likely first candidates for total autonomy as tankers carrying hazardous materials such as oil and liquefied natural gas will probably remain manned longer because of the perception that having a crew on board is safer.

To successfully replace crews unmanned ships will need constant and comprehensive computer monitoring to anticipate failures in advance and “redundant” systems to maintain availability. Computer systems can also be used to analyse ship information and optimise performance. Cameras and sensors can already detect obstacles in the water far better than the human eye. Of particular note is that human error causes most maritime accidents which are often related to fatigue. Unmanned ships would also reduce risks such as piracy, since there would be no hostages to capture, however, ships would become vulnerable to a different kind of piracy from computer hackers.

6.8 Ocean Monitoring via Surface and Underwater UAVs

Already it is possible to download free Apps that allow the real time position and pictures of the ships to be shown on Google Earth (see http://www0.marinetraffic.com/ais/ge_marinetraffic.kml). However, this only gives information of where vessels are, not what is actually happening at sea. The world's oceans cover 71% of the Earth's surface, yet, they are the least understood and most vulnerable resource on the planet. There is interest in monitoring accidents at sea, pollution spills, ocean acidification, wildlife, and also the relationship between the oceans and climate change. Traditionally, large ships have been used to take measurements, however, ships are very expensive and burn huge amounts of polluting diesel fuel during their operations. There are now several companies such as Saildrone [87] and Liquid Robotics in California working jointly with Fastwave Communications in Australia [88] producing unmanned self-powered sea gliders, and drifting bouy's for monitoring at sea. The Wave Glider [88] for instance is a low-profile, unmanned surface vehicle that is capable of long-range, extended deployments (up to one year) with minimal human intervention. It is propelled by wave generated energy, with solar panel arrays providing power for on-board communications, sensor payloads and computing. Typical applications include marine environmental monitoring, maritime surveillance, metocean data acquisition, fisheries and aquaculture management, marine mammal detection, dredge and outfall plume monitoring, CO_2 studies, hydrocarbon detection and pipeline leak detection.

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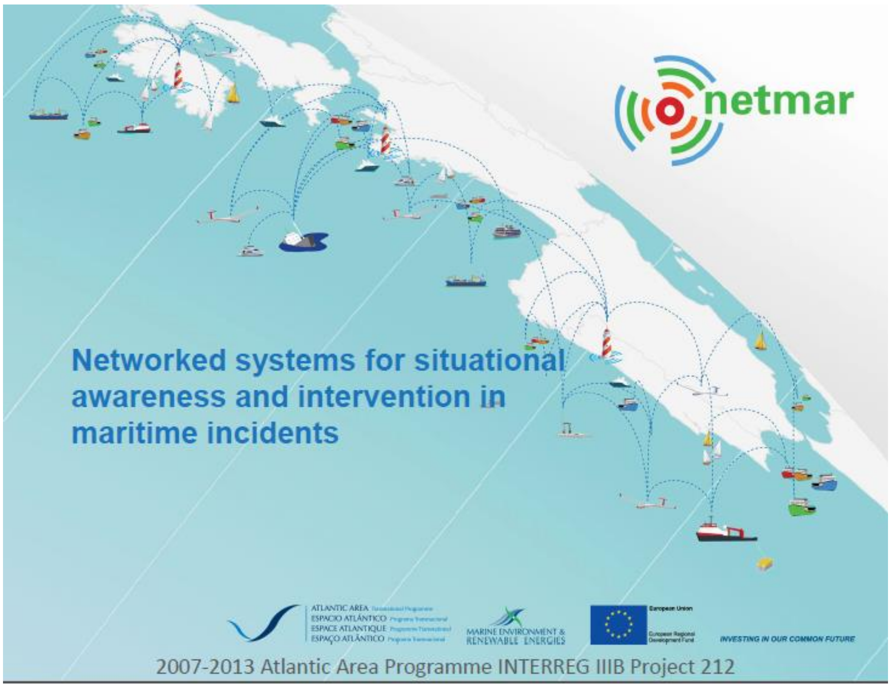

Fig. 26 - Netmar – Situational Awareness and Monitoring in Maritime Incidents [89]

Most of the current work is investigating the development of the individual platforms themselves but more recently deployments of multiple vehicles in Systems of Systems has been performed such as the NetMar deployment of surface and aerial vehicles to monitor a stretch of coast [89] (See Fig. 26). Monitoring of the oceans is seen as a major opportunity and Google are taking a lead in this organising the Ocean Agenda Conference [90] with the aim of gathering people together to exponentially accelerate and enhance the protection of marine life using new technologies. Already examples of sea life tracking have been demonstrated such as in May 2014 a team from Porto, working with researchers from the United States, Spain and Norway tracked tagged Ocean Sunfish (the largest bony fish in our oceans) using a combination of autonomous aerial, surface and underwater vehicles off the coast of the Algarve near Olhão [91].

At the European level the FP7 PERSEUS project [92] is developing a new maritime Systems of Systems surveillance system. This aims to increase the effectiveness of the current systems by creating a common maritime information sharing environment for the benefit of National Coordination Centres, Frontex and the European Maritime Safety Agency (EMSA). The solution will provide a description of the situation from coastal areas to the open seas in real time improving and automating detection and identification of suspicious or non-collaborative vessels, facilitating decision-making and reducing the response time of authorities. It will also help in interception and rescue missions at sea. The system will detect small boats and low flying targets through the integration of sensors and capacities. Interoperability among different institutions and states is an aim with integration of the new system with existing systems. Information will be fused to provide a common operational picture at regional and European levels. The data will be integrated and processed for better quality, thus obtaining filtered, reliable and more useful information. In particular, PERSEUS will support the implementation of EUROSUR. The project also plans collaboration with non-European countries and international agencies such as NATO and the International Maritime Organisation (IMO).

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6.9 Comments and Discussion

The maritime industry is being driven by the problems of increasing traffic in already congested waterways. Still by far the cheapest way to move goods around there is a continuous drive for improvement and reduction in shipping costs. This is being addressed through the introduction of ICT technologies and algorithms to optimise shipping movements and port operations. There is also a big drive to improve safety across all types of shipping due to high profile accidents. The increasing size of passenger ships and their operation in more remote and inhospitable locations is also leading to more concerns about safety. In recent years emissions have also become a major issue and local ports have introduced restrictions on operations. At an international level restrictions and legislation, e.g. IMO Tier III [75], is also driving for increased monitoring of emissions. The commercial requirements are for high performance, fuel cost reduction**,** reliability**,** safety**,** lower capital expenditure and lower operating expenses (maintenance). The business aims for suppliers are for simplification of the total system for the end customer.

In discussions with the maritime industry it is apparent that the concept of Systems of Systems is not a known term. There is more an idea of operations, fleet management and logistics of moving containers and goods. It is clear that Systems of Systems exist in the industry but currently there is a fairly low level of use of ICT and little connection between systems. The advent of supporting Satellite systems such as those from Inmarsat are introducing the capability to provide connectivity to ships which enables transfer of considerable amounts of data. Presently there is not a clear view of what data should be transferred and how this should be used. The fact that ships are regularly sold on to other ship owners makes investment in on-board technology such as monitoring more difficult as installed expensive equipment may be lost within a few years. The suppliers of equipment, e.g. Rolls-Royce, are now building in monitoring for their own equipment which is provided free as part of the package. The data from these systems goes back to the suppliers rather than the ship owners and helps with product improvements. The ship owners are offered the option of purchasing monitoring and management services by the suppliers, e.g. in power-by-the-hour contracts. In general at present there is a low uptake of monitoring technology in shipping with a tendency towards scheduled maintenance rather than on-condition maintenance.

The industry has very good system integration engineers as ships are highly complex systems but they may not think in a Systems of Systems way. The ship builders produce the ships and their systems but the operators are the ones who would benefit from a Systems of Systems approach. A Systems of Systems approach would allow much better coordination of port services around Europe and advances in this area are being driven by actions such as Waterborne and e-Maritime. The introduction of data exchange standards would be a major move forward allowing current installed systems to become interoperable. The increasing use of ICT within the industry and the new internet savvy crew and operators offer great potential for improvements in efficiency.

In the area of safety improved navigation systems, traffic management algorithms for busy sea ways and ports will improve safety and looking to the future there will be an increase in autonomous ship operations as crew levels are gradually reduced leading in the longer term to unmanned ships once regulatory authorities are happy that this is safe.

As systems become more interconnected it will be possible to combine mixes of autonomous underwater, surface and aerial drones to monitor accidents at sea, pollution spills, ocean acidification, wildlife, and also the relationship between the oceans and climate change. This is an area that is still in its infancy but already fairly large scale deployments are being trialled identifying Systems of Systems of issues. Much of the technology push here is on development of vehicles that can operate for long periods as this is a prerequisite for cost effective deployment. It

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is interesting to note that monitoring of the oceans is seen as a new commercial opportunity and this is supported by Google's interest in being a central player in this area.

7 STATE-OF-THE-ART IN THE LOGISTICS SECTOR

Fig. 27 - Logistics Issues – Traffic Jams [photo dpa-Zentralbild], Congestion from Deliveries [photo Abenblatt.de]

The consumer marketplace is becoming increasingly volatile, fragmented and dynamic being dominated by extreme service level requirements, multi-tier distribution networks, and a myriad of high- and low-volume stock keeping units [93]. Order-to-delivery excellence is now a key requirement for demand management driving new business models and Collaborative Transport Management. Customers expect on-time delivery with an eco-conscious approach driving Supply Chain Sustainability initiatives to reduce fuel consumption and lower emissions. Information provided by modern ICT systems is available at all levels of the supply chain offering unprecedented opportunities for optimization. Successful supply chains rely on complex System of Systems for accurately forecasting market demand, formalizing vendor-managed inventory consignment, reducing stock levels and focusing on buying/manufacturing inventory only when it is needed.

The challenges are that transport volumes keep growing globally (See Fig. 27) leading to congestion on roads, however, the sizes of individual shipments are not increasing and indeed there is a move towards shipments of smaller loads [94]. The move towards global sourcing has changed the dynamics of logistics. For example, 10 years ago 90% of the parts for a car would come from factories within a 200Km radius, now the parts are sourced from a world-wide supplier base. Customer service expectations are high with demands for fast and efficient on-time delivery. In order to execute transport tasks efficiently transport service networks play a vital role. These networks are dedicated, e.g. to parcel, express or less-than-truckload-shipments and related logistic services. Analysis and optimization of their structure can provide great benefits in terms of efficiency and also fuel cost and emissions reductions. More efficient operation of nodes (depots, hubs, terminals) provides greater throughput and lower latency. To support this operators are increasingly turning to simulation models to achieve robust solutions that improve their efficiency, reduce handling costs and increase the performance of their terminal operations. A key challenge is to link between material flow simulation and arriving and departing traffic.

The task of delivery in urban areas increasingly is leading to congestion (See Fig. 27) and ways of bundling deliveries at local hubs to reduce the numbers of vehicles making deliveries is also challenge. Urbanisation is a key challenge and air quality directives such as Euro 6 [95] are driving new truck and powerplant design. Likewise stricter standards are being introduced in the USA and China for fuel economy and emissions.

This is challenging for truck manufacturers who want to sell trucks on a world-wide basis where the term “long haul” means different things and fuel quality varies greatly. The requirements in different countries are also a factor. In China the key customer requirement is for safety as most truck drivers are owner operators. In India most trucks are owned by operators and here fuel economy is the key requirement. The dimensions of trucks are also strictly regulated which limits what is possible aerodynamically. Although aerodynamic additions can reduce fuel consumption by about 5% this is only at higher speeds (80Km/hr) and these can easily be negated by poor driving.

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At lower speeds the rolling resistance of tyres is the most important factor in efficiency. Design shows that larger trucks and double trucks would be far more efficient (around 35%) but this is not possible politically due to public opposition to larger vehicles. Additionally, member states have regulations in place that dictate that trucks cannot operate at night during curfews in urban areas. As a consequent trucks are often also operated in the rush hour traffic which increases fuel consumption by 50% as trucks are highly inefficient when stopping and starting. There are thus a number of political and public acceptance problems which need addressing in order to achieve significant improvements in operational efficiency and emissions reductions.

The trucking community is familiar with the use of ICT and already automatic tolling systems are used across Europe, however, there is a lack of harmonisation of systems and to operate across all of Europe a lorry driver needs a myriad of different devices on the dashboard. For main routes across Europe drivers typically need 7 different tolling devices.

The use of telematics and connectivity is seen as the future to make major improvements in management of freight efficiency, emissions, safety and personal effectiveness. Take up of telematics is, however, still low in the industry as the average fleet size in Europe is 10 trucks. Medium to large companies account for around 25% of the trucking companies in Europe and small companies for the remaining 75%. There is also driver resistance to being tracked. Typical experience shows that just by introducing a tracking device on a vehicle there is a 5-10% saving in fuel – indicating that drivers do not always use their vehicles for work.

There are a number of potential benefits from introducing tracking. These include monitoring of driving behaviour which can be fed back to the driver (highly fuel efficient trucks do not make a difference if the driving is bad), provision of routing to the cheapest petrol stations, and reductions in insurance claims (from providing proof of speed, etc. in court cases). Additionally, monitoring of key truck parameters can be used to optimise efficiency, e.g. truck tyre pressures have a big impact on efficiency, and there is a great interest in moving from remote diagnostics to prognostics as batteries and tyres account for 50% of breakdowns. Already companies such as Scania give away a free telematics system with all of their trucks and currently 800,000 vehicles are fitted with it. Services are provided based on this and customers have the option of buying them.

The key benefit of telematics is in gathering and exploiting data in fleet management. Customers want to know every minute where a delivery is and there is a move from reactive to proactive operations through data mining of big data. A major issue that contributes to unnecessary fuel consumption and emissions is the shipping of goods in half empty trucks and the return of empty trucks (where there is an immediate 40% penalty in fuel consumption). Means of co-ordinating and optimising deliveries across fleets of vehicles can thus bring huge savings.

7.1 DHL GOGREEN Initiative

The DHL GOGREEN initiative [96] is introducing optimized transport routes, alternative drive vehicles and energy-efficient warehouses to reduce CO_2 emissions and other environmental impacts in the transportation and storage of goods. By 2020 the company aims to increase the carbon efficiency of its operations by 30% compared with 2007 levels. Already the company has achieved a 10% reduction. Sustainability is seen as a competitive factor driven by consumer demands and also by investors who consult sustainability rankings when looking for viable investment options. To address this the GOGREEN initiative is considering a complete view of emissions with the aim to “burn less and burn clean” across all vehicles, buildings and aircraft. Already there are 11,500 green vehicles on test utilising a mix of electric and alternative fuels. A systems approach is being adopted and solar panels are used to charge electric vehicles at warehouses and a new rail link to China is being used as an alternative to flying goods. This allows goods to be shipped from China priority within 7 days by air or 28 days by rail depending on customer requirements.

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The company provides Carbon Reports and a Green Optimization service to identify ways to minimise greenhouse gas emissions and improve overall environmental performance. Carbon accounting has been integrated into financial accounting systems so that the emissions are automatically calculated from fuel and electricity consumption data. To compensate for unavoidable emissions a climate neutral approach is offered using energy provided by solar panels and wind turbine energy.

7.2 United Parcel Service

UPS perform 17 million shipments per day and are moving from being a trucking company to being a “technology company with trucks” with extensive use of package routing technology and telematics. All road, rail, air and shipping hubs are connected by a private IT system to provide a single network for all categories of service. They have obtained huge savings from network efficiency through development of the ORION (On Road Integrated Optimisation and Navigation) system [97] for predictive and prescriptive operations. This provides an in-cab computer that performs highly complex optimisation of deliveries to minimise miles driven and minutes vehicles spend idling while at the same time maximizing the number of pickups and deliveries made per litre of fuel used. It also gathers information on driving behaviours (which can be used to identify and improve driving performance to reduce fuel consumption) and collects information on mechanical variables from the engine and drive train that can be used for on-condition maintenance saving money and reducing waste (parts, oil, etc.).

Vehicles are used as rolling laboratories and data has been collected for 185 million miles since 2000. Small adjustments to operations can be made with large payoffs over 100,000 drivers around the world. For example, the most efficient vehicles can be matched to routes, the number of stops and starts performed can be minimised and safety can be improved by minimising backing up required in residential areas (which are full of other vehicles, fixed objects, people and pets).

In 2010 telematics-equipped vehicles eliminated more than 15.4 million minutes of idling time saving 103,000 gallons of fuel (and avoiding of 1,045 metric tonnes of CO_2). Additionally, the number of stops per mile were reduced delivering more packages with fewer engine restarts that consume fuel. The use of telematics saved 1.7 million miles of driving in 2010, equating to more than 183,000 gallons of fuel or 1,857 metric tonnes of CO_2. The company is also increasingly using electrification for local deliveries and biomethane as an alternative fuel for larger trucks to further reduce emissions.

7.3 Carbon Footprint

The growing freight transport sector is a major contributor to greenhouse gas emissions. Several initiatives exist for the calculation of the carbon footprint of freight transport chains. However, there are problems in terms of comparability, transparency and accuracy since these initiatives are based on different starting points, approaches or intentions in development. The EU co-funded project COFRET (Carbon Footprint of Freight Transport) [98] is developing a unified approach to calculate logistics related carbon footprint emissions along complex supply chains. Likewise there are efforts in the logistics industry to harmonise the measurement of emissions from trucks for specific driving cycles and introduction of badging of truck CO_2 efficiency by Green Freight Europe [99].

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7.4 Physical Internet for Logistics

A key issue is that logistics is changing to become far more dynamic. Customers demand flexible processes and this is being enabled by the increased use of technology. Networks are worldwide offering a range of individual services with a large number of different items. This presents great challenges in planning and controlling of logistical systems as information through the network is distributed and fragmented. To meet these needs the Physical Internet (PI) approach has been proposed [100] to provide an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols. An aim is to link classical distribution networks to better utilize transport and distribution resources. This would allow movement from point-to-point or hub-and-spoke transport networks to distributed multimodal transport networks with flexible, shared use of resources. This will enable better utilization of nodes within logistics networks.

Looking to the future cooperation between different retail and transportation companies would allow efficient group urban deliveries through local hubs. Here already there is work on a cloud-based tool [100] to support multi-modal transport chains and a global consolidation of freight. This includes a web application that can detect possible savings and the screening of transport flows for potential for combined transport including grouping potentials across companies.

7.5 Autonomous Vehicles

Fig. 28 - Automated Picking Machine [100]

At the warehouse level there is a lot of interest in the use of smart items and sensors based on Internet of Things technologies. Here it is believed that the future is a distribution of central control to a multiplicity of small self-organized units. Already autonomous vehicles are used in warehouses for picking goods for dispatch (See Fig. 28) and there is interest in automatic adaption to environmental changes without the need for reprogramming through communication between infrastructure and the vehicles.

Supporting this there is work on infrastructure to vehicle communications through concepts such as the Intelligent Bin in the InBin project [101]. Here the Intelligent Bin can communicate with people and autonomous machines allowing better control of logistics processes and management of the picking process. The bin can also manage its own environmental conditions monitoring temperature, vibration and position.

As warehouses become more complex there is interest in safely operating swarms of autonomous transport vehicles to perform tasks. The aim is to replace inflexible conveying systems by autonomous transport vehicles.

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Here the swarm is responsible for the task of transportation with scheduling being done within the group. This potentially will Increase flexibility and changeability allowing simple scale-up and scale-down of systems.

In the trucking sector more driver assist systems are being added such as detectors for blind spots and cyclist detectors but these are causing concerns about information overload for drivers operating in urban areas. Autonomous driving for trucks is possible but too expensive at present. There are also a number of implementation issues including the need for trucks to be connected to cars. Platooning of trucks has been considered but a driver needs to consider which road chain to join, is the driver in front an efficient driver and will joining the road chain compromise the required delivery time. There is also pressure on truck designers to produce more aerodynamic trucks when a “brick shaped” truck would be more efficient in a platoon.

Fig. 29 - Amazon Prime Air [102]

Going one step further Amazon are developing their Prime Air concept [102] with drones that deliver packages to customers (See Fig. 29). The main goal of the new delivery system is to get packages into customers' hands within 30 minutes or less using unmanned aerial vehicles. Actual deployment of such systems is still many years away as a major barrier is gaining approval from the FAA for operations. This would be even more complicated for operations in Europe due to the more fragmented nature of airspace control. Amazon do not see this as an issue but rather an opportunity to work on the underlying technology and improve payload and endurance which are presently very limited.

7.6 Comments and Discussion

Systems of Systems is not a new concept in the logistics domain with world-wide distribution systems being in place already for many years. The industry is facing new challenges in the shift from large individual shipment sizes to shipments of smaller loads. The transport volumes are thus growing rapidly introducing challenges in cost, emissions reduction and increased congestion on roads and in cities. At the same time customer service expectations are increasing with the need for order to delivery excellence. The universal nature of interconnectivity is allowing the design of co-operation networks to deliver goods. Here there is a need to create synergies and incentives and develop new service concepts. Data and knowledge are becoming key competitive criteria with tracking of items through the logistics chain being the norm and companies competing to provide efficient and cheaper services. The underlying ICT technologies for tracking and exchange of information are thus already largely in place.

A problem with increased interconnectivity in logistics Systems of Systems is that it exposes them to external risks, such as natural disasters and organized crime. Security and flexibility to reconfigure are thus key prerequisites and concerns. Congestion is a growing problem and there is a need for incentive schemes that produce a more balanced use of the vehicle, facilities and traffic infrastructure. The key aim here is to drive demand and reduce traffic bottlenecks. Schemes that allow bundling of deliveries from different companies would have a significant impact and there is a need to move more transport to off-peak hours. At a Systems of Systems level there is a need to understand how much centralised planning is needed versus the use of decentralised self-organized flexible delivery.

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Currently there is a drive towards tighter time limits on delivery. This makes it more difficult to implement energy-minimal logistics to reduce emissions. This is a Systems of Systems problem but at present customers are not demanding information on the carbon footprint of goods transportation but it may well be a factor in the future as customers become more eco conscious. Green operations are a key concern for larger operators who have shareholders and sophisticated systems are being introduced that allow optimization across large numbers of vehicles. Big savings in fuel consumption and emissions can be made by increased used of telematics and more efficient operations, in particular, to reduce the number of trucks running half empty or empty on return journeys.

The use of autonomous vehicles in not new in logistics with picking machines being commonly used in large warehouses. There is a drive towards more distributed autonomy for these vehicles to provide greater flexibility in operations. Moving out of the warehouse the industry is beginning to think about increased autonomy in vehicles for safety and the use of platooning for reduction in fuel consumption and emissions. Looking much further into the future automated delivery systems such as Amazon Prime Air are being developed but these are still many years away from deployment.

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8 COMMONALITIES ACROSS SECTORS

8.1 Identified Commonalities

This report has considered the automotive, rail, aerospace, maritime and general logistics sectors. It is clear that there are common issues being addressed in these sectors. Many of the challenges within Europe in the area of transport and logistics arise from the fragmented infrastructure that has evolved over many years. There are many borders within Europe and in order to operate transport across borders there is a need for cross border, cross-organisation, co-operation leading to a natural need for Systems of Systems approaches in order to meet the pan European transport flow of goods and people. In order to address many of the political, standardization and legislative requirements in order to harmonize systems across Europe the European Commission has a significant role to play.

Considering technology, a key commonality across transport sectors is an interest in the increased use of ICT for optimization of operations. Here there are drivers to reduce time, cost and emissions. As much of the infrastructure already exists and there is a need for increased capacity the main challenge is to use the existing infrastructure more efficiently.

The introduction of ICT and remote connectivity to assets also introduces the ability to perform increased condition monitoring of assets through deployment of sensors everywhere. This is expected to bring huge savings in maintenance of infrastructure for instance in the rail industry and also more reliable operation of cars, trucks, aircraft, ship and trains. A challenge here is the generation of big data and the need for tools to data mine large data sets to extract useful information. Here there is an opportunity to introduce new service industries and already in the aerospace and marine domains maintenance service contracts are being offered commercially by manufacturers.

Communication is seen as a key enabler in all sectors between vehicles/assets and intelligent infrastructure. Here there will be increased communication between cars, aircraft, ships, and trains to allow safer operation and also operation of more vehicles. Linked with this is the need for security of communications and also a need for guaranteed levels of Quality of Service. Safety is paramount in all transport operations and is a key driver in all sectors.

Finally, increasing levels of automation/autonomy are being pursued in all sectors. The aerospace sector is currently leading in this field with autonomous vehicles already deployed for many years driven by military applications and enabled by the controlled nature of airspace. Cars are expected to introduce autonomous features by 2015 and many Systems of Systems challenges are predicted. The rail and maritime industries are also pursuing more autonomy to increase safety. For the rail industry plans are already well underway with roll out by 2024. In the maritime industry ships are becoming increasingly more autonomous but there is still quite a lot of work to do before ships can become completely autonomous. A major new area that is developing is monitoring of the Earth and the oceans and here there is a great interest in sustained Systems of Systems deployments of autonomous vehicles.

8.2 Transport CPSoS and Mapping to CPSoS Attributes

Many of the ideas for Systems of Systems come from development of concepts in the military domain. In a military organisation, every force package or task force is an ad-hoc “contingent” (i.e. configured in response to a contingency) Systems of Systems. It is temporarily configured from available assets and resources for the task in hand, then stripped down to the component elements at the end of the operation. Similarly Systems of Systems

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that react to unforeseen events, e.g. air sea rescue operation, disaster relief operation or "blue light" major incident response, can also be considered to be "Contingent Systems of Systems". Here the problem is one of coordinating the available assets against a tight timescale. Already work is being funded by the European Union on these types of problems in the Systems of Systems cluster.

In contrast the Systems of Systems considered in this document for transport, e.g. the European rail network and air traffic management, etc., can be considered to be "business-as-usual" Systems of Systems as operationally and managerially the independent systems co-exist and co-operate in a dynamically stable and persistent Systems of Systems. Individual elements enter and leave the Systems of Systems but the Systems of Systems as a whole is persistent. A consideration here is that the concepts already developed in the military domain may not directly apply to these types of systems or may require considerable modification. There are thus still a lot of open research questions. The key CPSoS attributes identified in this report for transport and logistics are:

- ***Significant number of interacting components*** Examples of significant numbers of interacting components can be found in the automotive, rail, aerospace and marine sectors. Here the components are vehicles interacting with each other and with infrastructure.

- ***Control and management*** In all sectors control and management are key issues. Key drivers are for operational efficiency and this can only be achieved by better control and management.

- ***Partial autonomy of subsystems*** At a local level the cars, trucks, aircraft, trains, ships all exhibit autonomy and indeed there is a need for loose control of systems in order to support flexibility for reconfiguration.

- ***Dynamic reconfiguration*** All the transport modes are subject to a variety of external disturbances that are both predictable and also unpredictable. These include disturbances introduced by weather, congestion, accidents and vehicle and system failures. A key aim is to maintain a level of local control that can be used to dynamically reconfigure at a local level and allow an overarching optimisation of the entire system in a dynamic fashion.

- ***Possibility of emerging behaviours*** In any system where there are very many elements under local control there is an opportunity for emergence to appear.

- ***Continuous evolution*** The road, rail, air traffic and maritime networks have evolved over 100's to 1000's of years within Europe. These are constantly changing but the challenge is to increase the capacity of existing networks. The introduction of new technologies will allow this increase in capacity but introduce new problems of how to deal with obsolescence. A car for instance has a supported life of 10 years. The infrastructure requirements tend to be to last for 30 years or more. Introduction of today's communications technologies will become obsolete within a matter of a few years so sustainable evolution is required.

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9 ISSUES IDENTIFIED

In all sectors of transport there are greater demands being placed by an ever increasing flow of people and freight traffic. This is putting great strain on existing infrastructure which has evolved over many decades. To increase capacity and avoid congestion there is a need to use existing infrastructure more efficiently. To support this here is a need for forecasting and coordinated control among subsystems and optimal routing for dynamic traffic networks. Increasingly multi-modal traffic is being considered. In the rail domain, for instance, the end-to-end journey time and ease of travelling for the passenger is a key factor. The rail segment is only part of the complete journey and there is a need to be able to model multi-modal traffic and also the passengers as they move between transport modes. In the aerospace domain the transport of passengers to and from the airport terminal, the process of passing through security and the boarding and deplaning all needs to be streamlined in order to increase passenger movements to meet future demand.

With the increasing numbers of vehicles being operated the probability of accidents and fatalities becomes a significant issue. Both the US and the EU have set aggressive targets for reducing loss of life and limb from accidents related to mobility. These concerns are driving work on automated and semi-automated systems across multiple transportation domains to improve safety. The European Union is committed to halving fatalities on the roads and this is driving the introduction of increased communication between vehicles, between vehicles and infrastructure and the introduction of autonomous functionality. Similarly in the aerospace, rail and maritime sectors there are initiatives to increase levels of autonomy to reduce risk of accidents and fatalities.

Consumer demand and government regulation are driving the transportation sectors to use less energy overall, emit fewer harmful emissions and utilise an increased mix of sustainable energy sources. Countries around the world have agreed to CO_2 emissions targets that have been spelled out in the Copenhagen accord of 2009 [103], with the EU offering to increase its emissions reduction to 30% (from 1990 levels) by 2020. With the transportation sector emitting over 25% of CO_2 globally, this represents a significant challenge. To achieve greater efficiencies and reductions in emissions operators are now turning to Systems of Systems thinking to optimise the use of assets to minimise fuel costs and emissions. This needs to be achieved while at the same time delivering increasing levels of service.

In all domains the increased use of ICT is seen as the answer to many problems to allow better scheduling of traffic flow to reduce congestion, enabling increased communication with infrastructure and between vehicles to reduce congestion and avoid accidents, and as a central element in introduction of more autonomy within systems to improve efficiency and increase safety. The pervasive use of ICT will lead to highly complex interconnected Systems of Systems in the future.

9.1 Support for Development

Underpinning development of these future systems there is a need for a fundamental methodology to be developed for Systems of Systems Engineering. Much of the infrastructure is already existing so approaches to development are needed that can deal with legacy integration. As engineers are used to a clean sheet of paper design approach and classical V models of development a significant challenge is in developing new approaches to dealing with requirements engineering and model-based systems engineering that support systems that continually evolve and can never be considered to be finished. There is a need for comprehensive interdisciplinary heterogeneous, multi-scale modeling at different levels of resolution. This is needed for methodology development, multi-objective optimisation of performance, and for proving the economic benefits of increased integration/system-wide control as a means of unlocking investment. A key challenge here is gaining access to data and models which may be commercially sensitive/valuable. Modelling is also seen as key to giving confidence in

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safety and in identification of any emergent behaviors. For safety-critical and safety-related applications certification is required and this is complicated by the fact that the automotive, aerospace, rail and maritime industries have their own industry standards. Certification for a Systems of Systems is particularly challenging as they are not predictable and predictability is a fundamental requirement for many certification standards. There is thus a need to think differently about validation and verification and come up with new standards/techniques for the different transport sectors.

9.2 Autonomy and Increased Interconnectivity

Approaches to system wide control and coordination are required. Increasingly autonomous decision making will be introduced and this introduces sociotechnical issues about what systems should be made autonomous and what should be left to the human operator, and the need for homogeneous HMIs that allow users to interact easily and effectively with the system. In the future there will be a much higher reliance on communication technologies between vehicles leading in the longer term to the integration of both manned and autonomous vehicles being operated in the same airspace, rail networks, marine environments and on the roads. Here there is a need for interoperability, guaranteed quality of service and security of communications. Societal acceptance will be a key challenge. Trust is key and if a malicious entity managed to break into the system and cause an accident there would be a total loss of public confidence. Systems thus need to be secure but also need to fail safe even in the presence of a security breach (for instance one cannot shut down an aircraft engine if a security breach is detected). Privacy is also a key issue and increasing interconnectivity results in a potential loss of privacy. This is complicated by different national attitudes towards privacy in Europe. Finally, liability needs to be carefully considered to ensure that citizens, manufacturers and operators have a clear framework in which to legally handle the consequences of the inevitable accidents when they happen.

9.3 Situational Awareness Monitoring and Resilience

The maintenance of systems is an issue and a complex Systems of Systems will require a high degree of monitoring. To support this there is a need for low cost smart sensors, self-powered sensors and exploitation of the Internet of Things (IoT) to provide information and create new services. It is clear that component systems will inevitably fail, may be unavailable for periods of time or only offer degraded performance. To support continued operation the Systems of Systems need to be resilient with requirements for dynamic and self-configuration. This highlights the pragmatic need for a loose integration of systems rather than a tight integration. At an individual vehicle level there is a need to build in fault tolerance to situations that may arise such as a vehicle stopping unexpectedly or not following the “rules” of the rest of the system. The ability to deal with these situations strongly depends on real-time availability of high-quality data and on efficient data processing. Thus a key challenge for the future is data management. This needs to address the data deluge problem via large-scale online data integration and analysis of heterogeneous data sets to extract information. Visualization tools are also needed to present a view of the “real-world in real-time”. Supporting this there is a need for data exchange standards that allow the seamless integration of systems and provide interoperability. Challenges here are heterogeneity in the data but again also in maintaining security and privacy.

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10 RESEARCH PRIORITIES

10.1 Open Problems – Short and Long Term Priorities

The problems within the transport domain were prioritised into short term (< 5 years) and long term (>5 years) issues.

5 Years

- Data – instrumenting with sensors (energy harvesting is considered to be a key enabler), collecting and managing maintenance and diagnostic data, dealing with heterogeneous data considering provenance and quality of data, designing for resilience considering the reliability of data, providing security and harmonizing standards (which are different in EU countries)
- Modelling – providing different levels and types of model, e.g. for design and development, managing complexity (also incorporating legacy systems), creating economic models to show business benefits for Systems of Systems to unlock funding in industry
- Due to large scale and complexity failures are the norm in CPSoS – there is a need for resilience and fault tolerance at the systems level and fail soft mechanisms
- Legal issues across countries – there is a need for uniformity in laws to allow data to be obtained from infrastructure, e.g. this is not presently possible for traffic lights due to legal restrictions and there are issues with information relating to the speed of car which could be potentially be also used for identifying overspeeding

10 Years

- Integrity, security and trust – to deal with malicious entities, crime and natural disasters, models are needed to test cyber security and cryptography is required
- System complexity is a major issue and there are needs for self-adaptation and self- maintenance
- Simulation to prove acceptability of coordination and control of Systems of Systems
- Optimization – optimal routing and planning on-the-fly to respond to changes and multi-objective (with potentially conflicting objectives) decision making approaches

Other areas identified which are underpinning but cannot be classified into a timescale were:

- New business models and services for operators – the car manufacturer or mobile phone service provider will not provide the final service so there is a need for Systems of Systems operators to develop new business models and services, for instance cloud computing connected to assets could be used to create a new service allowing global optimization of city traffic to reduce emissions.
- Controlling interaction with users – there is a need to explore approaches to controlling demand, e.g. incentives/rewards to take different routes in traffic planning or persuade customers that immediate delivery of parcels is not necessary (to allow more flexible logistics approaches such as bundling). Additionally, approaches to co-ordinating control and scheduling that take into account vulnerabilities in the system, dynamicity and multiple decision levels need to be considered.
- Communication standards – although many of the necessary communication standards will largely be in place within a 5 year timescale there is still a continuous need to work on new architectures and standards and consider their exploitation, e.g. high datarate (Gbytes/s) wireless communications, 5G mobile phone communications, etc. as they will have a significant impact on future Systems of Systems.

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10.2 Proposal for a Strategic Research Agenda in CPSoS for Transport and Logistics

The proposed research topics arising from the analysis of the Transport and Logistics sector can be subdivided into three key categories covering:

- the development of Systems of Systems,
- the issues of autonomy and the increased connectivity between Systems of Systems,
- the operational issues of monitoring and maintaining levels of service in a Systems of Systems.

The 3 areas are outlined below along with the key underlying research subtopics that have been identified as important:

Support for Development

- Requirements engineering, model-based systems engineering and validation and verification that support “systems that are never finished” and legacy integration
- Modelling (interdisciplinary) and large-scale simulation of heterogeneous Systems of Systems
    - Multi-objective optimisation of Systems of Systems
    - Proving (economic) benefits of increased integration/system-wide control
    - Giving confidence in safety
    - Identifying any emergent behaviors

Autonomy and Increased Interconnectivity

- Autonomous decision making, system-wide control and coordination
- Socio technical issues of humans interacting with “autonomous” Systems of Systems (noting that not everything will be autonomous)
- Interoperability between systems and development of data exchange standards
- Trust – which becomes more of an issue as systems become more autonomous and highly interconnected (considering security, privacy, and designing to fail safe or operate in presence of security breaches)

Resilience and Monitoring (Situational Awareness)

- Condition monitoring, fault detection and reconfiguration strategies to provide resilience
- Low cost (self-powered) sensor technologies to provide data
- Management of data deluge via large-scale online data analysis to extract information and visualization tools to provide a view of the “real-world in real-time”

It is recommended that these research topics are addressed in a Strategic Research Agenda in order to enable the future development, deployment and maintenance of Systems of Systems within the Transport and Logistics domain.

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