D3.1
Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

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1. Introduction

1.1. Project background

WP3 is the second of the three content-related work packages of the SCORE project and presents the outlook on disruptive trends in the transport manufacturing industry. The work package will assess the trends and future perspectives for the value chains of the European transport manufacturing industry (Task 3.1), as well as the future requirements for the transport manufacturing industry from the demand side (Task 3.2). In addition, the work package will analyse future global competition arenas for transport manufacturers (Task 3.3), and derive the critical factors for assessing global future developments for the European transport manufacturing industry (task 3.4).

Together, WP2 and WP3 will create a knowledge base for WP4, which in turn will discuss insights regarding relevant framework conditions, and provide recommendations to relevant decision makers in the industry and at public authorities.

1.2. Objective of the task

The main objective of the task is the assessment of trends and future perspectives for value chains of the European transport manufacturing industry. In order to anticipate future dynamics of value chains in the European transport manufacturing industries, key technological trends and innovative concepts will be analysed and assessed in terms of their potential impact on manufacturing processes. The potential impact of these technological trends and their associated technologies on the value chain described within “D2.1 Technical Analysis” will be analysed. Regarding the success factors for implementing new technologies, main drivers, barriers, and implications will be identified from an exemplary, non-exclusive list of drivers and barriers into three fields of manufacturing (“ICT-enabled intelligent manufacturing”, “High performance manufacturing” and “Sustainable manufacturing technologies”).
2. **Automotive (VDIVDE-IT)**

The following key technological trends and innovative concepts have been assessed in terms of their impact in the current value chains and the success factors for implementing new technologies:

- **Artificial Intelligence** - Is Europe’s technology competitive when it comes to high-performance computing chips for artificial neural networks (ANNs)?
  
  Artificial Intelligence as a Key Technology and USP for Autonomous Driving. Is Europe's technology competitive when it comes to high-performance computing chips for artificial neural networks (ANN)?

- **Digitisation in terms of customer interface**
  
  New mobility patterns are expected as megatrends are reshaping the socio-economic developments. Which drive technology will prevail in the future? Which is the role of digitalisation to face new customer needs?

- **Cyber-physical systems in automotive manufacturing**
  
  In times of industry 4.0, talking products enable mass-individualization. What requirements does flexible manufacturing need to fulfil in order to achieve the vision (advanced automation, zero-default, individualization, etc.)?

- **Fuel Cell Propulsion Technology**
  
  Fuel Cells seem to be the path to emission free cars, especially if hydrogen is used as fuel. The engine is much simpler construction and need less maintenance. Are fuel cells the answer to the zero-emission cars in the future? What is needed to achieve so?
2.1. Artificial Intelligence - Is Europe's technology competitive when it comes to high-performance computing chips for artificial neural networks (ANNs)?

**Sector/Mode of Transport:** Automotive  
**SCORE:** 1 Europe has a competitive disadvantage in comparison

**Management Summary**

Artificial Intelligence (AI) is the key technology for self-driving cars. AI is able to process high amounts of data coming from various sensors attached to the car, to extract the relevant information and to steer a vehicle. The unforeseeable events and chaotic behaviour in traffic prevent any form of conventional programmable solutions. By means of deep learning algorithms, artificial neural networks (ANNs) are trained to sense the environment and to navigate a vehicle through traffic. Recent breakthroughs in such machine learning tasks make self-driving cars to one of the most promising technological trends of the recent time. All major car manufacturers announced ambitious plans to bring self-driving cars on the streets within the next few years. Various prototypes have been presented by numerous protagonists. A key component for the introduction of autonomous driving is efficient hardware able to run the compute intensive algorithms. The compute intensive training is performed offline on supercomputers while real-time inference in the vehicle has to be performed on compute and power limited hardware. Today, the performance of available hardware solutions does not satisfy the requirements of machine learning algorithms. The resulting demand attracted the interest of IC manufacturers which put a lot of effort to design more efficient chip architectures for various AI applications. In automotive only few IC giants can compete in this race for better AI chips. In fact, Nvidia and Intel/MobilEye dominate this market today. So far, a software implementation of neural network with execution on optimized system-on-chip (SoC) architectures with several accelerator cores is favoured. A hardware implementation of neural networks by means of neuromorphic chips promises much higher power efficiencies but until now most IC manufacturers show little interest in this technology.

All major OEMs and Tier1s start to cooperate closely with IC manufacturers which address their high hardware requirements. As a result, the IC giants gain a strong position in the automotive market and undermine the role of traditional Tier1s by offering more generalized automotive compute engines as well as corresponding software and virtual training environments. The alternative to such one-party solutions is an open platform which is favoured by OEMs and Tier1s. Both are possible in the future.

The innovation and life cycles of the IT industry is much shorter compared to automotive. As a result, the hardware and software providers may become the motor for future innovations. A continuous improvement of sensors and AI algorithms will necessitate higher computing power and better hardware. It can lead to several hardware and software upgrades within one car life cycle improving the IC manufacturer’s position in the value chain. Every update will increase the performance and the safety of self-driving cars. Regarding the user acceptability this will make efficient AI chips a unique selling point (USP) for autonomous vehicles. The two current dominant chip providers are located in the USA. Currently, Nvidia uses the 12nm-FinFET while Intel uses the 7nm-FinFET semiconductor technology for their chips to achieve the high power efficiency. The corresponding fabs able to manufacture in this technology are located in USA and Asia. Therefore, Europe has a competitive disadvantage in the field of AI chips.

**Description of the main concept**

AI is the key technology for self-driving cars. Its enormous potential has been shown by numerous breakthroughs in the last years. The various sensors attached to the car produce high amounts of data
what can easily accumulate to several TB per hour. Only AI is able to process such amount of data in real-time, to extract the relevant information and to steer the vehicle. The unforeseeable events and chaotic behaviour in the traffic prevent any form of conventional programmable solutions. By means of deep learning algorithms ANNs can be trained to solve tasks which are way too complex to be solved analytically. Thanks to these capabilities deep learning was named as a breakthrough technology by the MIT technology review in 2013 [1]. An ANN learns to deal with the complexity by itself during a training process either by providing it the correct answer for every input (supervised learning) or providing it a feedback at least from time to time (reinforcement learning). During training every wrong calculated output of the ANN is being punished while every correct given output is being rewarded. All connections between the artificial neurons adapt slightly by means of deep learning algorithms. Numerous iterations of such training steps continuously improve the ANN performance in making decisions. When a certain defined percentage of correct given answers is achieved, the training is terminated and the ANN can be used for decision making what is called inference. Using this technology enables cars to sense its environment thanks to various attached sensors such as cameras, radar, lidar and ultrasonic systems. A large amount of labelled data is necessary for the compute intensive training to enhance the reliability of object and drivable path detection. A more complex task for the AI is to learn a driving policy to navigate the car through the traffic. Today, OEMs have fleets of vehicles on the road collecting training data. Recently, virtual training environments gained more interest since these enable faster accumulation of data as well as higher diversity of traffic scenes. The motivation is to achieve automated superhuman driving capabilities what is widely seen as achievable. This is considered a requirement for the introduction of self-driving vehicles to be accepted by the users. The vast majority of car related companies are convinced to achieve this in the near future.

A very high data throughput is necessary to train an ANN. High-performance computing (HPC) is necessary to process the “big data”. Therefore, supercomputer technology became essential for the progress in AI making companies with the corresponding know-how and infrastructure (supercomputers, datacentre) the drivers of the AI technology. Moreover, inference requires high computing power as well. Additionally real-time capabilities are essential. Fortunately, strong hardware improvement is possible by means of optimization of the chip architectures to the mathematical operations of the ANN. One optimization strategy is to exploit the parallel structure of the calculations. In this case, the designers are speaking from an “embarrassingly parallel” workload.

There are several hardware solutions which have been used to run AI applications. Central processing units (CPUs) are very flexible and are designed to execute numerous operations. But training an ANN on CPUs leads to very long computing time and to a very high power consumption since these are not optimized to the machine learning operations at all. Strong acceleration can be achieved by adaptation of the processor architecture to the computational operations. Mathematical operations in ANNs correspond mainly to matrix multiplications. Graphics processing units (GPUs) are designed exactly for this task to process video data. Taking advantage of the corresponding parallelization accelerates the computing time significantly. Although a single operation of a GPU has a higher latency compared to CPUs, its much higher data throughput is crucial. Another hardware solution is
based on field-programmable gate arrays (FPGAs) which consume low power and offer high flexibility. FPGAs enable designers to reprogram the underlying hardware architecture to support software changing in the best way and are the optimal hardware choice for small volume applications. Their disadvantage is the high programming complexity. Application-specific integrated circuits (ASICs) outperform FPGAs since they are specialized for a certain task. These multiprocessor SoCs incorporate GPUs, CPUs as well as accelerator cores optimized for certain operations like image processing. The disadvantage is their inflexibility towards new operations and the very high development costs. Technically, a GPU is an ASIC optimized for processing graphics algorithms.

So far, the mentioned-of-the-shelf hardware is not optimized for machine learning algorithms. This implies a high demand for innovations thanks to the varieties of AI applications. The enormous potential impact in all industry segments led to a race for more efficient chips between IC vendors, tech giants, IP vendors and various start-ups [2]. It is remarkable that various start-ups (mainly in US and China) try to compete with the big IC giants in such a cost-intensive industry branch. Designing an ASIC can cost up to hundreds of millions of dollars requiring a large team of expensive engineers. The long design process (typically 2-3 years) necessitates a large number of chip sales and regular improvement is necessary to adapt to fast changing software development. Especially the early state of the AI technology can lead to significant changes in the hardware development in the upcoming years [3]. Only the enthusiastic conviction that the new chips tailored for AI applications can strongly outperform state-of-the-art hardware can justify such investments and the bravery to compete with heavily experienced IC giants.

When researchers started to use GPUs to accelerate training of ANNs, the corresponding market leader Nvidia used this opportunity and started to adapt their products for machine learning applications and gained a strong market position. Although the inference can also be performed by GPUs, the typical power consumption is way too high for real systems. Convinced by the future of AI, Google already produced its second ASIC generation called the “tensor processing unit” (TPU) to run deep learning algorithms in their Google cloud servers [3]. There is no intention to make these ASICs available to others. According to Google the acceleration by TPUs saved the company from building 12 additional datacentres to handle the AI workload [3]. The second TPU generation can be used for training as well as for inference and delivers 45 trillion floating point operations per second (TFLOPS) for machine learning [4]. So far, Microsoft favours Altera FPGAs from Intel for its Azure cloud servers to be able to adapt the hardware immediately to newest trends of AI algorithms [3]. ASICs have been designed for the inference in certain consumer products such as smartphones. Since AI-based image processing is now able to achieve human-level performance in recognition tasks, several companies introduced optimized chips in their products. Huawei introduced the “Kirin 970 SoC” with a “neural processing unit” (NPU) for smartphones. Intel presented their “visual processing unit” (VPU) for similar inference applications. These optimized chips led to a significant increase of power efficiency and shifted the inference from the cloud servers to the smartphones. For example, the start-up Graphcore based in the UK claims that its “intelligence processing unit” (IPU) accelerators are up to 100 times faster and more efficient compared to the fastest systems today [2]. A complete list of all companies focused on optimized AI hardware is out of the scope of this study.

In automotive, there is still a lack of optimized hardware solutions for machine learning algorithms. Today, traditional OEMs, Tier1s and new market entrants like tech giants (e.g. Google, Apple, Baidu), emerging OEMs (e.g. Tesla, BAIC) or mobility service providers (e.g. Uber, Lyft) start to cooperate closely with IC manufacturers (e.g. Intel/MobilEye, NVIDIA). Therefore, various hardware innovations are expected in the near future. Intel entered the automotive market by buying Israeli supplier MobilEye in 2017 which is very active in the research of advanced driver assisted systems (ADAS). MobilEye is currently developing its fifth generation SoC “EyeQ5” for fully autonomous driving which will be in series production by 2020 [5]. Its predecessor chips were manufactured by STMicroelectronics but the fabrication will most likely shift to Intel in the future. The target for the fifth generation chip is to achieve 24 trillion operations per second (TOPS) under a power consumption of
The most advanced 7nm-FinFET technology is considered for production to address the performance targets [5]. Intel will combine the EyeQ5 chip with its “Intel Atom” processor and develop an automotive AI computing platform for autonomous driving [5]. Intel/MobilEye claims that two EyeQ5 chips will be sufficient to enable fully automated driving. Meanwhile, 27 car manufacturers adopted their current SoCs according to MobilEye. The automotive supplier ZF built the “ZF ProAI” computing platform which is based on the “Nvidia DRIVE PX 2 AI” computing platform. ZF claims to follow a modular and scalable system architecture that can be applied to any vehicle and tailored according to the application, the available hardware and the desired automation level. Audi is using this platform in the worldwide first level 3 vehicle where AI steers the car in jam traffic on an autobahn up to a speed limit of 60km/h. Baidu cooperates with ZF and announced to use the “ZF ProAI” platform for automated parking [6]. Meanwhile, Nvidia designed its new SoC “Xavier” which will offer up to 30TOPS under a power consumption of 30W [7]. The chip was fabricated by TSMC in 12nm-FinFET technology [7]. But true level 5 autonomous vehicles will need at least two of such chips to provide sufficient computing power. Therefore, Nvidia’s new “DRIVE Pegasus AI” computing platform will incorporate two “Xavier” SoCs and two discrete GPUs [7]. It will enable 320TOPS and consume up to 500W [7]. According to Nvidia the computing power should be sufficient for fully autonomous driving [7,8,9]. Tesla is reportedly working in cooperation with AMD on its own AI chips which would replace currently used Nvidia hardware [10]. AMD has strong expertise in building CPUs as well as GPUs and would be another IC giant entering the automotive market. The European company NXP developed its “BlueBox” autonomous driving platform. It incorporates e.g. the “S32V234” automotive vision and sensor fusion processor capable of processing AI applications. It supports all major AI tasks for autonomous driving such as object detection and localization, classification and decision making (path and manoeuvre planning). Furthermore, it enables mapping, V2X communication as well as fusion of data streams from various sensors (e.g. lidar, radar, cameras and ultrasonic systems). The performance is stated as 90,000 Dhrystone million instructions per second (DMIPS) under a power consumption of 40W. The Japanese company Renesas has a similar automotive computing platform with their “R-Car” SoCs which achieve 40,000 DMIPS. Currently, the telecommunication company Qualcomm intends to acquire NXP. Qualcomm has strong expertise of fast and efficient SoCs from the smartphone market. For example, its “Snapdragon 845” SoC includes AI processing capabilities [11]. Combining their expertise, Qualcomm and NXP are able to rival the current market dominance of Intel and Nvidia.

In automotive low power chips for AI-based image processing have been shown e.g. by DreamChip under the frame of the European THING2DO project. But more general solutions are necessary due to the demand for higher computing power, lower power consumption and cost reduction. More sensors will be attached to the car in the future. The performance of object detection was increased under the frame of the ImageNet contest during the last years by means of higher model complexity. This tendency implies higher amount of parameters of the neural networks. Safety is the crucial issue for the breakthrough of self-driving cars. Therefore, more complex models will be presented to increase the robustness of object detection and decision-making by AI. It is a common sense that the number of accidents for autonomous vehicles has to be decreased by one or two orders of magnitude compared to human drivers [12]. Worse performance would not be tolerated by users and could prevent autonomous vehicles to be established in the market. Therefore, companies involved in the autonomous driving market will constantly improve their AI algorithms to outperform competitors. Higher safety or better AI capabilities will be a USP for autonomous cars. This corresponds directly to more complex AI algorithms, more computing power and a growing demand for better hardware. In automotive the new SoCs tailored for machine learning algorithms tend to be more complex since high data throughput is necessary and moving data between different chips deteriorates the performance. Moore’s law assures continuous increase of the number of integrated transistors on chip. Therefore, the size and scalability of future optimized SoCs will scale up. For example, Nvidia’s new “Xavier” SoC is one of the most complex systems to date with more than 9 billion transistors. It should be noted that it took a team of more than 2000 engineers over a four-year period and an investment of $2 billion in research and development to build this device [9]. It is questionable how many IC developers can
competes with this. Such investments will lead to high chip costs if these cannot be applied to other market segments taking into account that the number of sold cars worldwide (ca. 80 million/year [13]) is quite small compared to consumer products (e.g. smart phones: ca. 1500 million/year [14]). An overlap seems to be in the datacentre market [10]. The EU announced to spend €1 billion for an initiative to build supercomputers in the EU to close its gap to US, China and Japan in that segment [15]. Here, an EU microprocessor was announced based on EU technology. The strong know-how in the field of HPC can be applied directly into the design of optimized AI chips. But for now it is too early to anticipate what this announcement will lead to.

The aforementioned chip designs correspond to a software implementation of neural networks and its execution on conventional von Neumann chip architectures. An alternative way is to implement the neural networks directly in hardware by means of neuromorphic chips. This approach is investigated by academia and is widely ignored by the industry although it was called a breakthrough technology by the MIT Technology Review in 2014 [16] and the World Economic Forum in 2015 [17]. IBM was the first company investigating neuromorphic computing and presented its “TrueNorth” chip in 2011 before the actual breakthrough of deep learning and the resurgence of convolutional neural networks (CNNs) in 2012. In 2016 it was shown that a trained ANN can be mapped to such a neuromorphic chip and approach state-of-the-art classification accuracy [18]. The huge advantage was the very low power consumption of only 275mW while processing 2600frames/s. Currently, Intel is working on its own neuromorphic chip “Loihi” [19]. Here, the signal processing is based on asynchronous spiking similar to the biological neurons in the brain. This chip combines training and inference, supports different ANN topologies including recurrent neural networks (RNN), can be used for supervised as well as for reinforcement learning and is continuously learning [20]. Intel calls it a test chip and will share it with universities and research institutions. This technology is very young and a lot of research has to be done to explore its full potential and to verify its capabilities. The claims about its potential performance are orders of magnitude of higher power efficiency and orders of magnitude of faster learning capabilities [20]. If these promises are only half true, neuromorphic chips should attract high interest of the industry in the near future. Neuromorphic chips are ideal for classification tasks but not for precise calculations like conventional processors. Therefore, these have to be embedded in conventional hardware which deals with rule-based navigation in the traffic. In Europe, neuromorphic computing is currently investigated under the frame of the Human Brain Project (HBP) since 2013. Here, two approaches are investigated. The BrainScaleS system approach is based on physical (analogue or mixed-signal) emulations of neuron, synapse and plasticity models with digital connectivity, running up to ten thousand times faster than real time [21]. The SpiNNaker system is based on numerical models running in real time on custom digital multicore chips using the ARM architecture [21]. Furthermore, the Belgian research institute imec introduced its own neuromorphic chip in 2017 [22].

AI is an emerging technology for traditional car manufacturers as well as for Tier1s. These have to acquire the software know-how to prevent being replaced by IT giants entering the market. AI is the key technology for self-driving cars which will significantly change the traditional mobility concept. Companies with large fleets of automated and connected vehicles will offer transportation as a service what will gradually decrease car ownerships. The user acceptance is expected to grow fast thanks to such mobility-on-demand concepts, the passenger comfort and possible entertainment offers during transportation. Self-driving capabilities will be gradually more valued as a USP for future cars. Estimations predict 33 million sales of autonomous cars by 2040 [23]. Although pricy self-driving cars would be affordable only for a minority at the market entrance, the majority of users will familiarize to this technology by means of mobility-on-demand services. Through automation one sales argument for OEMs will always be saver transportation, especially from the user acceptability point of view. This will be continuously enhanced by means of more complex signal processing algorithms and better sensor performance corresponding to higher data rates from higher resolutions and frame rates. This will necessitate better hardware to process the data in real-time. Here, the automotive industry depends on the IC vendors’ expertise. Therefore, OEMs as well as Tier1s started to cooperate closely
with IC vendors to enable optimized chips for new automotive applications. Automation and connectivity opens a new market for sensor manufacturers, HD map providers and IC manufacturers. In general, hardware providers and suppliers will capture a larger portion of the vehicle’s total value [24]. Here, the AI chip will be the brain of the automotive platform. According to MobilEye the goal is to offer autonomous capabilities for a price of few thousands of dollars. A significant portion of this value should result from the AI chips.

Analysis & Assessment of the impact on present industry structures

The international Society of Automotive Engineers (SAE) defined 6 automation levels in 2014. Starting without any automation on level 0, the automated driving capabilities are expected to evolve gradually up to fully automated driverless vehicles on level 5. The stepwise improvement depends on traffic conditions and automated capabilities. While first traffic jam pilots and automated parking assistance is being introduced today, fully automated level 5 vehicles are expected to be introduced around 2030 according to several roadmaps. For example, the European Automated Driving Roadmap from the ERTRAC working group Connectivity and Automated Driving predicts full automation by 2030 [25]. Similar projections were given in the European Roadmap Smart Systems for Automated Driving (EPOSS). Most car manufacturers claim to build such vehicles already in few years. In fact, the fast technology evolution within the last two years may prove them right and full automation may be introduced significantly earlier than 2030. But besides the technological capabilities, actual verification of the system robustness is able to slow down the market entrance due to safety issues.

Prototypes of self-driving cars have been shown by various OEMs, Tier1s, IT giants as well as IC manufacturers. These show continuously better performance in more and more complex traffic scenarios and harder weather conditions. While the first prototypes drove only on sunny days on the highways in California, complex city traffic (e.g. Waymo in Phoenix, San Francisco, Atlanta (USA)) or hard weather conditions (snowy roads in the test area Muonio in Finland [26]) are investigated today and the published results are promising. So far, off-the-shelf-hardware has been used to demonstrate AI capabilities and the focus was on software improvement to verify the proof-of-concept. The results prove that at least certain levels of automation can be realized within few years. Therefore, all major car manufacturers announced the introduction of their first self-driving cars within the next few years. But autonomous capabilities will be at first restricted to certain driving conditions since the traffic complexity differs strongly. For example, Audi and ZF showed together the worldwide first car with level 3 capabilities where AI can take over the car within a traffic jam and steer it up to a speed limit of 60km/h. Baidu and ZF announced autonomous parking in 2018. In both cases the hardware is based on Nvidia’s “DRIVE PX 2” platform. The technology readiness level of autonomous driving can be assessed between level 2 and level 8 depending on the operational and environmental conditions such as on traffic or weather. The automotive hardware platform corresponds to a technology readiness level is on level 7. Nevertheless, this hardware consumes still way too much power and there are several optimization approaches under investigation. IC providers already announced better AI chips in the next years (e.g. Nvidia’s “Xavier” SoC, MobilEye’s “EyeQ5”).

There are two different technology paths for the chip development. One approach is to optimize the chip architecture to the mathematical operations of the ANN. In this case neural networks is implemented in software and conventional von Neumann architectures are used. Here, heterogeneous multiprocessor SoC architectures are used from all IC manufacturers in the automotive segment. Another approach is to implement neural networks directly in hardware by means of neuromorphic chip architectures. This technology is still very experimental and the future will show if these can play an important role. A possible solution can be a combination of both technology implementations. Here, neuromorphic chips can be used for object detection and classification tasks while von Neumann architectures will be necessary for precise calculations to assure correct rule-based driving behaviour.
Standardization of an open automotive AI platform can increase competition between IC manufacturers and make OEMs and Tier1s more independent from IC giants. Another possibility is close cooperation between IC manufacturers, OEMs and Tier1s leading to distinct solutions for automotive AI computing platforms. In such a scenario e.g. an “Intel Inside” label could be a USP similar to laptops if the performance differs significantly between IC manufacturers. Today, Nvidia and Intel/MobilEye offer hardware as well as software solutions [5]. Such closed system solutions attack the role of traditional Tier1s, whose software expertise becomes less in demand. But both market leaders offer separate solutions as well what enables module-based hardware integration in open platforms such as “Apollo” from Baidu. Such solutions are favoured e.g. by NXP. Both approaches can be successful and it is not obvious now which will be established. Nevertheless, it implies strong changes within the value chain.

- **Analysis and assessment of the impact of Disruptive Technologies on present value chain**

Efficient AI hardware is essential for self-driving cars. Traditional Tier2s or Tier1s do not offer components and systems which enable fully automated driving. Complex SoCs have to be designed to deal with the enormous computing power under a tolerable power consumption. This is the strong expertise of IC giants like Nvidia or Intel which did not play a major role in the automotive segment before. Today, these companies dominate the AI chip market and gain a strong position in the value chain. In fact, these do not tend to stay in the role of a chip provider. The market leaders offer software solutions as well and cooperate directly with OEMs undermining the role of Tier1s. But there is also the tendency to separate their software and hardware solutions enabling an open automotive platform. Nevertheless, chips able to process the enormous amount of data will be an essential component of self-driving systems. Efficient hardware is especially important for electric cars. Here, lower power consumption leads directly to longer drivable distances per charged battery.

It should be noted that innovation cycles in the chip industry are much shorter than in the automotive industry. Furthermore, the chip life cycle is significantly shorter than the life cycle of a car. Therefore, a regular hardware upgrade could be necessary. In this case chip providers could sell several chips per car within one car life cycle and improve their position in the value chain. Further innovations in electronics are enabled by Moore’s law which still predicts a higher grade of integration every two years. There will also be continuous software upgrades increasing the robustness of AI performance and the safety. The corresponding software providers will also benefit from the short innovation cycles. According to this analysis, innovations in automotive could be driven mainly by IC manufacturers and Tier1s.

Self-driving cars are still a futuristic topic for most of the direct users. There is no direct demand from the user side for self-driving cars since there is a lack of trust and imagination so far. Nevertheless, companies are very much motivated to build this technology to e.g. introduce fleets of automated taxis. The companies made huge investments to evolve self-driving technology during the last years and continue to do that. A fast adaptation to self-driving cars and the immediate creation of demand from the user side is expected when users gain trust in the technology through experience with mobility-on-demand services.

- **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

The chips able to process the compute intensive AI algorithms are mainly provided by the two IC giants Intel/MobilEye and Nvidia. The chip performances of traditional suppliers like NXP or Renesas struggle to compete with these. It should be noted that both market leaders use FinFET technology with the smallest available node size of 7nm (Intel/MobilEye) or 12nm (Nvidia) for their chips. This is
important to achieve highest integration as well as highest power efficiencies. The corresponding fabs are located in USA and Asia.

Semiconductor fabs located in Europe are more focused on the SOI technology. Here, the smallest node size of 12nm is currently under investigation by GlobalFoundries in Dresden. MobilEye used higher evolved technologies for every chip generation of their EyeQ series. For example, the first generations were realized in 180nm-CMOS (EyeQ1), 90nm-CMOS (EyeQ2) and 40nm-CMOS (EyeQ3). The EyeQ4 was built in 28nm-FD-SOI and the new EyeQ5 will be built in 7nm-FinFET. To deal with the intensive computing power, the highest evolved semiconductor technology is necessary. Therefore, only few fabs are able to build these. Such fabs are located in USA and Asia. In Europe, there is a lack of fabs able to manufacture the AI chips with the highest evolved technology.

References
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

[25] Automated Driving Roadmap, ERTRAC working group Connectivity and Automated Driving, Date: 29/05/2017

2.2. Digitisation in terms of customer interface

Sector/Mode of Transport: Automotive
SCORE: 1 Europe has a competitive disadvantage in comparison

Management Summary

The future of the automotive industry - like other industries - is confronted with the countless challenges of sustainable development, global urbanisation and the increasing individualisation of users' preferences. These megatrends shape key socio-economic developments that converge with the technological possibilities of digitization. This results in new mobility patterns. The central question remains which drive technology will prevail in the future. This is where the technological development of electric drive technology is emerging as the triumphant march of electric drive technology, with bridge technologies such as hybrid drives also playing an important role in the use of combustion engines. Autonomous driving will continue to prevail. Automobile manufacturers have to react to these technological challenges if they want to continue to survive and remain competitive. At the same time, the shift from ownership to sharing creates a fundamental change in user preferences. Instead of owning a car themselves, people want to use distributed systems to meet their mobility needs. As a result, car manufacturers are taking on a new role, increasingly becoming service providers for mobility-as-a-service and sharing concepts of all kinds. Against this backdrop, three major fields of application emerge in which new digital interfaces between drivers and the car of the future emerge: Connected driving, Autonomous driving, New digital ecosystem (digitisation of production and services relating to cars) and Digital driven mobility services. To be competitive in these areas and ultimately to be competitive requires new demands on business models, competencies, organisational structures and forms of cooperation for the established car manufacturers in Europe, North America and Japan.

Description of the main concept

The future of mobility is determined by the challenges of the megatrends sustainability, urbanisation, individualisation and digitisation. This has a direct impact on mobility and demand patterns in the automotive sector as well. In particular, it leads to new preferences that are reflected in a strengthening of sharing concepts, less ownership and growing service requirements. These innovation paths are primarily autonomous driving, connectivity and networked mobility. These are technological and consumer trends that can be tracked for some time - and they will play an important role in the reformatting of the automobile and will comprehensively reshape the automotive sector. It is still an open question which concrete characteristics and in which combination these mobility trends will prevail in which region of the world. And: These three paths differ very differently, but at the same time are closely related to each other.

This technological development radically changes the familiar vehicle and mobility concepts. The will to own a car sinks in favour of the desire to share cars. This is due to very clear rational considerations, driven in particular by the desire for more mobility but not just more possessions. The networked and ultimately autonomous driving car also replaces the well-known driving concept. Instead of concentrating on driving yourself, the "new drivers" have the opportunity to use this time in a different way. Security also plays a major role. If driving is supplemented by an intelligent assistance system or if the risk factor "human driver" is replaced, the probability of an accident decreases.

In addition, the manufacturing, distribution and after-sales system we know today will change radically. Vehicles of the future will be manufactured in networked value-added chains according to the customer's wishes. Maintenance is mainly software-based, on-site visits will become less frequent. In addition, a specific automotive data marketplace will be created. In times of self-learning and -training autonomous vehicles, the driving data have a high value in order to improve the driving characteristics. The data is also needed to make the production and dislocation of vehicles more sustainable. Thanks
to digital product IDs, it is now possible to track vehicles and their materials throughout their entire lifecycle.

The technological and economic potential of this development is enormous. The US will play a leading role in the introduction of communications and networked automotive applications. This will lead to significant technological developments on the infrastructure and vehicle side. However, Europe and Japan will follow with great effort. China is also playing an increasingly important role in the field of autonomous driving. Much depends on the introduction of 5 and 6G. With the introduction of the first 5G mobile radio networks, a much more efficient usability of connection technologies in traffic is expected. Against this backdrop, it can be assumed that almost all new registrations will be linked to this by 2020. Most of this connectivity is likely to come from embedded systems. The rest is done via integration with the user's smartphone or via connection to other network devices.

Promoted above all by Google, the vision of fully autonomous driving has established itself as an effective model for new mobility. Currently, North American, European and Japanese companies are still leaders in the development of driver assistance systems (ADAS). But the Chinese suppliers are catching up very quickly. Due to this competition, it can be assumed that ADAS features will be used more and more frequently in the coming decades. Fully automatic vehicles are expected to come onto the market initially as low-speed automatic shuttles; pilot tests for automated shuttles are already underway. Many experts expect driverless taxi services to be available in selected urban areas by 2020, while automated vehicles will be available for personal use from 2030 onwards.

The sharing of models for a growing part of the world's population will become a comfortable alternative to vehicle ownership, especially from 2020 onwards (car and bicycle). Riding, tailing and ride-sharing approaches will be increasingly represented in the metropolitan regions by 2030. After 2030, urban areas will largely adopt models for the sharing of vehicles and sustainable new mobility service models will be introduced in rural areas.

The European automotive industry is increasingly confronted with a massive innovation competition, which primarily entails organizational and structural changes. Despite the current positive overall situation, the European automotive industry is confronted with major changes resulting from the mobility trends outlined above.

Analysis & Assessment of the impact on present industry structures:


- **Urbanisation**: While about 165 million people lived in cities around 1900, it is predicted that 70 to 80 percent of about 10 to 12 billion people will live in 2050 (UN 2014, World bank 2015). In the 21st century, life in densely populated urban areas will be the typical form of existence for the majority of world's population. The more people have to come to terms with their diverse needs and vital life functions in an increasingly confined space, the scarcer the situation becomes. There is too little space for growing automobile fleets and their external effects. (ITF/OECD 2017, Arthur D. Little 2015, McKinsey 2016).

- **Sustainability** is the way to reduce external effects of industrial and fossil production and consumption. According to the OECD's World Transport Outlook, global traffic will at least triple by 2050. (OECD 2015) The external effects in the area of mobility are growing rapidly. More regulations are needed to contain the demand for fossil fuels and greenhouse-gas emissions, air pollutants, noise emissions, accident costs and material and space
requirements of mobility. With regard to the automotive industry: The diesel engine is currently being criticised and there is a dilemma between climate protection and health protection within this technology line. The internationally agreed targets for climate protection - far-reaching decarbonisation by 2050 - will only be achievable in the mobility sector if combustion engine drives will no longer be allowed from 2035 onwards (Öko-Institut 2016). At the same time it should contribute to social justice and services of general interest, good employment and economic resilience of the places of residence and work. (McKinsey 2016)

- **Individualisation** increases with the level of development of society. This makes mobility needs more specific, flexible and spontaneous and the demand is less able to be bundled. This is one reason why mobility patterns change more quickly and show a less stable and predictable demand pattern than before. Wherever individualisation took place, use of automobiles became more prominent. Until now, passenger cars have been the most functional vehicles to meet this megatrend. At the same time, more and more platform economies are emerging in the urban cultures of the world. Based on the enabling functions of digital technologies, but also draws from the growing complexity, flexibility and changeability of modern lifestyles: where life becomes ever faster, less predictable, spatially and temporally variable, ownership is a brake on flexibility. (ITF/OECD 2017) In mobility, the dynamics of efficient, shared products (car sharing) are also strongest at the moment (In Germany, for example, a car is used for an average of one to two hours a day, which means that it remains unused for 22 to 23 hours). (Öko-Institut 2016, Morgan Stanley 2015) The interaction of these subtrends of individualisation leads to changes in urban mobility markets.

- **A new market** is being created: the collaborative transport with relatively stable demand patterns and political regulation in the areas of less space-efficient, less sustainable but highly individualised private transport (private cars, rental cars, taxis) and the very space-efficient, more sustainable but so far less individual collective transport (tram, suburban and underground railways, buses). In the future, the established providers of urban mobility will be faced with the challenge of arranging themselves with old and new players in terms of organisation, technology, finance, business management and branding in order to enable more flexible offers that respond to individualised customer requirements. (ITF/OECD 2017, McKinsey 2016)

- **Digitization**: Due to its inherent exponential development dynamics in digital networking, automation, artificial intelligence and predictive analysis of large amounts of data, digitization has disruptive and therefore potentially very powerful innovation effects for established structures and actors. Digitization offers a wide range of approaches and opportunities to cope with the challenges in traffic development resulting from the megatrends (outlined above). (McKinsey 2016, ITF/OECD 2017) The expectation of these opportunities is essentially based on three possible effects of digitization: enormous increase in the efficiency of use of transport infrastructures and vehicle fleets; automation and thus the optimisation of control functions previously performed by people; very effective mediation between supply and demand through networking technology, smart terminals with software applications and new concepts for switching platforms. Each of these partial developments of digitization would in itself lead to enormous changes. However, in their interaction with each other and with the trends towards electrification and "benefits instead of possession", they generate the transformative development dynamics for the automotive industry that can be observed right now.

**Mobility innovation paths** are specific developments that can be even more differentiated spatially and temporally than the megatrends mentioned above. The most discussed new mobility trends in scientific, traffic and automotive policy discourse are currently Automation, Connectivity and networked mobility. (ITF/OECD 2017) These are technological and consumer trends that can be tracked for some time – and they will play an important role in the reformatting of the automobile and will
Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

comprehensively reshape the automotive sector. It is still an open question which concrete characteristics and in which combination these mobility trends will prevail in which region of the world. (ITF/OECD 2017, Arthur D. Little 2015)

Recently, however, the mobility sector has gained considerable momentum. On the one hand, due to the growing overmodulation of the megatrends and mobility trends mentioned above. On the other hand, new digital application possibilities offer concrete solutions. In the last five years alone in the field of automated driving has experienced unprecedented momentum. Ultimately, this trend should lead to fully automatic vehicles (SAE Level 5). At the same time, driver assistance systems (ADAS) were further and newly developed. (BII 2017) And thanks to a growing number of telematics solutions, infotainment developments and the continuous improvement of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, significant progress has been made in vehicle connectivity. In addition, hybrid and, above all, electric drive systems are being tested for new drive concepts that can create new, more sustainable mobility. (ACEA 2017) New mobility services triggered by consumers create completely new business models or change existing models with the help of technologies. Such new mobility services are made possible primarily by technology platforms and wireless connectivity that enable more convenient, efficient and flexible travel. And: so far, automobility has been associated with owning a vehicle and the need to control it. (Smith et al. 2017, CAR 2016)

Dieter Zetsche, CEO of the German automaker Daimler, summarizes this development with a view to the challenges facing established car manufacturers in Europe and also in North America and Japan: "Networking, autonomous driving, sharing and electric drives - each of these four trends has the potential to turn our industry upside down. But the real revolution lies in the intelligent combination of the four trends" (Daimler 2017).

This field of tension between the trajectories has at the same time different future paths for the different regions of the world with different spatial and settlement structural conditions. Particularly in densely populated urban areas, especially robotic electric driving as an efficient service in combination with public transport is an extremely realistic development perspective - provided that the technological feasibility promises can actually be met. It seems to be particularly advantageous in China, where urban settlement structures are still being rebuilt and the space and traffic planning requirements of automatic driving can be taken into account in the sense of an innovation leap. (ITF/OECD 2017) On the other hand, passenger car ownership in rural regions of the world is likely to remain relatively stable in the future, but also here with tendencies towards automation, as far as technological developments permit. At the same time, autonomous minibus fleets in rural and suburban regions in particular could enter into a clever alliance with public transport - and thus modernize and make it more attractive. (ITF/OECD 2017)

The following figure shows the central fields of new digital interfaces between drivers and the car of the future along the four major technological developments:
**Connected Driving**

In the "Connected driving" application area, the car is increasingly developing into a computer-controlled unit that is ultimately controlled by artificial intelligence (AI). And it is a hub for real-time data transmission with full connectivity to other vehicles, (traffic) devices, databases and objects. This is made possible by sensors on and in roads and other infrastructures (bridges, buildings, traffic lights) as well as by entertainment and navigation services connected to mobile applications (smartphone applications). Over the past few years, networked driving has developed at a very high speed. During the various phases of development, new functions and services were constantly introduced into the technological system and the surrounding eco-system. In addition, there were new players - and last but not least, new business models. It is estimated that this degree of connectivity is expected to be achieved by 2020 in 90% of newly registered cars - and that they are interlinked. (Accenture 2018, WEF 2016)

- **Infotainment technology** in the automotive sector has developed enormously recently. Instead of using proprietary software, more and more OEMs are turning to open source systems and mobile platforms. This also increases the degree of cooperation with external partners such as Google (USA) or Baidu (China). This makes infotainment more dependent on location and condition. At the same time, they can be adjusted to the individual needs of the drivers. Thus, for example, integrated intelligent route planning - even across several modes of transport - is also quite common in luxury class vehicles. While these location- and state-oriented infotainment systems are mostly networked car services of the future due to the more complex implementation requirements, subscription-based services have already arrived. However, they are usually limited to safety features such as breakdown assistance or emergency call systems in the event of accidents, which are also offered by insurance companies. (WEF 2016, Smith et al. 2016)

- In **Connected infrastructures** the possibilities of connectivity and vehicle-to-vehicle (V2V) communication continue to develop and triggers machine-to-machine communication potentials between vehicles and the roadside infrastructure (vehicle-2-infrastructure communication, V2I). Both - V2V and V2I - are the key factors for intelligent transport. Sensors, transponders and RFID readers in the street, at traffic lights, bridges and car parks are integrated into an integrated communication network of continuously moving digital information in order to increase safety and improve traffic flow. This considerably increases the benefits of onboard infotainment systems in vehicles (see above). In addition, the data...
obtained from V2V and V2I communication are useful for reducing traffic congestion and improving public safety. At the same time, however, this requires more cooperation and coordination between OEMs and, for example, public institutions. Not only to build up the infrastructure, but also to develop common standards for data exchange and data management. (WEF 2016, Smith et al. 2016)

- Networked driving also allows you to customize insurance offers: usage-based insurance. More and more insurances are moving in this direction, modifying and individualising policies based on individual driving behaviour. Telematic solutions, i.e. on-board sensors that transmit driving information, are still being used for this purpose. In the case of voluntary participation, drivers will be encouraged to generate discounts and other offers through adapted driving. This performance-based or usage-based pricing is a supplement to the emerging peer-to-peer insurance programs and pay-as-you-drive policies. This solutions are already helping to reduce the number of accidents and even lower accident rates will be achieved with a wide range of vehicles equipped with AI systems in the future. (WEF 2016, iii 2016) This development is likely to lead to a shift in liability. Instead of the driver's behaviour, the cover is placed on the manufacturer of a car, the software developer, the device manufacturer, the vehicle owner. (iii 2016) The insurance must be adapted to the circumstances of driving - the specific types of driver, the number of passengers or customers in the car, the purpose of the car (commercial or private), the way in which the passengers are insured. (WEF 2016)

- Multi-modal integration connects all forms of individual and public passenger transport on roads, cycle paths, footpaths, railways and waterways to build up seamless connectivity between modes of transport. For some time now, OEMs and suppliers have been working together with other industries as well as planning, tax and supervisory authorities and municipalities worldwide. Comprehensive multimodal integration would bring significant social and environmental benefits. One result would be more efficient traffic management and less congestion. Urban areas would produce better quality of life and urban planning and municipal investments would shift. (WEF 2016, ITF/OECD 2017) Current pilot projects on a small scale have demonstrated the feasibility of the concept, especially in Europe, but further scaling requires new partnerships and the development of advanced application program interfaces (APIs) linking the different operating systems. (WEF 2016)

**Expectations for further technological developments in the field of connected driving:**

The key question as to how the possibilities of connectivity can be used is to what extent the necessary technologies are available (see the following figure for the USA, Japan and Europe). According to Smith et al. (2017), the USA will play a leading role in the introduction of V2V and V2I security applications. By 2016 leading automotive and technology companies and governments have committed themselves to making considerable efforts to deploy V2V and V2I applications based on dedicated short-range communication (DSRC) in the 2020s. This will lead to significant technological developments on infrastructure and vehicle side. Europe and Japan want to create the necessary legal framework to invest in V2I infrastructure and support the development of V2V applications. Technologically, however, this development will not be limited to DSRC-based connectivity alone. The introduction of the first 5G mobile radio networks is expected to result in a much more efficient usability of connectivity technologies in traffic. (Smith et al. 2017)
Blackrock (BBI 2017) estimates that approximately 35% of the vehicles sold in 2015 have connection capacity (see figure below). According to the Blackrock forecast, almost all new registrations will be connected by 2020. Most of this connectivity will presumably come from embedded systems. The rest by integration with the user's smartphone or by tethering with other network devices. (BBI 2017).

**Autonomous Driving**

The seamless connectivity of millimeter wave radars, cameras, ultrasound sensors, lidar scanners, GPS technology, vehicle-to-vehicle and vehicle-to-infrastructure connectivity, and proprietary algorithms allows an increasing throughput of autonomous vehicles. The expectations in this development are very high. Mobile independence and travel become possible for almost everyone, traffic loads are reduced and road safety increases. The further development of autonomous driving is
also subject to various technical constraints and regulatory challenges. At the same time, existing infrastructures must be adapted and supplemented. The biggest challenge, however, is the acceptance of potential users. For car manufacturers, the production of self-driving cars means a complete reorganisation of the automotive industry and its supporting ecosystem. (Roland Berger 2017) And the path to a critical mass adaptation of autonomous vehicles is still unclear. The throughput is conceivable on the one hand with a long-term incremental introduction of discrete autonomous functions, but on the other hand also through direct development and the radical use of new technologies. Both paths are practiced in the automotive sector. For example, Google has produced a completely autonomous vehicle without a steering wheel. In Europe, Japan and the USA, autonomous cars with hands-free car kits are still being tested on public roads for the time being. Many OEMs are investing both in improving the capabilities of assisted driving and in exploring fully self-driving technologies. (Roland Berger 2017, WEF 2016)

- **Assisted driving** is already a very strong reality. The use of driver assistance functions in the car is growing from year to year. At the same time, the role of the driver is changing: from an active driver to a rather passive participant in an automated transport process. At present, technological throughput is still hampered by high initial costs, so such systems are still predominantly found in the premium segment. But with the suitability for mass production, however, costs will be significantly reduced and assistance systems will also find a broad throughput in the broad production of lower segments. In its study on the digitization of the automotive sector (WEF 2016), the World Economic Forum assumes that the economic benefits for consumers and society (worldwide) will amount to more than one trillion US dollars by 2026. According to this forecast, improved vehicle safety could reduce 9% of potential accidents by 2025 thanks to advanced driver assistance systems (ADAS) and avoid 5% of additional premiums. More importantly, increased security has the potential to save 902,000 lives over the next 10 years by preventing fatal incidents. (BII 2017, WEF 2016)

- **Assistance systems created the basis for self-driving.** Intensive work is being done to develop self-driving vehicles navigate themselves in mixed traffic conditions on all kinds of roads. The best-known is the Google Auto LLC, which according to its own statement by Google 2020 should be marketable. (Forbes 2015) At the same time, Tesla is also very strong in the development of electric cars that will drive autonomously, as is Apple. (Roland Berger 2017) But established manufacturers such as Audi, BMW, Mercedes-Benz, Nissan and Toyota are also working on self-driving cars. Volvo, for example, has already tested robot trucks. Self-driving vehicles are therefore already a reality, at least as proof-of-concept tests. However, the extent and number of legislative, infrastructural and technological barriers will slow down and significant questions also arise with regard to consumer confidence, data protection and the control of cyber security risks. (Roland Berger 2017)

**Expectations for further technological developments in the field of autonomous driving**

Promoted above all by Google, the vision of fully autonomous driving has established itself as an effective model of new mobility. However, feasibility and social acceptance are still highly controversial. Because technological development is certainly socially overshaped. From a purely technological point of view, relatively sub-complex, homogeneous and regular driving situations such as driving on roads can already be mastered very well today and can contribute to road safety. People are already moving in the area of highly automated driving. It is also undisputed that one of the first applications will be in road freight transport. In contrast, more controversial is fully automated driving in densely populated urban areas, where the effects would be greatest (e.g. space savings, efficient infrastructure utilization, ecological relief, and new public transport systems) However, the technological implementation is difficult because of complex mixed traffic situations in the cities. Due to the defensive nature of the control algorithms, automated driving has so far only worked reliably and safely in a self-contained homogeneous system - the more homogeneous, the better. This requires
better system-accesses and a massive increase in the digital connectivity of infrastructures. (OECD 2015, McKinsey 2016)

Currently, North American, European and Japanese companies are still leaders in the development of advanced driver assistance systems (ADAS). (BII 2017) But Chinese suppliers are catching up very fast. Due to this competition, it can be assumed that ADAS features will be used more and more frequently in the coming decades. (Smith et al. 2017) From CAR's point of view, fully automatic vehicles are likely to be launched on the market initially as low-speed automatic shuttles; pilot tests for automated shuttles are already underway. Many experts predict that driverless taxi services will be available in selected urban areas by 2020, while automated vehicles for personal use will be available from 2030. (Smith et al. 2017, BII 2017)

Figure 5: Roadmap for Advanced Driver Assistance Systems and Vehicle Automation Technologies. Source: Smith et al. 2017

Smith et al. (2017) believes that this technology path can be used to identify different behaviors of automobile manufacturers, which in turn will form sub-paths. Some manufacturers are developing vehicles with automated drive systems. Others will increasingly rely on the development of conditional automation (SAE J3016 Level 3). And yet other automobile manufacturers want to build vehicles with such a high degree of automation that a human driver is not necessary. These manufacturers justify this with the excessively high complexity of automated systems for humans. From the CAR's point of view, however, it is still unclear whether this will ultimately lead to the development of fully automatic vehicles (SAE Level 5), which is able to operate independently everywhere and in all situations. (Smith et al. 2017)

Digital Ecosystem (Digitisation of production and services relating to cars)

The digitization of the Automotive Sector is likely to trigger disruptive effects in the value chain. Above all, these are expected to result from increases in efficiency, cost reductions, better cooperation and more innovation. A key factor is the strong transformation of the current B2B approach of the OEMs into B2C-approaches. This provides OEMs with more touchpoints with end user, more communication channels and many approaches to aggregating data. With regard to the development of digital Enterprise and new eco-Systems in the automotive Sector, the future design of manufacturing processes in an industry 4.0 will play an important role. (WEF 2017, Smith et al. 2017, Roland Berger 2016, McKinsey 2016, Accenture 2016).
A central aspect of digital ecosystems in the automotive sector will be the **connected supply chain**. Its main advantage is cost reduction through a better managed end-to-end process. These national and regional manufacturing and supply relationships that have existed up to now have long lead times and are not very agile because of their highly complex structures. The possibilities of digitization allow a greater decentralization and a significant reduction of lead times, of costs and more transparency. For example, certain vehicle components can be monitored in real time throughout the entire production process thanks to digital product ID - even during and after use of the vehicle. Thanks to machine learning and predictive analysis, errors can be reduced and the design, manufacture and delivery of components and complete vehicles can be speeded up. This also enables to track vehicle and material usages (circular economy) in an end-to-end orientated manufacturing process. The greatest advantage is to produce vehicles in small sizes, including one size. (Roland Berger 2017) The exploding growth of data in an Internet of Things across the supply chain will also require new skills for workers and managers. In the longer term, 3D printing could become one of the most important tools for creating parts either in the main factory. This could lead to the collocation of suppliers and assembly plants and would enable continuous integration across the entire value chain to ensure seamless manufacturing and processing. (WEF 2017, Smith et al. 2017, McKinsey 2016, Accenture 2016).

Even today, the automotive industry is probably the industry with the highest degree of automation worldwide. In addition to humans, robots have been used in production for decades, and their capabilities have been growing continuously. This means that robots of the new generation are already able to perform a wide range of assembly tasks completely independently in a **digital manufacturing** system. The radical advances in robotics and artificial intelligence, combined with the Internet of Things, will lead to further positive advances in automation - especially in China and other locations of the global automotive industry still catching up in production technology. (ACEA 2017) However, intelligent factories require high investments. Not only internally in the automation of production lines, but also externally to strengthen connectivity in order to be able to aggregate the necessary data. Investments are also needed in technologies that enable virtualization of design and testing to achieve faster time-to-market and lower costs for physical prototypes and testing. Forward-looking plant maintenance will also anticipate and localize machine and component failures more precisely. In the intelligent factory, these networked and intelligent machines speed up operation, create flexibility in adapting or retrofitting a line and improve performance by reducing the error rate. The main obstacle to building an intelligent factory is the massive capital needed to replace existing infrastructure. New business models are also needed. The advantages (quickness, flexibility in adapting, improved operating performance, faster response to customer requirements and cost reductions) should compensate for these obstacles and the necessary investments in the long term. (ACEA 2017, WEF 2017, McKinsey 2016).

Likewise, the digital transformation will change relations across the entire retail chain to a **disrupted retail**. Customers increasingly expect a seamless experience across digital and physical touchpoints, no matter who they interact with, and use the manufacturer's digital capabilities (website, online configurator, call center, virtual agent and published online reviews) to inform themselves, configure vehicles individually, compare and test them virtually. (Accenture 2016) This challenges OEMs and dealers to find new ways to stay in touch with customers before and after sales. Some OEMs, such as Tesla, want to avoid middlemen completely in order to establish direct contacts with customers. (Roland Berger 2017)

In the future, car drivers will benefit from **connected service and maintenance systems**. Vehicles already remind the driver of necessary for maintenance or repairs. As more and
more sensors have been installed in vehicles in recent years, the accuracy of maintenance has improved considerably. Sophisticated, data-driven diagnostic systems (predictive maintenance) in the vehicle together with other intelligent components and data connectivity help to proactively signal when vehicles need to be serviced. This opens up completely new possibilities for preventive maintenance and reduces downtime and recalls. For OEMs are many opportunities to create and maintain touchpoints with the customer. (Roland Berger 2017) Digitization also changes service concepts. Instead of mechanical adaptations and repairs, software updates or upgrades are sufficient to optimize the functionality of vehicles. No on-site appointments are necessary for this, but software improvements can be carried out anywhere and at any time, even without direct driver activity. (Roland Berger 2017, WEF 2017).

- **A transformation to a digital aftermarket** can be expected. Looking at the existing fleet, there may be a medium-term need to upgrade older vehicles for new digital assistance systems. Existing suppliers in the aftermarket will shift their sales and services to meet the growing demand for upgrades that enable consumers to stay connected. (WEF 2016) To facilitate software and hardware upgrades, manufacturers and suppliers are expected to make their systems forward compatible. (Roland Berger 2017).

- With the digitization in the Automotive Sector, a separate **automotive data marketplace** is created. After all, the digital approaches primarily cause data-driven business models in which data is collected, aggregated and analyzed on a large scale (bid data) for the purpose of optimizing production, processes and offers. In order to fully exploit the value-added advantages of the generated data, a secure and robust data market is needed in which they can merge into trading data. (Roland Berger 2017). In this way, companies can make their data capture processes more targeted and efficient, both in support of their own business objectives and for transactions on the data market. (Roland Berger 2017, WEF 2017) This data is not only useful for car manufacturers, also non-manufacturers need the information. For example, TransportAPI consolidates data feeds from British transport services and makes them available to develop applications for local public transport. This combines the usability of individual vehicle data with data from the digital transport infrastructure. (transport API 2018).

In summary, the following diagram shows the complexity of the individual developments and the expected throughput times in the automotive industry.
Digital driven Mobility Services

The growing clientele, especially the younger population groups, is aimed less and less at the increasingly unelegant, ecologically inefficient and economically irrational ownership of vehicles in urban traffic situations. Instead, it expects reliable, flexible and at the same time cost-effective access to modern, combinable transport systems including automobile usage concepts. Historically, car sharing - pay per use instead of pay and use - was fed from ecological and moral motives. Today, on the other hand, a very rational mix of cost-consciousness aspects can be observed among younger users in particular, with tight budgets, sustainability motives and functional pragmatism (Deloitte 2017, McKinsey 2016).

Against this background, more and more new mobility concepts are taking shape. New Mobility Services have long since conquered the major cities of North America, Europe and Asia and, with their steadily growing importance, are finding their way into people's working and living environments. (CAR 2016, Deloitte 2017) The origin of its emergence lies in a change in user preferences away from the possibilities of transport towards improved mobility (see above). But there is also a change of system (CAR 2016): user-centered approaches (mobility) are now establishing themselves instead of system-centered approaches (mobility). The cities around the world are working very actively on this, and carmakers are also becoming increasingly involved in establishing a wide range of new mobility services. (ITF/OECD 2017) Both want to meet the needs of all users for movement and access to places, goods and people as far as possible in a holistic and systemic way. These include car sharing, ride sharing, ridesharing, microtransit, bike sharing and mobility as a service. They all follow the concept of "shared-use mobility", enables users to access the transport modes (vehicle, bicycle, motorcycle, etc.) at short notice and in line with their needs and increasingly blurring boundaries between public and private transport, between what is shared and what is property. (CAR 2016, Morgan Stanley 2015)

- **Ridehailing** services, established around 2000, connect users and drivers (often also taxis, such as in Germany) via smartphones, who use their private vehicles for a fee. This resulted in a large number of Transportation Network Companies worldwide, implement matching via
For some time now, ride sharing concepts have been establishing as opportunities for private vehicles to travel to common destinations. Travellers share their travel expenses via specially provided passenger platforms and charge a fee for using the connection. (CAR 2016) The trend began around the mid-2000s. So far, the concept has been most successful in Europe. The largest operator is BlaBlaCar, mainly active in Europe and South America. In the United States, mainly smaller platforms allow peer-to-peer ride sharing (usually for short distances), real-time car pooling or vanpooling. These services include vRide and Commutr. Waze (a subsidiary of Google) took a new step. The ridesharing pilot project launched in May 2016 with several companies in the Bay Area currently offers around 25,000 employees a ride with other Waze users use similar shuttle lines. Drivers can choose whether or not to accept this request. Users pay drivers a recommended amount based on the standard fare set by the Internal Revenue Service (IRS) - 54 cents per mile. (CAR 2016) Ridesharing is worldwide on the forefront. It is particularly established in Asia. In 2015, more than EUR 5 billion invested there in corresponding start-ups and structures. (BII 2017)

Carsharing is a short-term - also hourly - car rental. Customers have access to the vehicles via various electronic systems. Petrol and insurance are included. In recent years, however, the distinction between the two models has become increasingly blurred, especially as car rental is moving closer and closer to car sharing. (CAR 2016, Deloitte 2017) Carsharing is currently available in more than 25 countries in North and South America, Europe, Asia and Oceania. The largest car sharing market is Europe with more than two million members and a good 60,000 vehicles. North America ranks second with more than 1.6 million members and over 25,000 vehicles. (CAR 2016)

Microtransit is a new concept private transit services offer via minibuses flexible routes or timetables (or both) based on customer demand. This closes the gap between individual and public transport. (CAR 2016)

In the case of Mobility as a Service (MaaS) approaches, mobility needs are met via an interface with offers of different service providers. The bundling of several transport options (local traffic, car sharing, ride hailing, etc.) is thereby integrated in an integrated solution for the user via a smartphone application and payment of the service. for a single account. This combination is intended to create a universal mobility offer. Mobility-as-a-Service was first conceived in Europe. (CAR 2016)

Shared autonomous vehicles are fully automatic or autonomous without human drivers. Information on the origin and destination of the trip is also recorded automatically. Shared Autonomous Vehicles are to be commissioned by customers with the help of mobile phone applications. Various automobile manufacturers (Volvo, GM, Ford, Mercedes, etc.), technology companies (Google, EasyMile, Apple) and mobility companies (Uber, Lyft, Zipcar) are already working on the development of shared services. (CAR 2016)

**Expectations for further technological development in the field of new mobility services**

In the cities of the future, mobility services will become more diversified and the trend from owning to sharing will become increasingly pronounced. From the point of view of Smith et al. 2017, these
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developments will certainly converge with other trends. Especially with the increasing automation of vehicles and connectivity of vehicles and infrastructures. (CAR 2016, Smith et al. 2017)

Figure 7: Roadmap for New Mobility Services and Vehicle Automation Technologies. Source: Smith et al. 2017

Sharing models for a growing proportion of the world's population will become a convenient alternative to owning a vehicle, especially from 2020 (car and bicycle). Until 2030, riding tailing and ride sharing approaches will be increasingly represented in the metropolitan regions (Smith et al. 2017). After 2030, urban areas will largely adopt models for the sharing of vehicles, and sustainable new mobility service models will be introduced in rural areas. (Smith et al. 2017)

Figure 8: Growth of Car sharing worldwide and North-America. Source: on illustration based on Smith et al. 2017

- Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain

Increasingly, the European automotive industry is facing a massive innovation competition, which primarily entails organizational and structural changes. Despite the current positive overall situation, the European automotive industry is facing major changes resulting from the mobility trends outlined
Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

above (ACEA 2017, Accenture 2018, Ramsauer et al. 2017). The following explanation identifies challenges and possible solutions for car manufacturers and the European industry resulting from the digitization of the automotive industry – with relevant policy implications.

ICT competencies


- The integration of different development cycles of software and automotive manufacturers as well as connectivity solution providers has to be mastered successfully. An agile software development during the vehicle development is by a release comparison with the "Quality Gates" and the increasing maturity during the pattern development quite compatible. (McKinsey 2016, Ramsauer et al. 2017)
- Different software versions and bug fixes during the serial production of a series are currently common. In addition, the integration of software and service changes in automotive after-sale will also be available in the future through OTA ("over the air") updates. Safety-relevant functions play a special role and are discussed separately below. (McKinsey 2016, Accenture 2018)
- The increasing complexity of electrical and software-controlled vehicle components increases the risk of malfunctions. The safety integrity of a system must be guaranteed for every possible operating state (also in the event of misconduct). While compliance with functional safety for ECUs with embedded software in the vehicle is already standard, this will also apply to all relevant systems from the vehicle to the back end in future. The more the newly developed driver assistance systems actively intervene in safety-relevant driving functions, the higher the classification within the framework of the Automotive Safety Integrity Levels and the associated system, software and hardware requirements. (Accenture 2018, McKinsey 2016)
- The integration of back-end-based IT systems into the vehicle's safety-related functional chains brings completely new challenges of functional safety and for ICT solution design, development, validation and verification. Potential malfunctions must be counteracted by a solid automotive ICT security concept. A cross-system safety concept from the backend to the vehicle ultimately implies that the vehicle must continue to be equipped with sufficient intelligence and sensors in the future in order to validate driving interventions independently and without permanent Backend-interaction. Last but not least, automotive manufacturers and suppliers are called upon to push ahead with the expansion and safeguarding of the ISO 26262 standard for functional safety in the automotive industry towards ICT. (Smith et al. 2017, Accenture 2018, McKinsey 2016)

Collaboration between OEMs and more cross-industry-cooperation

In order to survive in international competition, the digital networking competence of the automotive industry will be crucial. As a base for new services and operating concepts, it guarantees the absorption of automotive and automotive-related value creation, while the pure production of vehicles will earn less and less money in the future. It can be observed that IT industry - in particular the globally operating companies from Silicon Valley, but also the corresponding Chinese IT companies - has been crossing industry boundaries for some years and attacking established automotive industry with new concepts of driving and using automobiles on the basis of their digital competence directly, visionarily, financially and aggressively. In addition, there are the diverse and quite aggressive activities of companies with a lot of venture capital, such as Lyft, Didi Chungxing or Uber. They do not want to develop new vehicles, but rather establish a new culture of use of the automobile on the basis of new digital networking and operating platforms (mobility services). Finally, the LeEco group of companies, Baidu, China's largest Internet company Tencent or the trading platform Alibaba, which are preparing for entry into this market, should be mentioned in this context. They are investing in
linking online user data, electromobility and automation technology for mobility services in Chinese conurbations. (McKinsey 2016)

The shift in the structures of mobility demand necessitates new competence mixes in order to be able to offer adequate services and products. It is hardly to be expected that this can be done fully within a company. In this respect, more cooperative value creation models will emerge that are flexible enough to meet such demands. In any case, a "lot size one" requires the reduction of value added depths while at the same time strengthening the value added widths in networks. In addition, the development of intermodal and multimodal transport systems requires more cooperation with manufacturers of other modes of transport.

ICT companies are already the most important partners and at the same time competitors of car manufacturers. It is becoming apparent that these companies will not build their own vehicles, but instead want to create digital platforms for autonomous driving and networked services. As a result of this development, established car manufacturers could run the risk of becoming just suppliers of vehicles. Examples of this are the cooperations between Google and Fiat-Chrysler or Daimler and Uber. In both cooperations, it is conceivable that a great added value for both partners will be offset by a loss of importance for the established carmaker. (Accenture 2018, Ramsauer et al. 2017)

Various car manufacturers have already reacted. For example, VW and "Mobility Asia" are looking for clearly defined partnerships with Chinese IT companies, as well as BMW, which recently entered into collaborations with the Israeli start-up company Mobileye and Intel. At the same time, value-added cooperations are developing between carmakers, as the example here shows. Daimler, BMW and Audi participated in the production of digital maps and navigation systems. In other words, the automotive industry also wants to compete with Google or Apple with independent business models. In particular, the formulation of technological standards should be prevented without the involvement of the established automotive industry. However, technological competition remains. The Chinese Smart-SUV Roewe RX-5 from SAIC is equipped with YunOS, a proprietary operating system with navigation, entertainment and Alipay from Alibaba. Until now, such solutions have not been found in vehicles of US and European manufacturers. (KPMG 2017, Accenture 2018)

**Organizational structures and –cultures**

Against the backdrop of current developments, three organizational models in the automotive sector will develop in the future (Ramsauer et al. 2017, Accenture 2018):

- **B2C (Business to Consumer):** The existing organizational model of established manufacturers acquires moderate. The core content of the company's activities remains R&D, production and sales of vehicles for the private and commercial fleet market, supplemented by a range of services. By offering services, we develop product and service packages around our own vehicle and thus build up our own ecosystem. The central customer benefit is the brand experience and mobility offer from a single source in the areas of automotive-related services (parking, refuelling, insurance, health, personal assistance).

- **B2B vehicle manufacturer (Business to Business):** Production of vehicles for mobility service providers. A B2B manufacturer has no direct contact with end customers, so it only becomes a supplier for the mobility service provider. It is probable that the vehicles will be completed by the mobility service provider with its own relationships to other suppliers. This is because data acquisition from the mobility services is necessary to achieve the desired technical and functional design of the vehicles. In particular, the presumably increasing market volume of mobility services (ride and car sharing) will lead to a new vehicle market segment in the area of fleet-managed vehicles. This ideal type is currently being implemented by the Italian-American company Fiat-Chrysler, for example, as part of its cooperation with Google.
Mobility service providers: offering mobility services. Key customer benefit aspects are an integrated, intermodal mobility offer with a high convenience factor (Seamless Mobility) and high process flexibility in the areas of availability, processing and payment transactions. This organizational model follows software- and internet-based structures with a focus on the operation of digital networks. Direct digital customer access via smartphone applications and web portals enables the rapid retrieval of customer data and thus opens up the targeted offer of highly customer-value services.

Decisive for the question of the organizational model is, how a change in one of the types can and should succeed. In addition, the different resource, process and competence requirements are points in need of clarification. An important aspect remains - the organizational culture. If non-material products and services are to be increasingly generated, it may be necessary to change from hierarchical decision-making processes and focus on the corporate goal of organizing production processes to clearly more agile structures. In any case, the challenge here is digital transformation. And also dealing with partners in new networks, which can differ from the actual manufacturer in mentality, speed, flexibility, capital strength, understanding of customer experience and risk affinity. From today's perspective, the foundations of the Daimler subsidiary Moovel or the Volkswagen subsidiary Moia can be seen as positive examples of the creation of the necessary agility. (Ramsauer et al. 2017)

Norms, standards and connectivity

Another aspect for the digitalized car of the future is to provide broader connectivity. In this context, global Permanent Roaming agreements may be an important factor for best coverage provisioning. This in order to keep the costs of data communication between vehicle and backend within bounds through global contracts. But also in order to keep the activation and maintenance of (eSIM-based) connectivity in the vehicle as uncomplicated as possible across national borders. Special attention must be paid to the legal and regulatory framework of certain countries (e. g. Brazil, China, India). If necessary, special provisions must be made there. This is primarily a challenge for the telecommunications industry. (McKinsey 2016)

That requires compatibility with various network technologies, expected to be available over the average life of a car, be ensured by software updates and multi-technology design. The manufacturers’ task will be to work towards new communication standards (protocols, interfaces, technologies). With the increasing functional integration of backends into grey and colorful services and into partially and fully automated assistance systems, new demands are increasingly being made on mobile communications. In this case, it is advisable for car manufacturers to enter into appropriate cooperations with the ECU suppliers with at least one of the four major telecommunications alliances. (Ramsauer et al. 2017)

Data protection and legal frameworks

One of the key challenges for the digitalization of the automotive industry is the correct handling of data, data ownership and globally heterogeneous legal requirements. Drivers' concerns about the use of data in particular can become a stumbling block for customer acceptance. The current uncertainty in data handling also offers car manufacturers the opportunity to generate a unique selling point through a transparent and secure approach. Two basic data classes can be identified in the context of automotive digitalization: Vehicle-related data (Data that originates in and through communication with the vehicle and the outside world (e. g. performance data)) and Customer-specific data (Data that is generated in the car as well as input from external and customer-specific data sources and is directly related to the driver). (McKinsey 2016)
The difficulty with these data is that they contain personal data, which - in Europe - can be subject to data protection. As a rule, such data must be made anonymous or at least pseudonymised if it is to be made available to the manufacturers. In addition, there are requirements in the appropriate encryption of data transmission. An important part of future business models in the automotive industry will continue to be data commercialization by OEMs and third-party suppliers. (Accenture 2018)

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2.3. Cyber-physical systems in automotive manufacturing

**Sector/Mode of Transport:** Automotive  
**SCORE:** 3 Europe has a competitive advantage in comparison

**Management Summary**

Industry 4.0 is a topic with high relevance for industrial production today and in the future. Different European countries (e.g. Germany, Sweden or Austria) are in a leading position with respect to the implementation of cyber physical systems. However, as other European countries are not at the front end with respect to the implementation of Industry 4.0 we come to the scoring that Europe has a competitive advantage in comparison. The automotive value chain is highly integrated across different European member states. This might facilitate spillovers among European countries and help to raise the Industry 4.0 readiness level in those countries that stay currently behind those who are leading. Industry 4.0 will change future production processes significantly.

**Description of the main concept**

The transformation of industries towards more digitalization is still ongoing. CEOs along the supply chain have to be aware that this increasing digitalization has a large impact on the future competitiveness of firms. The topic is of high relevant for SMEs as well as OEMs. Many processes that have to do with the further implementation of the internet of things (IoT) have a high potential to foster the dynamics of industrial production. The impact of the IoT on future production processes is currently discussed under the notion “Industry 4.0”, which describes the use of digital and often interconnected technologies in industrial production (compare OECD(2017)).

**Analysis & Assessment of the impact on present industry structures**

Different studies have analysed the impact of Industry 4.0 on future industry production. There is the general finding that industry 4.0 leads to growth in productivity. The following list highlights some of the main findings:

- Output and productivity in firms that adopt data-driven decision making is 5-6% higher compared to firms with conventional investments in information and communication technology (ICT) (Brynjolfsson et al. 2011).
- Improved data quality and access by 10% results in an increase in labor productivity by 14% on average. However, there are significant cross-industry variations (Barua et al. 2013).
- Average expected cost reductions connected to the IoT are 18% (Vodafone 2015).
- Autonomous mine haulage trucks have the potential to increase output by 15-20%, lower fuel consumption by 10-15% and reduce maintenance costs by 8% (Berger and Frey 2015).
- The internet of things is related to high energy consumption. For example, Google data centres use approximately 0.01% of the world’s electricity (Koomey 2011). In 2016 it was reported that AI has the potential to reduce energy consumption by up to 40%.
Even though from an economic perspective high expectations are related to future growth within the industrial sector (BCG 2015), the empirical evidence about completion of implementation processes of industry 4.0 within countries is rather weak. The reason behind is that the number of IoT devices connected to the Internet is difficult to measure. Countries are now just at the beginning to collect data.

One data-source (Shodan\(^1\)), a search engine for Internet-connected devices) allows to measure the use of IoT. The sample consists of 363 million observations about IoT devices. From those devices are 84 million registered to China and 78 million to the United States. Korea, Brazil and Germany follow with 18 million connected devices, and Japan, Spain, the United Kingdom and Mexico make up the rest of the top ten countries, with 8 million to 10 million devices each. As the countries differ in country size, the counts of IoT per capita is used as a measure. The top ten countries based on the described IoT-Data are depicted at Fehler! Verweisquelle konnte nicht gefunden werden.. Ranked first is Korea and ranked fourth are the United States. All other countries ranked under the top ten are European countries. From this perspective it seems that the European industry is well prepared for the fourth industrial revolution.

On the European level differences between countries can be observed. There are “frontrunners” like Germany, Sweden, Ireland and Austria, “potentialists” like Belgium, Denmark, Netherlands, UK und France, “Traditionalists” like Czech Republic, Slovakia, Slovenia, Hungary and Lithuania and “Hesitators” like Italy, Spain, Estonia, Portugal, Poland, Croatia an Bulgaria (EU 2017a).

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\(^1\) https://www.shodan.io/
One major driver for this success are national initiatives accompanied by European initiatives, supporting the implementation of Industry 4.0 on the state level. For this reason the political initiatives within the three core regions of the SCORE-project (Europe, US and China) are looked at in more detail.

**Europe**

There are different policy measures within European countries, supporting the digital transformation towards Industry 4.0 in the private economic sector. For European member states the exchange of ideas and best-practices is of high relevance. For this reason, representatives of different national initiatives meet at the European level twice a year to discuss Industry 4.0 at the High-Level Roundtable of the European Commission in Brussels. As Figure 3 shows, within Europe more than 30 national initiatives are set to push Industry 4.0 within the member states economies. Especially the exchange of best-practices from “Frontrunners” to countries which are behind in implementing Industry 4.0 bears high potential.
Industry 4.0 is of high strategic relevance for the European Union. One important strategic aspect is that Industry 4.0 for developing an integrated digital European market. In addition to this, fostering Industry 4.0 comes along with an increase its competitiveness.

The exchange of virtual products goes in hand with an intensified European market integration. So far, this European market integration is mainly focused on the exchange of physical products with respect to goods services and migration of labor forces. For the time being framework-conditions for virtual products were not in the main focus. To exchange virtual products, there are still a lot of barriers. Only 7% of small and medium enterprises within the EU offer their goods and services in other European member countries (Plattfrom Industrie 4.0 2017).

One major challenge with a significant innovation potential is related to the implementation of industry 4.0 within SME’s. For this reason the European Commission initiated I4MS to help smaller companies to implement ICT-technologies across the whole value chain. The knowledge necessary to improve the skills in this direction is provided as part of the funding scheme.

For the European Union the automotive sector has a high priority (EU 2018). Since October 2015 there is the High Level Group GEAR 2030 which analyses and discusses key trends and challenges which will affect the automotive industry over the next 15 years.

As an outcome GEAR 2030 produced jointly agreed roadmaps that set objectives, specify milestones and clearly define the responsibilities of different stakeholders (EU 2017b). Current policies are part of the CARS 2020 Action Plan established in 2012. Its aim is to reinforce the industry’s competitiveness and address current challenges related to the climate, environment and society. The following four areas built the core of the strategy:

- Financing innovations
- Improving market conditions
- Facilitating internationalization
- Responding to change
Additional initiatives to foster competitiveness of the EU’s automotive industry are related to improvements in four main areas:

- Smart regulation
- International harmonization
- Bilateral regulatory dialogues
- Access to finance and market access support for small and medium-sized enterprises

Automotive products are regulated through EU laws for vehicle type-approval. The area of smart regulation aims to improve the level playing field for approval of vehicle parts. Its aim is to increase the trust of consumers, and reduce administrative burden that is related to competitiveness proofing.

The international technical harmonisation is a second key factor with high potentials to strengthen the competitiveness of the EU's automotive industry. The major focus is on common technical requirements (e.g. under the UNECE framework). Such initiatives have the potential to reduce development costs and avoid the duplication of administrative procedures.

The aim of bilateral regulatory dialogues is to ensure a coherent regulation between European and non-EU countries. The addressed core topics are energy saving, emission reduction and mitigation for the burdens related to certification.

Access to finance is one topic of particular relevance for SMEs. There are two major initiatives addressing the needs of SMEs and larger firms:

- **COSME**: the focus of COSME is on improved access to debt and equity finance
- **SME Instrument**: the focus is on finance for research undertaken by highly innovative automotive SMEs.

### United States

The US government has its own initiatives in order to support digitization within industry’s. The initiatives are summarized in the report “A Snapshot of Priority Technology Areas Across the Federal Government”. Part of the initiative are the following core topics, with relevance for the automotive sector within the US (NSTC 2016):

- **Manufacturing technology areas of emerging importance**
- **Advanced materials manufacturing**
- **Manufacturing technology areas of established importance, including the mission themes of the US National Manufacturing Innovation Institutes:**
  - additive manufacturing
  - advanced composites
  - digital manufacturing and design
  - flexible hybrid electronics
  - integrated photonics
  - lightweight materials
  - smart manufacturing
  - revolutionary fibres and textiles
  - wide bandgap electronics.

- **Further technical areas of interest identified by the US Department of Defense include:**
  - advanced machine tools and control systems
  - assistive and soft robotics
  - bioprinting across technology sectors
  - certification, assessment and qualification
o securing the manufacturing digital thread – cybersecurity for manufacturing.

- Technical areas identified as being of interest by the US Department of Energy include:
  o chemical and thermal process intensification
  o sustainability in manufacturing
  o high-value roll-to-roll manufacturing
  o materials for harsh service conditions.

Part of the strategy is to regain international competitiveness and to reshore U.S. manufacturing. For this reason companies are asked to adopt a more comprehensive total cost analysis. The guess is that many offshoring strategies will not pay-off. The major reason behind is related to rising offshore labor rates and “hidden costs” that in many cases counterbalance any remaining savings from cheap price or labor abroad (RI 2017).

Another relevant argument is that separating R&D from manufacturing has a negative impact on the strength of the innovation system (e. g. ITIF 2012). For those reasons Industry 4.0 is a strategy which is connected to the expectation of industrial recovering of the U.S. Economy.

Parts of the strategy might already show some results. According to current studies the degradation of jobs within industry has stopped. In 2014 and 2015 there was already a reshoring of US industrial manufacturing employment. Due to offshoring in 2000-2007 the United States lost net about 200,000 manufacturing jobs per year. Within the last seven years about 265,000 manufacturing jobs have been brought back to the U.S. (RI 2015). Industry 4.0 can be considered as a strategy to strengthen this development.

China

In order to push industry 4.0 within the national economy, the Chinese government recently released implementation guidelines for the “Made in China 2025” strategy. Based on the “Made in China 2025” initiative, it is the aim to lift the country into a higher value-added economy (OECD 2017) (Euromonitor International 2017).

China has priority funding for many R&D projects with a special focus on digitizing the economy. This will impact the competitiveness of the manufacturing sector in the next years. R&D funding with close connection to the automotive sector are the following:

- New energy and energy-saving vehicles:
  o energy-saving vehicles
  o new energy vehicles, including batteries and motors
  o intelligent vehicles.

- New materials:
  o advanced basic materials, e.g. textiles and steel
  o essential strategic materials, e.g. special alloys and high-performance fibres and composites
  o cutting-edge new materials, e.g. 3D printing materials and metamaterials

The “Made in China 2025”-Initiative is one response to current slowdown of the Chinese economic growth. From 2006-2016 the Chinese manufacturing turnover in real terms was growing by 10%. Part of this growth was an increase in production in intermediate and high-tech goods. In the last years a slowdown in growth could be observed. In 2016 the rate decelerated to just 5%, compared to over 20% per year a decade ago. The reasons for this observable slowdown are rising wages in China, coupled with maturing domestic market and limited global economic expansion. (Euromonitor International 2017).
The “Made in China” strategy is of high relevance for the Chinese economy (e.g. UK Trade and Invest 2016). A failure might lead to the so called “middle income trap”, characterized by high production costs without enough growth to ensure sustainable development. This could lead to unemployment or inflation (Euromonitor International 2017). One weakness of the Chinese innovation system is the low share of higher value production. Even though China has a high share in industrial production, core design centers for products are usually located within the developed countries. For this reason China connects the “Made in China 2025” Strategy to the foundation of 40 new R&D centers (USITC 2017), with the aim to boost innovations in the manufacturing sector. The R&D centers shall be able to compete with those located within developed countries. The future success is still an open question, as developed countries have well-established R&D capabilities.

From a macroeconomic perspective two major risks are related to the future development of the Chinese economy. Low-cost countries try to take advantage of the increased wages in China in order to attract additional value added and other developed countries try to increase the competitiveness related to higher value added products (e.g. Europe and the U.S. economy) (USITC 2017). When Chinese strategy pays off, foreign companies will keep attracted by the Chinese market. As a consequence the argument of increasing labor costs gets less important for industries to leave the country.
From an international perspective one major concern of foreign investors is that the Chinese strategy includes prioritization of domestic products. This comes along with the risk that foreign investors reduce their activities within China. The threat is that FDIs in China are reduced as one response to the protectionism (Euromonitor International 2017).

One further problem is related to the specialization of Chinese firms on lower value added products. When China changes the production output to higher value added products this might come along with an increase in unemployment with the related social consequences. Additional important topics are problems in data protection, cyber security and net neutrality. As these topics are not so well elaborated, this might be a barrier for the expansion of Industry 4.0 within China. The reason is that Industry 4.0 comes along with massive amounts of data, which buyers, suppliers, manufacturers, logistic-service-providers and others agree to share, in order to achieve efficiency gains. If this agreement is not settled among the stakeholders, Industry 4.0 might not work properly.

Analysis and assessment of the impact of Disruptive Technologies on the value chain

When it comes to the concrete channels through which Industry 4.0 changes productivity within industry, different relations and interconnections have to be taken into account (OECD 2017). For example:

- Based on new sensors, control devices, data analytics, cloud computing and the IoT machines and systems are getting increasingly intelligent and autonomous.
- More intelligent production processes offer opportunities to eliminate production errors. Items can be monitored by making use of sensors and actors and drawing samples from batches is
getting less relevant. The real time monitoring offers opportunities to reduce machine downtime and repairing costs, as intelligent systems are able to predict maintenance needs.

- Another important factor for an increase in cost-effectiveness is that products and processes can be simulated more easily, what helps to save money and to increase product quality.
- The time to deliver orders can be reduced by the data gathered along the whole supply chain. Based on digital technologies it gets easier to reduce the quantitative outcome of cost efficient production processes, what helps to meet current demand. The whole production gets more efficient. Firms benefit by getting more flexible by getting rid of the necessity to hold high quantities of inventories. Costs savings come along with reduced failure rates for new product launches.
- The IoT allows to increase the integration of robots in the production processes. As robots are faster, stronger, more precise and consistent than workers, robots have especially in the automotive sector contributed to an increase in productivity. The major focus was on stationary robots automating processes along the assembly-line. In the future there are new opportunities to make use of robots interacting with workers within the factories.
- Industry 4.0 goes in hand with additive manufacturing. The use of 3D printing offers additional opportunities for disruptive cost-savings within production processes.
- The advances in materials, science and computation allow for an improved simulation-driven approach to develop new materials and processes. This reduces time and costs, as companies will be able to build the desired qualities into materials from the beginning, instead of searching for materials with the desired qualities by making costly and time consuming experiments.
- Nanotechnology offers new opportunities possibilities to make plastics electrically conductive. This comes along with new opportunities for more efficient processes. There are predictions which come to the result that the automotive industry is able to remove the need for a separate spray painting process for plastics, which allows to reduce production costs by USD 100 per vehicle.

The automotive industry is a sector for which Industry 4.0 has a high priority. This sector is characterized by strong OEMs as well as TIER I suppliers and an overall value chain which is internationally diversified. Because Industry 4.0 allows to connect suppliers and customers along the value chain, new opportunities to reorganize production processes occur. There is the occasion to restructure relations from hierarchically top-down control systems to more self-organized bottom-up systems between suppliers and customers. This comes along with new opportunities for subcontractors offering products and services.

Figure 14: Scenario about interaction along the value chain without Industry 4.0. Source: Own presentation oriented on (Wischmann/Wangler/Botthof 2015, p. 39)

Figure 15: Scenario about interaction along the value chain with Industry 4.0. Source: Own presentation oriented on (Wischmann/Wangler/Botthof 2015, p. 41)
Because of Industry 4.0 especially SMEs have new opportunities to increase revenues by providing products and services to other firms being part of the automotive innovation system. This increased market potential increases opportunities especially for SMEs as well as TIER I suppliers. But also for OEMs it get more easy to cooperate with each other. The related dynamic has high potential for future innovations. New opportunities for economic value creation arise. Especially on the base of the interconnected production data firms have the opportunity to create new revenues, by offering additional goods and services (e.g. Wischmann/Wangler/Botthof (2015)).

The IoT will further raise productivity by generating synergies among technologies (due to the increased interoperability of machines). Industry 4.0 allows automotive companies to use “generative” software algorithms to create industrial designs which optimize product weight and strength in completely new ways that are not evident to human designers. Such new methods allow simulating the evolution of multiple variants on an initial design by eliminating the least fit designs in successive stages. This allows to increase significantly the fit of (industrial) designs. For example, the so called “Dreamcatcher software” was used in order to optimize the chassis of the world’s fastest motorbike, the so called “Lightning Electric Motorcycle” (Kinkead 2014).

This shows that data-driven optimization processes offer many opportunities for the automotive sector. Based on these software algorithms new highly complex designs are generated. Very likely the new designs can only be manufactured in an economic way by using new additive manufacturing tools like 3D printing. Industry 4.0 generates new requirements for the combination of different technologies. Augmented reality (AR) is one example. AR allows engineers to see in real-time projections of the inner working of machines. This feature can be used to train employees and/or to give guidance for maintenance. AR can be considered as a core technology which has to potential to make production processes more cost efficient.

How fundamentally the automotive supply chain will change can further be demonstrated by taken the platform economy into account (Engelhardt/Wangler/Wischmann 2017). For instance, firms can send the data for 3D-printed prototypes to potential suppliers and receive the printed products from retailers. The transaction happens by the mediation of an online marketplace where manufacturers compete for the contracts to print the prototype.

One further relevant aspect changing the whole future industry-production is the topic of artificial intelligence (AI). For example, the use of AI allows to make use of machine-learning algorithms to find out which combination of robots and tools is the most efficient in assembling the device.

Based on these set initiatives it is an interesting question to discuss how production in the automotive industry will look like in 2030. The following scenario gives a first impression on how automotive production will look like in 2030.

**Automotive production in 2030**

The following description tries to give an impression on how future production processes may look like (please compare also (OECD 2017, pp. 78)). Some components, such as systems-on-a-chip and sensors, are still produced by the existing manufacturers. For other devices new supply-structures become relevant. The mass production of the components will mainly be executed by autonomous robots. The produced components and the associated data are then sent to the assembly facility of the OEM. Block-chain is one core technology to allow for automatized transactions between firms. In order to integrate the different automotive parts, the robots along the assembly line retool and arrange themselves. Robots will move the components and assemble the devices. When robots assemble a device, computers make use of the machine-data in order to control for the efficiency of the production process. The calculation gives information whether the process still fits the parameters and whether there is potential for further optimization.
When the product is finished it is boxed by a robot, and the box is loaded by another robot into a self-driving truck. This autonomous vehicle brings it to the retailer. The upload is also done by robots who automatically place the product in the correct warehouse storage location. The order for the product is made automatically. When an order comes in, robots transport it to the customer’s front-door.

For the case that sales exceed expectations and orders increase from around the world, it becomes necessary to increase the production capacity. The OEM will then get to the market, which means that he contacts via an online-platform manufacturers in the region. Those manufacturers will compete with each other in order to get the contract that allows them to produce larger or smaller batches of the product. When the subcontractor gets the assignment, he will also get access to the machine-learning algorithms from the previous production processes, which allows him to start immediately with an efficient production. After the factory has finished producing its order, reorganization and retooling is done automated by the robots. The transaction between contractor and subcontractor is monitored automatically via a blockchain.

In 2030 an automotive will mainly be produced by robots. After the car is designed, significant less workers will be employed within the factory itself. The major task which is left to employees is related to monitor the production process. For many processes like plastics moulding, assembly or the logistics, the need for workers within the production process will be reduced significantly. Automotive production is highly flexible and OEMs are able to fulfill individual needs and wishes of their customers. Many of the car-features are produced individually for the particular customer.

- **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

This shows that Industry 4.0 comes along with “creative destruction” of established businesses, markets and value networks within the automotive industry. In the future many current organizational structures and many business processes will be affected by this development (Wischmann/Wangler/Bothof 2015). Existing business models from today involve costs that cannot be recovered (so called sunk costs). Employees working within these industries fear the consequences that might result in job losses. This causes resistance against too disruptive changes (Christensen 1997). Especially with regard to big OEMs like Volkswagen, General Motors or PSG it is an interesting question how these big companies are able to deal with the disruptive changes of Industry 4.0.

From a firm level perspective it is clear, that an organizational culture which is mainly characterized by resistance among management and their employees against the Industry 4.0 related changes can be a threat for the consequent future competitiveness of the firm (Christensen 1997). Such developments come along with a so called “innovator’s dilemma”, meaning that companies might fail to innovate in the long run, because they are currently successful and fail to put enough emphasis on current changes related to Industry 4.0. One major reason is the “fear of change” which bears the risk that the management acts too conservative, meaning that it sticks to the established business model. As governments are aware of existing barriers and the economic relevance for implementation of Industry 4.0, many R&D funding schemes have been implemented to support innovation and digitization within the automotive sector.

**References**


2.4. Fuel cell propulsion technology

**Sector/Mode of Transport:** Automotive  
**SCORE:** 1  
Europe has a competitive disadvantage in comparison

**Management Summary**

Fuel cells are electrochemical power devices that directly convert the chemical energy of a fuel into electric power. While fuel cells share principles of operation with batteries, they differ in the way that the electrochemically active materials are stored externally and are continuously supplied to the device and can produce electricity for as long as fuel and oxygen are supplied. The appeal of the technology is that it is possible to build emission free cars, if pure hydrogen is used as fuel and, depending on the hydrogen generation, be completely emission free. The engine is a much simpler construction (60% fewer parts, 90% fewer moving parts) and needs a lot less maintenance, compared to internal combustion engines (GM 2010). In Europe all major car manufacturers have been working on fuel cells for many years and all of them have roadmaps that lead to a market introduction in the next few years.

**Description of the main concept**

Fuel cells are electrochemical power devices that directly convert the chemical energy of a fuel into electric power. From hydrogen and air (oxygen) or another oxidizer they produce electricity. While fuel cells share principles of operation with batteries, they differ in the way that the electrochemically active materials are stored externally and are continuously supplied to the device and can produce electricity for as long as fuel and oxygen are supplied.

All types of fuel cells consist of an anode, a cathode and an electrolyte which enables hydrogen ions to move between the electrodes. At the anode a catalyst ionizes the hydrogen. The resulting protons (hydrogen ions) flow to the cathode through the electrolyte and the electrons are drawn to the anode through an external circuit, forming a direct current. At the anode, a different catalyst causes protons, electrons and oxygen to react and form water.

The appeal of the technology is that it is possible to build emission free cars, if pure hydrogen is used as fuel and, depending on the hydrogen generation, be completely emission free.

Fuel cell propulsion is a different approach to reduce greenhouse gas emissions from vehicles and research on the technology has been going on for many years. It picked up momentum in recent years, resulting in announcements of production vehicles from Toyota, Honda, and Hyundai for markets with existing hydrogen infrastructure. Fuel cell propulsion shares aspects with both, cars with internal combustion engines (ICEV) and battery electric vehicles (BEV), and combines advantages from both systems. Like electric vehicles, fuel cell propulsion produces zero tailpipe emission, if supplied with hydrogen. They only produce water. The environmental impact can be optimized by the way the hydrogen is produced (e.g. through renewable energy). The engine is a much simpler construction (60% fewer parts, 90% fewer moving parts) and needs a lot less maintenance, compared to an ICEV (GM 2010).

On the other hand, the external supply of fuel to the fuel cell makes higher ranges possible than in BEVs, only depending on the tank’s size. Additionally, these tanks can be refueled as quickly as a petrol tank.
The potential for fuel cell propulsion in general is comparable to that of BEVs, since both are different technological paths for the solution of the same problems. Nevertheless, both have to overcome different technological obstacles, which make it hard to predict which technology will be favorable.

Their impact on infrastructure is very different. For refueling BEVs rely on a network of charging stations with the opportunity to decentralize the process of refueling, i.e. charging at home, at work, etc. In contrast, fuel cell electric vehicles (FCEVs) are using centralized stations like ICEVs. Thus, achieving a successful transition to hydrogen powered vehicles automotive market will require strong and sustained commitment by hydrogen producers, vehicle manufacturers, transporters and retailers, consumers, and governments. The interaction of these agents in the marketplace will determine the real costs and benefits of early market transformations policies, and ultimately the success of the transition itself (ORNL 2008).

Analysis & Assessment of the impact on present industry structures

An assessment of the technology readiness level (TRL) has to be segmented for different means of automotive transport. Fuel cell industrial trucks achieve the highest levels, TRL 8 or 9. Especially in North America extensive experience in large numbers is available. The longest and most extensive operational experience is available to fuel cell buses. They are in operation with transit agencies and universities around the world and have reached TRL 7 to 8. First passenger cars with a fuel cell drive are now available as series production vehicles (Honda Clarity Toyota Mirai, Hyundai ix35 Fuel Cell, Hyundai Tucson Fuel Cell) and are at TRL 8. The technology components and operational experience relating to fuel cell buses can in principle be transferred to trucks. Medium duty vehicle classes 4 to 6 (US GVWR classifications) are at an early prototype stage and TRL 6 to 7. For Heavy duty class 7 to 8 first concepts are available (TRL 3). (CaFCP 2016, SHE 2017)

Some of the main technological objectives that need to be achieved by 2020, in order to ensure that its performance will allow for their progressive deployment and integration in the economy up to 2050 are described in the multiannual working plan (MAWP) of the fuel cell and hydrogen joint undertaking (FCH JU). The productions costs of fuel cell systems used in transport applications need to be reduced by an order of magnitude (currently 500 €/kW for cars (Nia 2016)). This will be possible through scaling effects of series production as well as scientific and technology progress (DOE 2016). The durability of proton exchange membrane fuel cells (PEMFC), predominantly used in transport applications, needs to be quadrupled from currently 8000-15000 h. Furthermore, the production of fuel, i.e. hydrogen, from electrolysis needs to become more energy efficient by 10 % from currently 67 % while reducing the investment cost below 2,000,000 €/t per day capacity (today 3,000,000 – 4,000,000 €/t) (Nia 2016, FCH JU 2014). Today, hydrogen is primarily obtained by steam reforming of natural gas, thus producing greenhouse gases. The main research topics include novel materials and fuel cell design concepts to reduce the usage of precious metals. The second topic is the simulation and understanding of the functionality of 3D structured electrochemical interfaces. Thirdly, the focus will be on new concepts and designs to improve the efficiency of the solar cells (FCH JU 2014).

One thing widely seen as needing to change before FCEVs could become practical has not changed over the years: technology for carrying hydrogen on-board the vehicle. Despite a plethora of promising lab developments, there has been no practical breakthrough in hydrogen storage. The new FC vehicles all use high pressure gaseous hydrogen stored in polymer-lined, fibre-wound pressure tanks.

All major car manufacturers have been working on FCEVs in some way. The first one to introduce a concept car was general motors with a van back in 1966. It was a van because at that time the room was necessary for the fuel cell system.

- In Europe:
In Europe all major car manufacturers have been working on fuel cells for many years and all of them have roadmaps that lead to a market introduction in the next few years. Several times market introduction of FCEVs was announced but never came true so far. Daimler recently announced a GLC F-Cell plug-in hybrid model. It is planned to launch in 2018. AUDI introduced a FCEV concept in 2016, announced a cooperation with Ballard to exchange IP, and that it will lead the FCEV efforts of the Volkswagen Group. BMW stated the company will enter the FCEV market with small production runs early in the next decade (DOE 2016).

A huge part of the engagement is based on the identification of hydrogen as part of strategic energy technology (SET) plan of the European Union (SET 2017). This is consistent with the EU 2020 Strategy (EU2020 2010), the energy 2050 roadmap (EU2050 2012), the white paper on transport (EUTrans 2011), the strategic transport technology plan (STTP) (EUSTTP 2012), and the FCH JU-2-MAWP 2014.

**Worldwide:**

The rest of the world acts comparably. All big manufacturers have expressed their commitment to the technology. 83 % of all patents concerning fuel cells between 2002 and 2012 were issued in the US (47 %), Japan (31 %), and Korea (5 %) with the top 5 Companies being Honda, General Motors, Toyota, UTC Power, and Samsung. Nevertheless, Japanese (Honda, Toyota) and Korean (Hyundai) companies are the first and until today the only companies to offer FCEVs commercially in small quantities in markets with existing hydrogen infrastructure (i.e. California, Europe, Japan, South Korea).

In principal different types fuel cells exist and are classified according to their choice of fuel and electrolyte. The six groups are alkaline fuel cells (AFC), phosphoric acid fuel cells (PAFC), solid oxide fuel cells (SOFC), molten carbonate fuel cells (MCFC), proton exchange fuel cells (PEMFC), and their subcategory direct methanol fuel cells (DMFC). In automotive applications almost exclusively PEMFCs are used. They offer high power density and bring the advantage of low weight and volume. PEMFCs operate at relatively low temperatures (80°C). This allows for less warm-up time and quick starts, resulting in less wear on system components and better durability. (EGG 2004)

**Analysis and assessment of the impact of Disruptive Technologies on present value chain**

The advantages of fuel cells are weight, capital cost and refueling time/range of operation. In case of FCEVs the range of operation is only dependent on the tank’s size and refueling takes as long as for an ICEV. The fast refueling, that is a strong advantage today, might diminish in the near future. Several manufacturers and initiatives are working on fast charging technologies for BEVs with 15 minutes for a range of 400 km being realistically on the horizon (POR 2016). Thus, it is not clear whether fuel cells can outperform BEVs in this regard. Nevertheless fuel cell systems in vehicles outperform battery packs in terms of weight significantly today (EP 2017) and system price in the future, depending on scaling effects. Both technologies have to overcome significant obstacles, with their development not being unrealistic but hard to predict.

In case of a wide deployment of fuel cells for automotive propulsion the value chain will see only minor changes since the business model is very comparable to that attributed to ICEVs. Cars will be built by the same manufacturers, possibly with different suppliers. Fuel production will introduce new players like Linde and Air Liquide into the automotive market due to their expertise in gas handling and production. As long as hydrogen is predominantly produced from natural gas mineral oil companies remain in a strong market position. Fuel stations might be integrated into the existing network of petrol stations.
The value chain will not see huge changes in its architecture. In certain parts of the chain new players will appear, especially concerning fuel production. As long as the hydrogen production is based on natural gas, mineral oil companies and gas companies will play an important role. Advancements in electrolytic production might be a chance new market entrants to enter, but significant cost reductions of electrolytic conversion are not on the horizon for the next years, slowing down its widespread adoption (PE2 2017).

The development of a low-carbon economy with a widespread adoption of hydrogen technologies has to be viewed on the long run with a horizon reaching up to 2050 (Nia 2016, FCH JU 2014). According to the technology roadmaps of the car manufacturers the introduction of FCEVs will remain slow, only gaining limited market shares, especially with further development of BEVs. For the foreseeable future fuel cells will be more expensive than combustion engines and remain a premium feature. As described in T2.2 demand is highly price sensitive and thus the slow introduction into the market will not have a strong impact on the overall demand. This can, of course, change rapidly in case of spontaneous regulatory changes concerning taxes or the oil price after natural disasters or from authoritarian regimes.

Due to the complexity of the technology with huge investments necessary for new entrants the market entry barriers are very high. In principle an entrant like Tesla with their BEVs is possible for fuel cells as well, but has not yet entered the market.

- **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

  The automotive market is a very complex one and is driven by different factors like customer demand, technological advancements, governmental regulations and environmental issues, all depending on each other. A huge driver will be the installment of a sufficiently dense network of fuel stations to remain the flexibility customers are used to from ICEVs. This and the addressing of possible safety concerns from customers can market FCEVs as viable alternatives for BEVs and ICEVs. Cost issues for fuel cell systems can be compensated by scaling effects and can therefore be comparable to existing solutions.

  A main barrier can be a too hesitant approach to the market. It is clear, that huge investments in research and development and infrastructure are crucial. Without them the tipping point of the market cannot be achieved.

  For a long term success of fuel cell vehicles an independence from natural gas and thus fossil energy sources needs to be aimed at. Therefore, efforts have to be undertaken to make electrolytic production of hydrogen with electricity from renewable sources more economic. In combination with that further advancements concerning hydrogen storage are an important factor.

  Cross sectoral collaborations are not crucial but highly beneficial. Since heavy investments are necessary on all sides, fuel cell development and infrastructure, collaborations are able to show its participants commitment to the technology. Additionally, integration within the fuel cell industry will assist with market growth and lower cost through increased benefits from scale effects. Mergers and acquisitions can lead to pooling of capital and make larger projects feasible. Especially Europe is taking a collaborative approach. The aforementioned FCH JU as a public-private partnership and H2 Mobility (http://h2-mobility.de) as a private partnership are examples for that. Nevertheless, worldwide collaborations between different players are formed (e.g. Ballard / Toyota, US Hybrid / Sumitomo, Arcola Energy / IMS ECUBES, Ballard / VW).

  The European industry is well aware of fuel cell technology and has been investing in research and development for many years, resulting in prototypes and announcements to enter the market in the
next years or in the beginning of the next decade. In terms of market readiness European car manufacturers are lacking behind their Asian competitors, where different manufacturers are selling production vehicles in several markets. Thus, the majority of intellectual property lies in Asia and North America, giving those industries an advantage. This already manifests in today’s collaborations of European manufacturers. For their fuel cell programs they all have cooperations with international partners (e.g. Toyota / BMW, Ballard / VW, Mercedes / Ford / Automotive Fuel Cell Cooperation) (DOE 2016). Nevertheless, Europe has a fruitful scientific community working on fuel cells (e.g. Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)).

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D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry


3. Aeronautics

The following key technological trends and innovative concepts have been assessed in terms of their impact in the current value chains and the success factors for implementing new technologies:

- **Alternative propulsion technologies for tight environmental regulations**
  How can electric hybrid air open rotor propulsion revolutionize the application field of aircrafts (e.g. in urban areas, commuters)? What about clean and green technologies? Which of these concepts will be the future?

- **Product service systems airline business model**
  What are the future potentials for product service systems (PSS) business models for airlines? With PSS moving the responsibilities of maintenance back to the manufacturers, how will smart technologies improve performance and reduce costs? What needs would be needed for future technologies?

- **Implementation of Cyber-physical systems in aeronautics**
  With the emerging I4.0 and smart factories, how will specific technologies support the manufacture of future concept vehicles? How will this support OEE rating? What about concepts of multidisciplinary design and blockchain affect the industry throughput.

- **Attractiveness of MRO services and fuel burn efficiencies**
  What are the future potentials of MRO services and burn efficiencies? What about Digital MRO and new materials and additive manufacturing?
3.1. Alternative propulsion technologies for tight environmental regulations

Technological solution: All electric, hybrid, open rotor, biofuels, etc.
Sector/Mode of Transport: Aerospace
Score: 3 Europe has a competitive advantage in comparison

Management Summary

Conventional fossil-fuel based power sources are being limited and environmental restrictions are getting harder. While other transport modes have totally or partially shifted to alternative propulsion systems, aerospace is still tied to fossil fuels. In aviation, energy sources such as bioenergy or fuel cells may replace traditional fuels, while advances in energy storage will favour the growth of renewables at a global level. Nowadays, the EU aeronautic industry is on par with the US. In particular in engine technologies, flight mechanics and aerodynamics the EU commands a good position, but if new technologies are not adopted fast enough, this competitive advantage can disappear.

Description of the main concept

Conventional fossil-fuel based power sources are being limited, though they can last many more decades. On the other hand, alternative propulsion technologies are being developed, some of which are more disruptive but other can be developed in short time. Many other transport modes have totally or partially shifted to alternative propulsion systems (especially railway), while the automotive industry is already changing. But aerospace, with higher and more complex requirements, remains a harder nut to crack. Even so, all indications suggest that it will eventually follow suit.

The environmental goals set by European Commission (EC, 2011) recognised the need of aviation sector to accelerate its efforts to reduce emissions that impact climate change and air quality to allow sustainable traffic growth. The UN Framework Convention on Climate Change conference (Paris, 2015) confirmed the goal to keep global temperature increase below 2ºC compared with preindustrial levels. Aviation produces around 2% of all human-related CO2 emissions. This share may seem low, but it risks even more with traffic increment if sufficient measures are not taken.

Additional climate impacts result from nitrogen oxide (NOx) emissions and condensation trails that may lead to induced cirrus clouds.

Air quality, in particular regarding NOx and particulate matter, is also of increasing concern in and around airports.

Aviation can reduce emissions by improving the fuel efficiency of the entire system through technology, operations and infrastructure, but also by developing sustainable low-carbon aviation fuels.

Alternative fuels and energy sources have the potential to disrupt the geopolitical balance of power, as well as to affect how businesses and the public consume energy. In aviation, energy sources such as bioenergy or fuel cells may replace traditional fuels, while advances in energy storage will favour the growth of renewables at a global level.

Demand for jet fuel may be reduced by the use of biofuels or the introduction of new engine and aircraft designs. Meanwhile alternative energy sources will come into use outside of aviation.

If adoption of new technologies by the industry is slow, airlines increasingly run the risk of being seen as “conspicuous consumers” and face increasing pressure in a low-carbon, renewables world.
Airlines that invest in alternative fuel technologies or radical designs may be perceived positively by travelers and increase their share of the market.

There are several reasons to study alternative propulsion systems for aircrafts, especially electric systems. The observed growth of air transport is clearly visible despite any temporary drawbacks (Airbus, 2017). This growth leads to increased fuel burn and a stronger impact of aviation on the environment. The aviation industry (manufacturers as well as operators) are currently introducing new technologies and operating schemes to achieving a strong reduction in fuel consumption per flight in the order of 15-20%. However, it will take many years until all aircraft are replaced with new generation vehicles and on the other hand the growth of air traffic will lead to increasing overall fuel consumption and hence emissions from air traffic.

Besides the problem of emissions and pollution the amount of oil is limited (IMF, 2017). Even if it is not clear when the oil resources will be depleted, the price of oil has been steadily climbing for many years following a rather unsteady but clearly visible trend.

Attractive features of electric propulsion systems are that they benefit from better efficiency in the energy conversion chain and that they can be considered as locally zero-emission – albeit depending on how the electric energy is produced.

However, introducing electric propulsion systems into ground transportation seems to be relatively simple compared to the implementation in aviation. While ground based vehicles can easier cope with additional mass due to not fully developed electric storage and propulsion systems, aircraft are much more sensible to mass. Furthermore typical trip distances as flown by aircraft are much larger that trips in ground vehicles (cars, buses, trains) and safety standards in aviation are extremely high. Finally one must acknowledge the fact that current aircraft are already very efficient in terms of fuel burn per payload and distance.

All these facts make it no easy task to develop electric propulsion system concepts for aviation, but it is of strong interest and necessary to determine the physical limitations of using electric energy for aircraft propulsion and to work out the requirements and guidelines for future development.

Analysis & Assessment of the impact on present industry structures:

A different TRL will be given for each different analysed technology:

- Electric and hybrid aircrafts (Electrical propulsion): When talking about electric or hybrid aircraft TRL, a distinction should be drawn between TRL for different components. For example, regarding fuel cells, two types of fuel cells that have been developed for automobile transportation and stationary power generation applications can be considered for aviation: the proton exchange membrane (PEM) and the solid oxide fuel cells (SOFC). There are no currently certified fuel cell systems on commercial aircraft, so TRL for fuel cells can be between TRL 4 and TRL 5 (National Academies of Sciences, Engineering, and Medicine, 2016).

In general, taking into account that electric and hybrid aircraft development is going at different speed for commercial aircraft and general aviation, it can be said that TRL is currently 4 for commercial aircraft, even it has reached 6 for other type of aircrafts.

- Open rotor: Open rotor propulsion offers particular promise in energy efficiency but also presents strong challenges in integrating novel sub-systems, engine and aircraft systems and addressing noise emanating from the unshielded propellers. There have been many project and demonstrators in the field of open rotor concept in the last years. Within Clean Sky
initiative, projects like SAGE1 (under Rolls Royce leadership and with GKN Aerospace and ITP) and SAGE2 (led by SAFRAN/Snecma in cooperation with Airbus) have brought the TRL of open rotor technology to TRL 5 (Brouckaert, 2015).

- Biofuels: Being developed since 1970s, Biofuels have reached to practical production stages. United States, Brazil and New Zealand are among the leading nations in producing biofuels. Automobile industry is one of the first consumers of biofuels. The reason for early adoption of biofuel by auto industry over airline sector is that the automotive industries in each country must adapt to the national rules and regulations, whereas the airline industry has more global nature and therefore requires a globally recognized and verified fuel. Virgin Atlantic was one of the frontrunners in testing biofuels on commercial aircrafts. A Boeing 747 fuelled with biofuels, flew without passengers on 24th February 2008, from London Heathrow to Schiphol airport in Amsterdam (Marsh, 2008). Air New Zealand and Boeing have created a research partnership to sustainably produce biofuel from Jatropha. Among the plants considered up until now, Jatropha is one of the best candidates for the biofuels production (Barta, 2007). A two-hour test flight between Auckland and Wellington (New Zealand) was performed by consuming biofuels and involved one of the airline’s Boeing 747-400 aircraft (Simon Blakey, 2011). In such flights a combination of new biofuel with Jet A-1 were successfully tested on current jet engines. So, it can be said that technical feasibility has been achieved, but the economic feasibility is still to be proven. So, different types of biofuel technologies can be nowadays at TRL 7, TRL 8 or even TRL 9.

According to ACARE (Advisory Council for Aviation Research and Innovation in Europe) Roadmap, alternative propulsion systems are included under Challenge 3 – Protecting the environment and the energy supply. There are different Action Areas that affect alternative propulsion technologies (ACARE, 2017).

Under Action Area 3.1 (Develop air vehicles of the future: evolutionary steps), it is said that propulsion developments need to target higher thermal and propulsive efficiency. As with airframes, materials will play a significant role with new lightweight structures and high-temperature materials for engine cores. Awareness of adverse health effects of NOx and combustion particulates, especially for local airport air quality, must drive research and innovation in combustion systems. Alternative fuels such as high-blend drop-in kerosene will play an important role in overall CO2 reduction, and their effect on engines and aircraft systems must be mastered. Also, close collaboration between airframe and engine manufacturers will be needed to install advanced, even larger, more complex propulsion systems onto aircraft. In this respect, ultrahigh bypass ratio engines of all types will present new challenges. Moreover, these will use high power, high speed gearbox components requiring new technology for their development and introduction.

Action Area 3.2 (Develop air vehicles of the future: revolutionary steps) goes further and says that it is necessary that alternative sources of energy become feasible for aviation. These alternative sources will include non-kerosene, renewable energy such as electrical and hybrid power for both thrust generation and on-board functions. On-board storage of non-kerosene energy demands a huge research effort, especially given the weight-, volume- and safety-critical nature of aviation. Key areas of research will focus on energy/power density, recharge/discharge rates, re-use capability, materials (such as avoiding rare elements) and heat management. One or two orders of magnitude increase in capability will be needed. Where traditional carbon-based fuel continues to be used, engines may have radically different configurations with changes to the overall energy release cycle.

Finally, Action Area 3.6 (Provide the necessary quantity of affordable alternative energy) is focused on finding disruptive solutions with near-zero emissions. Here, sustainable drop-in alternative fuels are seen as a promising way of reducing the carbon footprint of aviation in the short and medium terms.
Sustainable alternative fuels can be produced from various sources such as biomass streams, including waste and residues from agriculture and forestry, or from industrial and domestic waste, including industrial fumes. Processes are being developed to produce alternative fuels from renewable energy and CO2 from industrial sources or from the atmosphere, with, for example power-to-liquid and solar-to-liquid technologies. Ideally, only renewable carbon sources will be used in the future.

Talking about specific developments (R&I needed to achieve the above mentioned challenges), those are the main expected developments related with propulsion systems under each Action Area:

**Develop air vehicles of the future: evolutionary steps:**

- Improve the thermodynamic and propulsive efficiency
  - High-Temp materials e.g. CMCs, turbine disks, blades and blings.
  - Improved aerodynamics - higher component efficiency (rotative and static parts) with increases in overall pressure ratios and cycle temperatures.
  - Improved aeroelasticity; e.g. flutter response with short engine intake and UHBR engines.
  - High efficiency and low heat loss power gearboxes.
  - Thermal management and cooling systems, e.g. turbine cooling, power gearbox, critical parts and secondary air system cooling.
  - Variable geometry, e.g. variable pitch fan blades for optimum engine efficiency and operation (e.g. flutter and stall) and nozzles.
  - Lean burn technology, e.g. engine control and stability, lightweight and compact systems (low complexity and reduced envelope).
  - Low drag / low noise Inlet / nacelle technology for UHBR and CROR engines, e.g. short intake, low weight and compact thrust reversers.

- Reduce combustion emissions - NOX, CO, UHC and partulates
  - High-blend drop-in kerosene, e.g. compatibility issues around key attributes like lubricity, material compatibility and impact on particulate emissions.
  - Low smoke, particulate combustion systems.
  - Lean burn technology for low Nox.
  - Characterise and quantify full engine emissions including particulates.

**Develop air vehicles of the future: revolutionary steps:**

- New Energy Sources, storage and power transmission:
  - Battery and capacitor capacity.
  - Battery and capacitor weight.
  - Discharge and recharge rates.
  - On-board power distribution and management.
  - Super-conducting technologies for electric machines, power electronics and power transmission.
  - Hydrogen technology (storage, distribution, combustion system), including synergies with current energy carriers (fossil fuels, alternative fuels, other gases...).

- Novel architectures for propulsion systems that offer game changing reductions of environmental impact and energy consumption:
  - Develop novel propulsion system concepts and associated power management systems.
  - Develop new concepts for electrical components, heat exchangers, noise attenuation technologies and optimized integration.
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

- Embedded engine: Boundary layer ingestion and drag reduction.
- Thrust measurement and efficiency assessment methods in disruptive configurations.
- Variable geometry nacelles.
- Combined thrust and drag areas: distortion tolerant specific fan, integrated exhaust, structural integration and certification issues.
- Noise Technologies for Embedded Powerplants (BWB).
- Multi sources propulsion / power system and associated power management.
- More electrical propulsion power: hybridation with high power density electrical component on gas turbine.
- Innovative turboshafts and APU architectures for heat exchanger integration.
- Distributed propulsion (First application).
- High dynamics bearing and rotating interfaces for turbomachinery.
- Power management between main propulsion and Non Propulsive energy.
- Variable exhaust systems (nozzles/mixers).
- Turbine and fuel cell hybridation.
- More electrical propulsion power: more electrical FAN.
- Centralized power unit + distributed propulsion / power (Dedicated to new aircraft and rotorcraft architecture).
- Reverse flow and off-centre cores (distributed propulsion).
- UHBR integration improvements - enabling maximum benefit from CROR.
- Short and slim nacelles.
- Multifunctional nacelles.
- Unducted propulsion systems integration.

Provide the necessary quantity of affordable alternative energy:

- Availability of innovative drop-in fuel production pathways
  - To develop economically viable routes for producing commercial quantities of drop-in sustainable fuels.
  - To be ready to implement the available technologies and having the required information to trace the roadmap and implementation strategies.

- Optimisation of the aircraft & fuel
  - Facilitated approval of new drop-in fuels.
  - Efficient processes for rapid, cost-effective technical approval of new fuels are needed.
  - These processes must be based on an in-depth understanding of the relation between chemical fuel composition and properties: storage, combustion, emissions, effect on engine and aircraft fuel systems as well as the distribution system.

- Radically new solutions, low emissions non drop-in fuels and energy carriers
  - All bricks of radically new aircraft concept for fuel in rupture: aircraft configuration, energy storage, energy conversion, associated propulsion, airport logistic, fuel production and transport, associated sustainability evaluation.

Future technologies are intensively being studied nowadays both by industry and by academia. Many research projects and demonstrators are being developed and millions are being invested. At a glance, the civil airplane has undergone very few changes over the past few decades. Aircraft emissions, regulations, and standards, along with the cost of fuel, are causing a need of new aerospace technology.
In Europe:
- European Commission launched in 2008 an open rotor demonstrator led by Safran within the Clean Sky programme with 65 million euros funding over eight years; a demonstrator was assembled in 2015, and ground tested in May 2017. (Safran, 2017).
- Airbus, Rolls-Royce, and Siemens have formed a partnership which aims at developing a near-term flight demonstrator which will be a significant step forward in hybrid-electric propulsion for commercial aircraft (Aviation Report, 2017).

Worldwide:
- NASA is investigating low-noise open rotor systems in collaboration with industry in two projects: the Environmentally Responsible Aviation Project and the Subsonic Wing Project (NASA, 2010).
- Boeing Co and JetBlue Airways Corp announced plans to bring a small hybrid-electric commuter aircraft to market by 2022 (Reuters, 2017).
- In November 2017, Boeing announced the acquisition of Aurora Flight Sciences, an advanced aerospace platform and autonomous system developer. This is seen as a strategy to improve its capabilities in electrical propulsion (Boeing, 2017).

Agencies and organization in government, industry, and academia with an interest in developing propulsion and energy system technologies that could reduce CO2 emissions from global civil aviation and that could be introduced into service during the next 10 to 30 years agree that highest priority on research agenda is on four approaches:

- Advance in aircraft-propulsion integration.
- Improvements in gas turbine engines.
- Development of turboelectric propulsion systems.
- Advances in sustainable alternative fuels.

Analysis and assessment of the impact of Disruptive Technologies on present value chain

There are no different selling points for alternatively propelled aircrafts, but their early adoption could greatly increase competitiveness of airliners. For example, if new alternative propulsion systems are developed, with improved fuel economy, those early-adopters could benefit from them, offering lower prices to customers. Also, public image of those companies would also improve, giving them competitive advantage.

The value chain to mass-produce electric or hybrid aircrafts does not exist today, neither for open rotor engines or engines using biofuel, so new dynamics will be created.

Electrification has arrived to other sectors like automotive or railway, so there is much to learn from those sectors and their production systems. Even so, there are lots of battery manufacturers, electrical engines are being developed and improved continuously and other mechanical elements (such as gearboxes or axles) are quite similar to currently existing products.

An increase in electrification of aircraft systems would see the market share of EHA (Electro-Hydraulic Actuator) / EBHA (Electric Backup Hydraulic Actuation) / EMA (Electromechanical Actuator) suppliers increase, while hydraulic/pneumatic system share decrease. Aerospace TIER 1 and OEMs, who are down-stream in the value chain (and buy and assemble these components), would not see a significant change and are not expected to experience major changes in market share outside of the regular existing cycle of new program launches and contracting (Roland Berger, 2017).
Open rotor concepts should also not change the industry in excess, as the main suppliers of current fuel engines are involved in the development of this new type of engines.

The use of biofuels should not have an excessive impact in the industry value chain; only the engine manufacturers will have to make some changes to their production process, but components should be quite similar.

The future concepts described will completely change the aircraft industry. Both civil and cargo aviation can benefit from these solutions as competitiveness of air transport will be increased and cost-efficiency will be improved. Also, aviation's environmental footprint in terms of greenhouse gases will be reduced, improving air quality and reducing noise. Finally, an increase in the safety level of aviation is expected from the application of these technologies.

Even so, the implementation of future concepts in aircrafts won’t be immediate, but will apply first for some type of flights (i.e. Urban Air Taxis or Regional Aircrafts).

It is difficult for new entrants to join the aircraft manufacturing industry, but if propulsion systems are shifted to disruptive technologies (such as electric or hybrid), there is an opportunity for electric systems manufacturers, battery manufacturers, and even engine manufacturers could have an opportunity.

But even not being new entrants, companies like Embraer, Bombardier, Comac or Irkut could pose a challenge to Boeing and Airbus dominance and get a significant market share. Those companies tend to assume more risks in technological developments, so they could get competitive advantage if they are able to include disruptive technologies before Boeing and Airbus.

- **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

The main drivers that will facilitate the implementation of alternative propulsion systems are:

- Tax policies supporting innovation and advanced manufacturing.
- Policies for enhancement of sustainability.
- Revenue growth fuelled by lower energy costs or lower operational costs.
- Reduction of pollutant emissions.
- Other environmental implications of product and process innovations.
- Lower power consumption.
- Increased visibility and awareness of energy consumption.

The main barriers that will obstruct the implementation of alternative propulsion systems are:

- Variety of political, regulatory, juridical, tax and labour environments in different countries.
- Difficulties in evaluating cost-benefits of investments.
- Increased inter-firm rivalry due to misalignment of motives and behaviours among partners.
- Difficulties in developing cost-efficient solutions.
- Integration of technologies is non-trivial.
- Lack of standards.
- Need to balance business profit with environmental impacts and benefits.
Aeronautic sector can benefit and collaborate with automotive in the field of electrification and new materials development, but an overall collaboration seems difficult due to the considerably different safety, security, quality and legal requirements of both sectors.

The European aeronautic industry was created from national industries. Initiatives started at the end of the 1960s, when it was recognized that individual states did not have the potential to catch up the lead of the US industry. The efforts resulted in the creation of EADS and Airbus.

Nowadays, the EU aeronautic industry is on par with the US. In particular in engine technologies, flight mechanics and aerodynamics the EU commands a good position. Europe can also count on a strong know-how basis in air traffic management systems –ATM- (EC, 2009).

The EU aeronautic industry has also a long-standing experience in the management of cross-border value chains. This experience reduces the risk of OEMs in their efforts to focus on their core activity, system integration and outsource more work packages to suppliers inside and outside the EU.

References


3.2. Product service systems airline business model

**Technological solution:** Product Service Systems (PSS), Availability Contracts, Airline Code Share Agreements.

**Sector/Mode of Transport:** Aerospace

**SCORE:** Europe has neither a competitive advantage nor a competitive disadvantage

**Management summary**

Long-term competitiveness is now the norm between aviation companies and their supply chain network. With innovative manufacturing and advanced technologies being introduced rapidly into the industry, the sector is turning to integrated solutions such as service packages as part of the sale, contracting for availability (CfA), whole life cycle cost (WLCC) monitoring and other risk management toolsets mainly to maintain profitability and continued growth in business. If manufacturers’ business models are a challenge to the sector, the others come in the form of increased complexity in services that are being demanded by the short-haul market and the low-cost carriers (LCC) markets. In order to remain competitive and attract passengers, traditional and full-service airlines have adapted to new products such as code share agreements, network and route streamlining and aggressive marketing that could be linked to a search conducted by an ordinary passenger on a particular route. The digital infrastructure has now come to a level globally, that airline fares are now being monitored through advanced algorithms that now challenge the industry to remain competitive. This section lends a perspective view on the impact of various business models and strategies that govern both the manufacturer and the end user such that both demand and competition are met.

**Description of the main concept**

Global competition drives the aerospace sector. Previous sections under work package 2 of this project provide an overview of the market size and the demand and how various ‘push’ and ‘pull’ factors govern the growth of the aviation industry. The innovation offered by product service systems is unique and has been addressed in literature, mainly due to the reason that the service and maintenance responsibilities are now reverted back to the manufacturer (Meier, Roy and Seliger, 2010; Erkoyuncu, Roy and Harrison, 2012; Zhu et al., 2012; Wallin, Parida and Isaksson, 2015). In the past, the service package was optional and it was at the discretion of the end user as to how they planned their service contracts, with the possibility that the manufacturer would only be supplying replacement parts. However, a 25 year long contract, which has evolved over the last 15 years, has now identified the whole lifecycle cost of the asset, thus giving a fixed price which needs to be in-line with the projected economic growth. This also means that the manufacturer is now forced to adapt to provide best service without compromising the performance and yet make profit on the awarded service contract. This completely shifts the strategy for short-haul and low-cost carriers as they are more interested in getting their aircraft on the runway at the lowest possible maintenance cost.

The end-users, in this case the airliners, are attracting different segments with different strategies. Where network and streamlining of airline schedules are being adopted, the facilitation of these services comes through airline code share agreements that interconnect long-haul, short-haul, full-service and low-cost carriers in a dynamic model thus increasing the passenger load capacity. Whilst, the long-haul market is still dominated by full-service airlines, competition comes in the form of on-board experience and a wide range of choices and options that attract the passenger. The LCC still are heavily dependent on efficient route planning and lower fares that help improve their business. However, their strategies in terms of on-board experience is being developed.

The challenges presented only provide an overview and the impact of growing traffic, reduction of resources, pilot shortages and passenger management systems is what controls and governs the aerospace sector. It should be understood that this work differs from other areas of assessment, as it
purely reviews the impact of servitization and product service systems models, which are more a business strategy as opposed to a technology in itself. Hence, the current work will not evaluate the current status using the TRL framework.

On the manufacturing front, streamlining manufacturing processes and providing effective maintenance with the lowest cost are becoming the norm. On the airliner’s front, digital and financial management together with attractiveness in the form of onboard experience and competitive pricing is what controls the current market. Terms such as strategic advantage and strategic target have become the focus for a majority of industry players. These push the sector to adapt to digital architecture, advanced materials and innovative manufacturing and maintenance processes. How this will shape the future is an area that is currently under debate. Whilst there is strong evidence that PSS and other business models drive the current aviation sector, only limited insights to future business models are evidenced. Further, the dependence of growth and attractiveness of a variety of players will shape the future of the sector. It should be understood that the business models and strategies only conform to the direction of the industry and there is a lack of measurement framework that will see progression of these toolsets.

To demonstrate the impact of business models, metrics such as air traffic and airport revenue are considered. The 2015 statistics presented by EC reported a growth of 7.2% in terms of passenger numbers amounting to a total of 3.6billion with the airports reporting a revenue of US$142billion (8.2% YoY growth) (European Commission, 2017).
Both the metrics indicate a growing sector due to the current business models in existence. However, the trends need to be monitored regularly to measure the overall impact due to the introduction of future innovative products.

Analysis & Assessment of the impact on present industry structures

Servitization models are predominantly looking at business approaches that work for an organisation. The asset being made of high value parts, with an average life span of 25 years, it is necessary that new and innovative ideas be exploited to maximise profitability to the organisation. With economy prediction models heavily reliant on the local and global shocks, industries within the aerospace sector are bracing themselves up with a variety of business models. For example, where the standard complete maintenance of a majority of the aircraft is between 3 and 5 years, low cost carriers, extend this through intermediary safety checks and send it to full maintenance somewhere between 6 and 8 years. Whilst this is in accordance with the joint airworthiness regulations and other international civil aviation regulations, there are risks associated with such practices especially on the life of the parts, with the airline operator forcing the aircraft into early retirement. However, with aircrafts that are made with modern technologies and advanced materials, the LCC sector is now moving into this style of business.
Another viewpoint that needs to be addressed is related to the aircraft leasing business model occurring during the sale or lease of a new or a second lease aircraft. Where previously, manufacturers relied on post sales service as merely a venue to sell spare parts, PSS systems now force the responsibility of the entire aircraft back to the manufacturer, where maintenance is now part of the leasing agreement. The current challenge is now in estimating the cost of maintenance that the asset (in our case the aircraft) will require in the next 25 years in line with the anticipated market rate for the future. This has now forced manufacturers to identify technologies that may improve not just the maintenance performance but also save costs. A major corporation recently reported that, about 52% profit is made from modernising their MRO technologies and streamlining their activities.

As indicated earlier, the above insights are purely to highlight the impact of business models and how it promotes the development of new technologies on the long-run to achieve sustainability and profitability. As this assessment does not consider any direct technologies, the TRL framework is not adopted.

Business strategies have evolved over time mainly due to competition facilitated by economic growth. A majority of the international and regional roadmaps, (see above sections for details), focus mostly on environmental impact and inform growing markets, with market studies reporting growth in the business globally. These market analysis reports also provide information on the overall market behaviour so that industries are able to plan ahead in case new entrants change the market dynamics. Whilst all of these promote healthy competition and provide a platform for the players of the sector to decide on how they would make strategic decisions, a clear road map discussing the impact of such PSS based business models isn’t readily available and almost non-existent. It is envisaged that, with digital architecture and complex prediction modelling being developed rigorously, it is only a matter of time when such roadmaps come to light.

The closest road map styled report was developed by Sabre Airline Solutions which looks mainly at the LCC and Full Service airline market and their business evolution. The figure below shows the status and nature of strategies adopted by three airline companies (Sabre Airline Solutions, 2010).
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Figure 18 Airline business models 2008-2010 (Sabre Airline Solutions, 2010)
Servitization and PSS systems are widely adapted by all major airline manufacturers across the world.

- In Europe: Airbus, Rolls-Royce, Bombardier and Lufthansa Technik are the major players in Europe
- Worldwide: Globally, Boeing is the top player, with Embraer, GE and UTC employing these business models.

Due to the complex nature of how business models will perform, especially with their heavy dependence on the market, alternate developments paths do not exist in the current form.

- **Analysis and assessment of the impact of Disruptive Technologies on present value chain**

Business models for both manufacturers and airliners are usually on a case by case basis. Where aircraft leasing has become the norm, the level of service support is tailored to match the standard and basic requirements as set by airworthiness regulations with any additional activities as optional available at a price. Similar strategies are also adapted by airlines thus splitting the strategies between the LCC and full service sectors. Due to the nature of the business models and the wide range of available models, assessing specific models is challenging. Hence the following case study is reported to establish the competitive advantage of the models that are being adopted by current markets.

Erkoyuncu, Roy and Harrison (2012) reported the impact of PSS systems using aerospace case studies. The authors report that, one of the major challenges comes at the conceptual stage where the design team has limited information on the customer’s requirements. Multiple assessment approaches are reported, with emphasis on the impact on the service life over the next 30 years. This also puts into perspective the type of service contracts that need to be adopted by industries largely to estimate the overall cost of the service contract which could be as much as three times the value of the assets.

The business models play a major role in governing the strategies of the sector, and with the continuous growth in future markets with shifts happening from Asia-Pacific to China and Africa over the next 20 years.

This assessment is looking at the implementation of new and alternate business models. This has direct influence on the entire value chain as it dictates the future directions of the business. Further, it is believed that, a good business strategy is what sells the product, and the failure in implementing those successful technologies are purely business and or policy related. It should also be understood that, a successful product is one, which satisfies all the customer requirements and comply with all regional, international, safety and environment regulations. The following figure bears an example to how the value chain may change in the MRO sector.
In order to identify the current business strategies, the entire business model assessment becomes a burden and hence the MRO section has been used to identify the developments. Aviation week reported that the multiple strategies are currently being reviewed and adopted by various business, the key ones are as follows (Elliott, 2017):

- **ABCD to MSG-3**: Where A, B, C and D are types of traditional aircraft checks, a more flexible maintenance plan (MSG-3) has been adopted by companies. For example, an aircraft undergoing a D check can also be booked into a C check to reduce maintenance burden.
- **Phased-maintenance**: This looks at planning maintenance in accordance with the total flying hours as opposed to a set time line as indicated traditionally.
- **Shorter visits**: Efficient planning in arranging aircrafts to occupy hangers only for the set required task, and evaluate maintenance requirements based on flight routes and time of the year, (peak times and holiday season).

This would then imply that, a variety of technologies especially in the resource and management planning activities needs to be made dynamic such that only mandatory maintenance activities are undertaken by the service provider thus addressing the active developments the industry is approaching to match demand.

Business models impart competitiveness amongst industry players. As with any industry, the need and ability to outperform their rivals is a symbol of healthy growth. Evaluating their performance and targets with quality being the top priority, and reconfiguring their value chain in response to new technology introduction and there by opening up the value chain to new entrants is becoming the norm. For instance, the introduction of additive layer manufacturing into mainstream business is now challenging the 6000 year foundry industry. With new players posing a challenge, the mind set of small and medium enterprises will need to change such that they absorb this new technology. But whether it will impact the entire metal foundry industry is an unknown.
• **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

Identifying drivers for business models has been challenging. The key drivers based on available literature:

- Economic infrastructure
- Trade engagements
- Global fuel costs
- Integrated supply chain
- Technology infrastructure
- Maintenance infrastructure
- Airline partnerships

The main barrier comes from the fundamental attributes, propensity to travel and emerging and growing world economies. Whilst these attributes are positive in nature, the negative impacts could affect the business itself. The barriers are:

- Regulatory and political policies
- Integration of multi-tier partnerships and risk sharing agreements
- Revenue profit balance
- Network and route streamlining
- Trade standards and controls across international borders.

As reported before, cross sector collaborations becomes difficult mainly due to the product itself. Though the entire manufacture, service and maintenance of the aircraft be put under a general framework, the nature of business is entirely different, be it the technical strategy or the economic and management strategy. Cross-sector collaborations are welcome, however the current level of implementing those technologies or the framework to introduce them under a technology readiness level is almost non-existent. This needs to be reviewed to make sure if business models can also be exploited in a controlled manner such that the industry becomes resilient to any negative impact if they were to occur during the lifetime of the asset.

A majority of the business strategies have been developed by market duopoly controlled by both Airbus and Boeing. With vertical integration models, product service systems and contract for availability taking the center stage, it is becoming more and more challenging for industries to try and adapt to these business models. Further, with digitalisation occurring, the availability of enhanced software architecture is providing the necessary support in improving the business as a whole. However all these changes are occurring globally and show an international working culture. Assessing these business strategies with special concentration on Europe against the world will be a study in itself and could last a few years to provide a comprehensive picture of the status of the aerospace industry. Based on the existing literature and interaction with the industry groups, the current outcome for this assessment is neutral where Europe has neither a competitive advantage nor a disadvantage when compared across the world.

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3.3. Implementation of Cyber-physical systems in aeronautics (IK4)

**Sector/Mode of Transport:** Aeronautics  
**SCORE:** 3 Europe has a competitive advantage in comparison

**Management summary**

Cyber physical systems applied in aeronautics sector connects everything: aircraft, engines, systems, machines, equipment and even humans. Mostly, though, it can connect smart aerospace to new revenue streams, faster business outcomes, competitive advantage and improved profitability. The evolution of analytics capabilities is currently at a transformation point: the islands of insights and fiefdoms of data are ready to be broken down and reconnected into powerful vision of ubiquitous connectivity and unprecedented analytics capabilities that incorporate data like never before. Cyber physical systems, with IoT, are no longer just a vision; it is ready to become reality. The aerospace company that acts now will be the first mover, setting the pace for industry and its customers, dictating how the industry will connect, and ultimately how the future will play out.

The European aviation has a good position in the competitiveness of the sector, in sustainable aviation products and services, meeting the needs of EU citizens and society. Europe must seize the opportunity of the expanding aviation market, and preserve its pre-eminent position to ensure the continued success and economic contribution of its aviation industry in European and export markets.

**Description of the main concept**

The manufacturing industry, including aircraft manufacturers, intensively pursues this fourth step of industrialization, designated by the term "Industry 4.0". If such a real-virtual-immersive system does not only comprise production processes but service processes as well, then it is called a cyber-physical system (CPS). This can include many more activities and offers of other participating systems or parties, such as public transport or airports.

![Figure 20 - Cyber-physical systems (European Commission, December 2013)](image)

Cyber-physical systems research is likely to have an impact on the design of future aircraft and air traffic management systems, as well as on aviation safety. Specific research areas include (1) new functionality to achieve higher capacity, greater safety, and more efficiency, as well as the interplay and tradeoffs among these performance goals; (2) integrated flight deck systems, moving from displays and concepts for pilots to future (semi)autonomous systems; (3) vehicle health monitoring and vehicle health management; and (4) safety research relative to aircraft control systems. One of
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the key technical challenges to realizing NextGen involves verification and validation of complex flight-critical systems with a focus on promoting reliable, secure, and safe use for NextGen operations. As the complexity of systems increases, costs related to verification and validation and safety assurance will likely increase the cost of designing and building next-generation vehicles. The broader aeronautics community has identified verification and validation methodologies and concepts as a critical research area (National Science and Technology Council, 2010).

The goals of research in verification and validation of aviation flight-critical systems include providing methods for rigorous and systematic high-level validation of system safety properties and requirements, from initial design through implementation, maintenance, and modification, as well as understanding tradeoffs between complexity and verification methods for supporting robustness and fault tolerance. Some of the control engineering challenges include (Radhakisan Baheti and Helen Gill, 2011):

- Large-scale, real-time, deterministic robust or stochastic optimization algorithms;
- Multiple-objective, multiple-stakeholder optimization frameworks;
- Design of automation with graceful degradation modes;
- Safety diagnosis/health monitoring methods;
- System architectures that facilitate distributed decision making;
- Data fusion from heterogeneous sensors and assessment of the value of the derived information.

Forecasts about how many things will be connected in the next few years are mind-boggling. They range from calculations by tech researcher Gartner that there will be 25 billion connected things in use by 2020 to internet networking specialist Cisco ISBG's forecast of 50 billion connected devices. The crucial issue is that these devices will, for the most part, be communicating with each other to negotiate and organise themselves, communicating with people only to take instructions or report back. (GE, 2015).

For the airline sector, IoT offers multiple opportunities to improve operational efficiency and offer increased personalisation to passengers. It may even have the potential to change business models. In fact, there is so much opportunity that the challenge currently is where to focus efforts.

Among airlines that have started experimenting with IoT, there are projects to improve passenger experience, baggage handling, tracking pets in transit, equipment monitoring, and generating fuel efficiencies. However, in an industry still struggling with integration across legacy systems chief information officers face challenges in getting the underlying architecture right as well as addressing security issues.

Most airline IT bosses are alive to the benefits IoT presents, reveals the 2015 Airline IT Trends Survey produced by SITA in association with Airline Business. Two-thirds of them believe IoT offers clear benefits for their airline right now and 86% say IoT will generate benefits over the next three years. Today, 37% of airlines have already allocated a budget for IoT implementation, according to the study; however, over the next three years 58% are planning to invest resources into IoT, with the emphasis on pilot projects, although 16% are preparing for major programmes.

By almost any measure, commercial aviation is one of the safest modes of transportation. The number of people killed in airliner crashes is so far from the number of people killed in car crashes. And in those rare cases when something goes wrong, pilot error is often the cause. Pilotless flight could make aviation accidents even more of a rarity.

Improved automation might have averted at least some of aircraft disasters — for example, by making it harder for pilots to override autopilot system. A plane could be programmed to reject a course
change that would take it too far from land, for example, or a change-of-altitude command if it would
direct the plane below the height of surrounding terrain.

The real business value in the aerospace IoT comes not from ideas like sensors and connectivity, but
how the newly connected analytics applications will change day-to-day business operations and
performance. Following are the top-level solution areas for operations and services (that is, providing
services to fleet operators in aftermarket operations).

A McKinsey report for example, estimates that in 2025, the total value from condition-based
maintenance of aircraft could be $35 billion to $73 billion per year, including the value of reduced
delays and longer equipment life.

Areas that can be benefit from cyber physical systems in aeronautics are Operation and services and
Service management optimization. Subareas inside Operation and services that can be benefit from
these systems are the following:

- Fleet management / tail allocation
- In service fleet reliability analysis
- Unscheduled aircraft maintenance

In the case of Service management optimization, Scheduled maintenance - Planning & execution and
Material management can be remarked.

In line with the growing demand for air transport, the global demand for new civil aircraft will grow at an
average yearly rate of 4.7% (20 year world annual traffic growth). In October 2012 Airbus released its
Global Market Forecast for the period 2012-2031. This report shows a global market demand for
28,200 new aircraft (large civil aircraft with 100 passengers and more, excluding freighters) over the
next twenty years (2012-2031). The global turnover represented by these new civil aircraft represents
a value of € 3 billion. The global military aircraft market is forecasted to grow to € 1.9 billion.

Figure 21 World air travel remains a growth market (Ref 3; RPK = Revenue Passenger Kilometres). Source (Lucht- en
Ruimtevaart Nederland, 2013)
Analysis & Assessment of the impact on present industry structures:

Although there are several cyber physical systems developed in European aeronautics sector, there is still a long way to go. European aeronautics sector’s aim is to develop exploitable breakthrough technologies and concepts for the medium term that are not currently used or that have not yet being put in combination for civil aviation. There are still several technologies and concepts that are at low Technology Readiness Level today (up to TRL 3) and can potentially achieve Technology Readiness Level 6 by 2030-2035. Some of the areas that would still be in TRL 3 are the following areas:

- Innovative aircraft configurations and airframes (e.g. short take-off and landing, long wing span; personal vehicles).
- Novel and integrated multifunctional systems.
- Autonomous, intelligent and evolving systems (e.g. Remotely Piloted Aircraft Systems)

European Commission has started some initiatives for the following years (EC, 2011) in order to have an efficient and integrated European mobility system:

- **A Single European Transport Area: Capacity and quality of airports**
  - Revise the Slot Regulation to favour more efficient use of airport capacity.
  - Clarify and improve conditions to enter and provide quality services, including ground handling: ensure that all actors in an airport system meet minimum quality standards.
  - Airport Capacity – develop an approach to deal with future capacity problems including better integration with the railway network.

- **Secure Transport: High levels of passenger security with minimum hassle**
  - Promote improved screening methods, fully respecting fundamental rights; such methods should underpin development of a ‘Check point of the future’ – such as security corridors which would allow a high number of passengers being controlled with minimum hassle and intrusion. They should also support security provision in other vulnerable areas such as major transport interchanges.
  - Promote, also through funding, the development of more effective and privacy-friendly technologies (scanners, detectors of new explosives, smart chips, etc) as well as more privacy-friendly solutions in existing technologies.
  - Define common detection performance standards and certifications procedures for detection equipment.

- **Acting on transport safety: saving thousands of lives: A European strategy for civil aviation safety**
  - European aviation safety is high but not the best in the world. Our aim should be to become the safest region for aviation. In order to do so, we will develop a comprehensive European aviation safety strategy, building on the work of the European Aviation Safety Agency (EASA), which includes the following aspects:
    - Improve the collection, quality, exchange and analysis of data by reviewing legislation on occurrence reporting in civil aviation.
    - Adapt the regulatory safety framework to the development of new technologies (SESAR).
    - Ensure the implementation of the EU aviation safety strategy consistently across all aviation domains.
    - Promote transparency and exchange of safety information with ICAO and other international aviation partners, in particular in the framework of the Global Safety Information Exchange initiative; cooperate with non-EU countries, in particular the U.S., on safety matters on regulatory convergence, mutual recognition and technical assistance.
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

- Develop a Safety Management System at EU level that incorporates safety performance targets and measurements in order to identify the risks and to achieve continued improvement in safety levels.

- **Service quality and reliability: Passengers’ rights**
  - Develop a uniform interpretation of EU Law on passenger rights and a harmonised and effective enforcement, to ensure both a level playing field for the industry and a European standard of protection for the citizens.
  - Assemble common principles applicable to passengers’ rights in all transport modes (Charter of basic rights), notably the ‘right to be informed’, and further clarify existing rights. At a later stage, consider the adoption of a single EU framework Regulation covering passenger rights for all modes of transports (EU Codex).
  - Improve the quality of transport for elderly people, Passengers with Reduced Mobility and for disabled passengers, including better accessibility of infrastructure.
  - Complete the established legislative framework on passenger rights with measures covering passengers on multimodal journeys with integrated tickets under a single purchase contract as well as in the event of transport operator’s bankruptcy.
  - Improve the level playing field at international level through the inclusion of care quality standards in bilateral and multilateral agreements for all modes of transport, with a view to further passengers’ rights also in the international context.

To achieve these objectives, European Commission has defined a technology roadmap for the following years. Fragmentation of research and development efforts in Europe is most harmful, and joint European efforts will bring the greatest European added value in areas such as:

- Clean, safe and silent vehicles for all different modes of transport, from road vehicles to ships, barges, rolling stock in rail and aircraft (including new materials, new propulsion systems and the IT and management tools to manage and integrate complex transport systems).
- Technologies to improve transport security and safety.
- Potential new or unconventional transport systems and vehicles such as unmanned aircraft systems, unconventional systems for goods distribution.
- A sustainable alternative fuels strategy including also the appropriate infrastructure.
- Integrated transport management and information systems, facilitating smart mobility services, traffic management for improved use of infrastructure and vehicles, and real time information systems to track and trace freight and to manage freight flows; passenger/travel information, booking and payment systems.
- Intelligent infrastructure (both land and space-based) to ensure maximum monitoring and inter-operability of the different forms of transport and communication between infrastructure and vehicles.

Technology around cyber physical systems is intensively being studied nowadays both by industry and by academia. Many research projects and demonstrators are being developed and millions are being invested:

- **In Europe:**
  - Airbus is developing an autonomous air taxi dubbed Vahana. The tilt-wing, multi-propeller craft is designed to take off and land in tight spaces and able to fly about 50 miles before its batteries need recharging. (NBC News, 2017).
  - Airbus is looking towards a future of pilotless planes. (Independent, 2017).
  - Airbus and Schaeffler are using Digital Twin engines and Digital Twin bearings, respectively, to transform their production process,
increasing operational productivity and improving design elements. (Brandwatch, 2017).

- **Worldwide:**
  - The world’s first passenger drone made by Chinese tech company EHang Inc. made its debut in the southern city of Guangzhou on 06/02/2018. (Euronews, 2018)
  - The electrically powered vehicle, also known as EHang 184, is operated by an automated flight system so passengers don’t have to bother with driving. (EHang, 2018)
  - The Boeing Company is working a rich set of application areas that are benefiting from CPS research: air (military and commercial), space (high-reliability applications) and land. It is developing new applications that involve multiple networked CPS systems as safety-critical aspects, security and need for predictability in face of dynamic environments. It is also working to rich new aircraft platforms: Stringent Certification and V&V processes and standards in the case of commercial aircrafts, and piloted and autonomous aircraft, support all services and varying levels of V&V requirements in the case of military ones. (Boeing, 2008)

- **Analysis and assessment of the impact of Disruptive Technologies on present value chain**

Environmental protection has been and remains a prime driver in the development of air vehicles and new transport infrastructure. In addition to continuously improving fuel efficiency, the continued availability of liquid fuels, their cost impact on the aviation sector and their impacts on the environment, has been addressed as part of an overall fuel strategy for all sectors. Aviation continues to exploit liquid fuels, prioritised by operational and technology considerations. Producing liquid fuels and energy from sustainable biomass has become an important part of the energy supply. A coordinated approach to fuel development is taken across the sectors that are highly dependent on liquid hydrocarbon fuels: aviation; marine and heavy duty transport and is a key part of managing carbon dioxide emissions from the transport sector as a whole.

Disruptive, step-change technologies have played an integral part of the development process. European industry has introduced to the world market a complete set of new products and services including a real new generation of air vehicles and ever-more efficient, environmentally friendly and quiet engines. These are leading edge and recognised as reference products by the whole aeronautics community. As a result of these efforts society in 2050 considers that travel by air is environmentally friendly. Europe is recognised globally for the innovative concepts realised in its products and services driven by a vibrant and successful industry and enabled by efficient policies. Strong, coherent research networks and partnerships between private and public actors drive European innovation and are enabled by strong public funding and a range of globally-recognised, efficient instruments. (European Commission, 2011)

However, the industrial competition is becoming ever fiercer from established, traditional rivals such as the US and even more so from new and strong challengers, notably Brazil, Canada, China, India and Russia. Regions such as the Middle East and Asia at large have emerged as strong competitors for air
services and infrastructure. Authorities in these countries have understood the strategic nature of aviation and support their industries accordingly, enhancing competition at all levels.

Europe must succeed despite this increased competition. For that to happen, Europe must address three key challenges: increase the level of technology investment, enhance its competitiveness in world air transport markets and accelerate the pace of policy integration.

Technological leadership, the root of Europe’s current success, will continue to be the major competitive differentiator. Break-through technology will be required to secure future competitive advantage, most notably in terms of energy, management of complexity and environmental performance. Substantial and sustained investment in the technologies of today and tomorrow is needed to guarantee the future, as well as readiness to spin-in advances arising from defence investment where appropriate.

- **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

The main drivers to facilitate cyber physical systems in aeronautics are the following showed below:

- Tax policies supporting innovation and advanced manufacturing.
- Enhanced company performance in decision-making, reduced operative and admin costs, improved business processes.
- Cyber-enabled systems for validating.
- Process documentation for quality control, cost minimisation and efficiency improvements.
- Cloud computing provide hosting platforms for new service models.
- Current IT systems can support collection of needed information for disassembly and recycling analysis.

The main barriers to implement cyber physical systems in aerospace sector are:

- Management of political, regulatory, juridical, tax and labour environments in various countries.
- Resistance to change, challenging culture change management.
- Difficulties in evaluating cost-benefits of investments.
- Integration of technologies is non-trivial.
- Lack of standards.

The European aviation community leads the world in sustainable aviation products and services, meeting the needs of EU citizens and society.

Europe must seize the opportunity of the expanding aviation market, and preserve its pre-eminent position to ensure the continued success and economic contribution of its aviation industry in European and export markets.

With its leading knowledge and manufacturing capability, the European aviation industry is in a position to define and shape a sustainable future. Remaining competitive is also about the timely delivery of competitive products and services. It is linked to a common level playing field of government support, which requires policy action to redress distortions and facilitate a favourable environment for innovation.
Building on the vision (Group of Personalities Jan 2001) for 2020, and the ensuing ACARE initiative, this document lays out our vision for European aviation to 2050. Today and even more so tomorrow, a safe and efficient Air Transport System, led by innovative technology, will be a vital vector for our economy, our society and the cohesion of Europe and the world.

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3.4. Attractiveness of MRO services and fuel burn efficiencies

Technological solution: MRO Technologies, Digital MRO, Materials and additive manufacturing.

Sector/Mode of Transport: Aerospace

SCORE: 3 Europe has a competitive advantage in comparison

Management summary

The aviation industry has experienced disruptive technologies of various forms throughout its history. These inventions have each in their own way contributed to the improved performance of a specific aspect of the industry and have traditionally occurred as significant step changes. Today, we continue to see disruptive technologies emerge and transform the aerospace sector, however, these technologies tend to be developed through a more structured, incremental innovation process such as Technology Readiness Levels. Current and future disruptive technologies are driven by a compilation of specific needs which have been identified as fuel burn efficiency, emissions reduction, affordability, noise reduction and maintenance time reduction. With the assets such as an aircraft, a majority of the systems are complex and made of high-value parts. In order to maintain these technologies over a decade, innovative maintenance technologies are a must. Concepts such as engineering for life, bespoke repair technologies, in-situ repair and retrofit technologies control the market. This section focuses on two of the disruptive trends in the aviation industry; MRO services and technologies (NDT, engineering for life, digital MRO) and trends that improve fuel burn efficiencies (advanced materials and additive manufacturing).

Description of the main concept

The product, in our case the aircraft comes into service after manufacturing with an average operational life of 20-25 years. These high-value products need regular maintenance such that the value of the asset is extracted before it is retired from service. Concepts such as through-life engineering and engineering-for-life are being adopted more and more to improve the maintenance performance (Roy et al., 2016). Business models such as product service systems (PSS) have now transferred the maintenance responsibilities back to the manufacturer, where the service of the aircraft is part of the purchase agreement (Meier, Roy and Seliger, 2010). Thus, manufacturers are actively looking at technologies and business models that could not just boost their maintenance performance but also account to overall profitability of the business.

Some of the key technologies that support concepts such as continuous maintenance are automated non-destructive evaluation and degradation assessment, repair technologies, remote maintenance and digital MRO services that support all the associated maintenance activities (Roy et al., 2016). On the other hand, manufacturers are also looking at alternate technologies for better fuel burn efficiencies to achieve emission targets set by the governing institutions. Predominantly, materials available for use in engineering application are grouped into three categories: metals, ceramics and polymers. For more than half a century, aluminium continued to dominate the aerospace industry. In contrast to metallic alloys, composite materials retain its separate chemical, physical and mechanical properties and provide a lightweight alternative yet maintaining the strength and rigidity the parts need to offer. These developments are purely to abide by global environment regulations to cut the fuel consumption and the associated emissions.

Additive manufacturing is already commonly considered to be a disruptive technology across many manufacturing industries with its ability to create complex shapes and objects with minimal raw material waste. Looking to the future, local bodies and manufacturers have constructed a roadmap of future additive manufacturing applications across a range of manufacturing sectors, with the aviation sector pushing the boundaries to achieve smart and innovative components fit for future. The industry experts envisage that technologies within the additive manufacturing theme have the potential to
continue to disrupt the aerospace manufacturing industry for decades to come. This ranges from analysing current components on how additive manufacturing processes could reduce their weight to concepts such as printing entire wings or even planes.

The ability to determine the health and accurately predict the remaining useful life of the product is the current challenge. Developments in materials and manufacturing processes have promoted the introduction of those next generation technologies into service. Parallelly, maintenance technologies are also being developed to support products of the future, such that the life of the part is extended thus improving operational efficiencies.

Advanced materials will continue to develop in four major areas, lightweight super alloys, polymer composite materials, self-healing materials and piezo electric materials as indicated in the value chain propositions of the previous deliverable D2.1 within the SCORE project. All of these technologies, not just produce superior components, but help achieve improved efficiency and directly compliment the regulation to reduce fuel consumption and emissions caused due to fuel burn.

There are five key strengths of additive manufacturing that have contributed to it becoming a recognised disruptive technology;

- It accelerates the design and prototyping cycle meaning a designer can instantly evaluate the feasibility of a design.
- Due to the nature of the process, it has enabled the development and use of advanced materials.
- It has reduced the time and cost of creating and manufacturing customised components.
- Because material is added, not subtracted as with traditional methods, it has reduced manufacturing footprint and waste.
- Previous barriers when creating complex parts such as cost, effort and skill have been reduced.

However, the full potential of additive manufacturing has not yet been reached and the processes have the potential to continue to revolutionise the manufacturing industry for years to come.

A recent report suggested that the advanced composites market size at global level was at USD 17.47billion (2015) in the aerospace sector. The following is the market review of three popular composite materials used in the aerospace sector evidenced from Figure 22 below (GVR, 2016).
If composites form one side of the market, ceramics take up a bigger share of the market when compared with metallics. It has been reported that the thermal barrier coatings market was valued at USD 12.86 billion (2016) with an expected CAGR of 6.70% (2017-2025) taking the market share to 33.5% (Coherent Market Insights, 2017).

The value of the additive manufacturing industry has grown at a rapid rate in recent times and shows no signs of slowing down. Since 1989, the value of the industry has increased at an average CAGR of 26.2%. Furthermore, the CAGR of the industry of the past three years is 33.8%. Looking at the value of the aerospace additive manufacturing sector specifically, it is expected to continue to grow over the next five years at a healthy CAGR of between 20-21%. Growth in this sector is expected to continue until at least 2025 and it compares favourably against other additive manufacturing sectors (Li, Myant and Wu, 2016)
In terms of geographical value, North America currently holds the largest value at 41%, with Europe in second followed by Asia and the rest of the world. This is expected to change slightly by 2025 with Europe and Asia’s markets expected to grow at a slightly faster rate than North America.

The insights provided in both the advanced materials and additive manufacturing explain above show not just the size of the market, but also establishes the complexity in the assessments currently in place. This also introduces the challenge of understanding the degradation of those parts during regular operation and how those changes can be quantified such that the performance of the asset as a whole is optimum. Oliver Wyman reported that the total MRO spend for global fleet as of 2017 is
estimated to be USD 75.6 billion with an anticipated projected growth to USD 109.2 billion by 2027 (Cooper et al., 2017).

![Global fleet MRO market forecast for 2017-2027 (Cooper et al., 2017)](Figure 26)

**Analysis & Assessment of the impact on present industry structures**

Automated degradation assessment: As with any machine, for long term and effective functioning of the aircraft regular and planned maintenance is a must. This is achieved by the maintenance, overhaul and repair (MRO) unit. The activities associated with aero-engine maintenance, for instance, is so complex that each and every part of the engine is isolated, checked for damage, repaired as required and then fitted back. The entire activity could last a few weeks incurring few tens of millions in cost. With this intensive process and extensive maintenance cost, the sector has been investigating into technologies such as non-destructive testing or NDT where, the damage of the part is measured without damaging the part any further. Technologies such as x-radiography, ultrasonic testing, eddy current testing and thermography. A majority of the technologies have been fully integrated into the MRO activity. However, inspection down-time, operator expertise and legacy architecture all favour the adaptation of digital services together with the benefits automation brings in. A few of the technologies such as water jet automated ultrasonic inspection is still in the development stage. Active thermography has been showing promising results, especially with composites. With a majority of the NDT techniques developed for large metallic parts, the techniques struggle to fully characterise damage in composite materials. Pattern recognition, machine learning together with advanced signal and image processing algorithms are being developed parallelly to compliment the automation of these technologies. Collectively, these technologies sit between TRL4 and TRL7 (Roy et al., 2016; Addepalli, Zhao and Tinsley, 2017).

Digital MRO: With the ageing legacy systems, having up to date systems that can facilitate MRO technologies has become the top priority for the aerospace sector. The product-service systems and servitisation concepts now cap the revenue into the MRO sector. A recent study reported that more than 51% of the revenue was saved through the use of automated and digital systems that support heavy engineering activity (Roy et al., 2016). A few of the digital systems include computerised maintenance management systems (CMMS), Supervisory Control and Data Acquisition (SCADA), manufacturing execution systems (MES), and programmable logic controller (PLC) (Roy et al., 2016; Capgemini, 2017). There are specific challenges associated with the incorporating these toolsets into the actual platform due to a variety of challenges the industry faces. These include handling big-data, data mining, and data visualisation (both virtual and augmented). The other societal challenge is the availability of experienced personnel capable of building and using such systems in the MRO environment. Industry 4.0 plays a major role in shaping the digital architecture that supports the
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

development of digital MRO (Roy et al., 2016; ATI, 2017). The technology readiness sites between TRL 3 and TRL 6.

Only overall technology roadmaps such as Flightpath 2050 (Darecki et al., 2011) and an aviation strategy for Europe (European Commission, 2015) together with groups such as ACARE and ATI cover the development of new and next generation technologies and products. However, there are no direct roadmaps that make control the specific activities of the MRO technology areas. However, as mentioned in the previous section 3.1 of this document, fuel burn efficiencies are a major area where the sector is concentrating, mainly to reduce emissions and improve operational efficiency of the system and is in line with what was presented in the section above. The European Commission (EC) is actively reviewing the competitiveness of the sector by actively publishing the trade statistics such as the current market size, production rates, airlines policies and business models including spend in the MRO technologies (European Commission, 2017).

The technologies supporting the continuous functioning of aircraft is a challenging area to address, with a majority of the revenue is spent into the manufacturing of products to meet the demand, and next generation products being phased in as and when they meet all the existing certification, regulation and operational requirements. Oliver Wyman(Cooper et al., 2017) report that with over 58% of new-generation aircrafts in service by 2027, the MRO industry needs to grow significantly to match the demand.
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

- **In Europe:**
  - As far as Europe is concerned, Airbus MRO takes the big share in business. Other companies include Lufthansa Technik, Rolls Royce Holdings Plc, Air France Industries KLM Engineering & Maintenance, MTU Maintenance, British Airways Engineering and Iberia Maintenance (Visiongain, 2015). With the deliveries in the Asia-Pacific increasing in numbers, regional companies are collaborating with European MRO providers to build and run their regional hubs in countries such as China, India and the South-East.

- **Worldwide:**
  - Boeing has the largest MRO network both in size and partnerships worldwide, with its base in the US. Others include GE Aviation, United Technologies Corporation, Hong Kong Aircraft Engineering, Abu Dhabi Aircraft technologies, Air China Technic / Ameco Beijing, Delta TechOps, AAR Corporation and the list goes on. It was also noted that the largest concentration was either in the USA or Europe mainland with middles-east and south-east now expanding their operations.

Aircraft maintenance is an intricate and complex engineering process almost matching the original manufacturer’s part and assembly specification. However, in order to determine the current health, technologies such as automated NDT, digital MRO and integrated supply chain logistics are being implement to complement the maintenance activity. Each major system and subsystem requirement needs to meet stringent regulations and undergo certifications such as Joint Airworthiness Requirements (JAR). As the asset is built with high-value parts, it is forcing the companies to reduce scrappage of parts and see how well degradation and health monitoring technologies and help extend the life of the component. All these technological developments, for instance the NDT, needs to go through the gate review (TRL ladder) before it is fully integrated into the system. Due to the complexity and a wide variety of technologies that are being parallelly developed, it is difficult to determine the development paths for these technologies, as they are not standalone, but an umbrella of technologies.

- **Analysis and assessment of the impact of Disruptive Technologies on present value chain**

The technologies supporting MRO are a combination set where multiple technologies are needed to provide a comprehensive health assessment of the part. Further, materials and manufacturing processes to improve fuel burn efficiencies are incorporated into new and next generation technologies. The only major selling point as a competitive advantage is to see how to save maintenance costs due to the incorporation of these technologies of the future. It should also be understood that within the aerospace sector, MRO, materials and manufacturing technologies are all introduced to provide a step-change and may not completely be classified disruptive. On the other hand, these technologies do improve performance of the asset and is profitable to the industry.

Value chain for these future technologies is currently evolving in the manufacturing sector. Further, the maintenance activities in their current form are heavily based on papers and adapting to a digital environment is current taking place, hence the value chain and how these will change the market dynamics is not yet fully understood.
NDT technology has been adopted by multiple industries including railways, automotive and heavy engineering industries. These techniques, were originally developed for metallic components and currently are being adapted to advanced composite materials. Further, it must be understood that a majority of these techniques are operator intensive and need experienced personnel to interpret the results. The analysis methods, post processing algorithms and their file formats are still being converted to a universal format. Combining automation, including parameter selection, inspection and sentencing of the part becomes a challenge with a majority of the decision making still lies with the ageing skilled workforce. This will certainly change the dynamics of the market, at least for the next decade where both results from the actual inspection and the software architecture that may visualise those results into a much more user friendly platform, will aim to improve the performance of the MRO activity.

The digital MRO will also go hand in hand. Where blue-prints are currently being digitised, a 3-dimensional, real-time information of the part with superior augmentation will become the future norm. The ability to incorporate augmented reality (AR) and virtual reality (VR) are now being assessed and perhaps in the TRL level 6. The next decade will see supported real-time maintenance where digital architecture will govern the entire activity including the decision making and repair activity autonomously.

The concepts for MRO technologies and improvements in fuel burn efficiencies may not be disruptive in the current market. However, when all electric aircrafts, open rotor crafts and blended wing aircrafts come into service, their maintenance requirements will need a huge revamp mainly due to the use of advanced materials and manufacturing processes. Further, the maintenance requirements will need to be developed parallely to adapt to such scenarios. It is anticipated that the development and introduction of these technologies will be incremental in nature and whether it becomes disruptive is an answer that is governed by technology and market demand.

As mentioned in the deliverable 2.1, players such as Bombardier (Canada), Embraer (Brazil), Irkut (Russia) and Comac (China) are all engaged in a fierce competition with the duopoly industries Airbus and Boeing mainly in the single-aisle jets section. However, the MRO market in both US and Europe market is saturated which is giving rise to newer facilities in both South America and the Asia-Pacific markets. It should be noted that the technology provision is still largely being controlled and shared by both Airbus and Boeing. With a strong European MRO sector, and even stronger US MRO sector, the technological development and introduction will still be within these companies and will continue to be the pioneers over the next 10-15 years.

- **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

The key drivers for the above technologies can be classified under a broader category named performance. As discussed in the earlier sections, the performance is mainly driven by two categories

- MRO
- Fuel burn

Further the drivers for the two categories are;

For MRO:

- MRO Spend / Expenditure
- Fleet Availability
- Reject Rate
For fuel burn efficiencies:

- Global Fuel Cost
- Fuel per Kilometre
- Fuel per Seat

The barriers that will obstruct the implementation of the MRO technologies are similar to those found in the previous sub-sections and include:

- Political, economic and regulatory policies in different countries
- Integration of multiple technologies – especially the process of digitalisation.
- Need for revised standard and new certification requirements to suit and introduce newer concepts.
- Economic / business profit balance with environmental regulations and their impacts.
- Process streamlining between various suppliers and service providers.
- An integrated supply chain structure to suit new technologies.

Cross-sector collaborations will certainly benefit the aeronautics sector, especially with the concepts of Industry 4.0. With digital MRO becoming the priority, and stringent regulations controlling the broader sector, technological transformation through cross-sector collaboration is a challenge. It is envisaged that the future in certain sectors of the automation of health assessment and through-life engineering aspects will be adopted by the sector through cross-sector collaborations.

According to Flightpath 2050, the European aviation industry is considered the world leader for delivering high-quality vehicles engines and services. Flightpath 2050 highlights the EC’s desire to ensure this leadership is retained through continuing its focused investment in new technologies and capabilities by benefiting from public-private partnerships, research organisations, education and most importantly, industrial collaboration (Darecki et al., 2011). Strengths in collaboration, organisational structure, manufacturing capabilities add to Europe’s receptivity to new technologies to make the region competitive.

References


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4. Rail/Rolling stock

The following key technological trends and innovative concepts have been assessed in terms of their impact in the current value chains and the success factors for implementing new technologies:

- **Artificial Intelligence**
  Adaptable artificial intelligence capable of learning and high resilient to cope with incidents, accidents, cyberattacks and transition with human interventions can offer long-term competitive advantages. In what way can artificial intelligence become a USP for railway services and how can that be achieved?

- **Energy Efficiency of propulsion technology**
  Converting effectively energy resources into traction and reducing the environmental impact of rolling stock are key issues for innovation. Innovative technology applied to improving diesel fuel engines is required along with the development and incorporation of hybrid energy solutions that maximize operational effectiveness of rolling stock. New energy management systems of trains require regenerative braking, what benefits would that bring on fleet level?

- **Effects of digitalisation**
  The digital revolution will affect not only the production but also maintenance of trains and infrastructure. On the one hand, predictive maintenance allows the monitoring conditions of wear-and tear parts in components and infrastructure to plan maintenance resources and more over to prevent unscheduled downtimes. On the other hand, automated maintenance through drones and robots can be carried out under hard weather conditions to relived employers

- **Hydrail: hydrogen-powered trains**
  What new fuels make trains more energy efficient at higher speeds? What does that imply for production in Europe?
4.1. Artificial intelligence for a performance jump of railway systems: the case of autonomous train

**Sector/Mode of Transport:** Rail/Rolling stock  
**SCORE:** 3 Europe has a competitive advantage in comparison

**Management Summary**

For the railway industry, automation represents an excellent opportunity to reinforce the security of the systems, reduce energy consumption, improve the quality of service and make better use of expensive and saturated infrastructure. As the autonomous train (not to be confused with the automatic train) is likely to be the norm in the future, the most important railway manufacturers are currently putting a great interest in these systems. In this context, the technologies developed in the field of Artificial Intelligence (AI) have a real potential to ensure a high level of safety and efficiency of autonomous vehicles. Nevertheless, before reaching both industrial production and commercialisation levels of mass transit systems, such as trains, these new technologies have to mature, and new security mechanisms have to be implemented.

**Description of the main concept**

For decades, the industry has been trying to replace the drivers of different transport modes with autonomous and programmable computers, which are both more efficient and safer than human operators. However, driving tasks, such as image recognition and interpretation, require a large number of skills that are difficult to program algorithmically into a computer. For this reason, despite significant efforts, including the automation of several driving tasks, fully autonomous vehicles, without human supervision, have not been developed so far.

Nevertheless, the accelerated development of certain technologies, in recent years, has led to significant progress in the field of autonomous vehicles. Indeed, recent advancements in the field of AI (including "deep learning" techniques) have allowed developing autonomous systems capable of interpreting their environment in a precise way, and therefore to plan and then to act appropriately while ensuring a high level of efficiency and safety.

An autonomous train is different from an automatic train because it will circulate in an open and dynamic environment. Currently, the most sophisticated driverless trains are automatic, but are not autonomous: the absence of a driver in the cockpit is therefore not sufficient to classify a train as autonomous, it is the onboard decision-making capacity that makes a train autonomous. For example, trains are remotely controlled by computers with, sometimes, the presence of a driver or an assistant on board. The train sends data and receives instructions, but it does not make the decisions. Decisions are instead made by external systems (Innotrans, 2016).

An urban guided transport can be exploited at different levels of automation as defined by the standards (IEC 62267: 2009, NF EN 62290-1: 2007). These levels of automation, better known as GoA (Grade of Automation) result from the distribution of responsibility for basic functions data of the operation of trains between the operating personnel and the system. In addition, given that rolling stock comes in a widely heterogeneous variety of forms and circulates on tracks equipped with various signalling systems, it is necessary that these materials can adapt to their environment.

The "Victoria" subway line (inaugurated in 1968 in London - UK) is considered the first large-scale automatic rail system. This line is currently classified as GoA3: The driver is present in the cabin, but starting and stopping are automated as well as the closing of the doors and the train moves automatically between the stops. The "Port Island" subway line (opened in 1981 in Kobe, Japan) was the first fully automatic GoA4 rail system (driverless). The Lille - France metro network (inaugurated in 1983) was the first fully automatic rail system (GoA4) in Europe. In July 2016, there are 55 automated
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

metro lines in 37 cities worldwide according to the International Union of Public Transport (UITP). Half of the automated metro infrastructure is concentrated in 4 countries: France, South Korea, Singapore and the United Arab Emirates respectively (UITP, 2016). It is important to note that these systems are limited and framed in urban areas relatively isolated from certain potential hazards.

<table>
<thead>
<tr>
<th>Grade of Automation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (GoA 0)</td>
<td>On-sight Train Operation (TOS) This level of automation relies entirely on train driver and no system required for supervision. Nevertheless, switches and single lanes can be partially supervised by the system.</td>
</tr>
<tr>
<td>1 (GoA 1)</td>
<td>Non-automated Train Operation (NTO) A train driver controls starting and stopping, the operation of doors and handling of emergencies or sudden diversions. The system supervises the driver’s activities. This supervision can be punctual, semi-continuous or continuous, especially as regards the respect of signals and speed.</td>
</tr>
<tr>
<td>2 (GoA 2)</td>
<td>Semi-automated Train Operation (STO) Stopping is automated, but a driver in the cab starts the train, operates the doors, drives the train if needed and handles emergencies. Acceleration and braking are automated, and speed is continuously monitored by the system.</td>
</tr>
<tr>
<td>3 (GoA 3)</td>
<td>Driverless Train Operation DTO Starting and stopping are automated, but a train attendant operates the doors and drives the train in case of emergencies. As there is no driver in the forward cabin, additional measures are necessary.</td>
</tr>
<tr>
<td>4 (GoA 4)</td>
<td>Unattended Train Operation UTO Starting and stopping, the operation of doors and handling of emergencies are fully automated without any on-train staff (additional measures are, therefore, required). The system provides detection and management of hazardous conditions and emergencies such as evacuation of travellers.</td>
</tr>
</tbody>
</table>

Figure 28: Grades of automation of urban transport according to the EIC 62290 standard

Although AI is commonly considered as a unique technology to treat all problems, in reality, it is a set of techniques adapted to solve specific problems with its strengths and weaknesses. AI is, therefore, a set of methods and technologies that enable a machine to perform tasks by reproducing human cognitive mechanisms, with the aim of improving overall performance. Also, the concept of AI is not stable: some technologies identified as AI in the 1990’s are no longer considered (categorically) as AI-related nowadays (e.g., fuzzy logic). Also, it should be mentioned that the integration of new systems will probably not replace the ATP system (Automatic Train Protection) aimed at ensuring compliance with speed limits or signals along the track and therefore will not change its regular behaviour.

Similarly to road transport, AI methods are also used for train scheduling and rolling stock planning. The use of AI for autonomous driving is, however, less developed than that of autonomous cars. By nature, the railway environment is more restrictive than that of the road. At least two main dimensions can be identified. The first dimension is the number and diversity of elements present in the environment. Whereas in a typical downtown road a vehicle can interact with other vehicles (of different sizes and shapes), people and animals, the elements present in a railway environment are restricted to the access of people or unauthorised vehicles (except in specific areas, such as level crossings). The second dimension consists of all the available actions that can be performed by the vehicle. While cars can perform a large number of actions quickly on the road (e.g. advance, turn, back, and stop), train movements are limited by rails (trains can only accelerate and brake). Even if the number of possible actions is lower than that of a car, the actions of a train require a considerable analytical effort to be effective, in particular, foresight. Indeed, given its size, weight and low grip, the consequences of actions taken on a train are not immediate. For example, trains require a considerable distance and time to stop completely, and acceleration also involves time and significant energy consumption. Despite a more restrictive environment, the railway field may be more suitable for the implementation of AI technologies. However, it does include several features that make it more challenging to develop an autonomous driving technology that is sufficiently efficient and safe (mainly related to the demonstration of safety).
Analysis & Assessment of the impact on present industry structures

The autonomous train should be able to roll without the intervention of a human driver (FranceIA, 2017). To ensure the detection and management of hazardous conditions and emergency situations (GoA 4), the system should be able to determine its positioning, perceive its environment and be able to decide whether to move forward, brake, stop, open the doors, among others. Various technical components for obstacle detection, speed monitoring and train control systems are already available, and their integration has been proven in operation in subways. Additionally, as with autonomous vehicles, a variety of technologies make it possible to tame the environment, such as radar, laser, GPS, odometer, computer vision, and computer systems. Advanced control systems interpret sensory information to identify relevant obstacles and signals.

The next step will be to equip the train with sensors, cameras and computational capabilities, such as the Google car, so that it can process data from various devices and make decisions for itself in complete autonomy (TransportShaker, 2016). The term “autonomy” is defined by ISO 8373: 2012 as the “ability to perform expected tasks from the current state and detections without human intervention”. The research and development work carried out on the autonomy of trains is evolving, as in many areas, towards the use of AI to face the challenges ahead. The research work associated with the Autonomous Train is based on proven technology that can be adapted to the challenges of railways. For these reasons, we can indicate a TRL scale between 6 and 9, the aim targeted by European operators (in France and Germany) is to have systems deployed by 2022.

Regarding autonomous systems and driver assistance, there are several types of companies recognised for their expertise:

- Companies that have developed autonomous systems: Waymo autonomous car (Google, US), ARMA (Navya, FR) and EZ1O (EasyMile, FR) autonomous shuttles
- Leading companies in the rail sector currently working on driver assistance or autonomous systems: Thales (FR), Alstom (FR), Bombardier (FR), Siemens (DE)
- Companies offering innovative services in IT R&D: ATOS (FR), CGI (CA).
- Laboratories and companies (SMEs) specialising in IA technologies
- Companies offering software tools and specialised equipment for autonomous vehicles: Nvidia (US), Intel (US)

In general, there is an intense concentration of areas of expertise in Europe and the United States. It should be noted that European start-ups are particularly well represented.

- **Analysis and assessment of the impact of Disruptive Technologies on present value chain**

A non-exhaustive list of AI techniques, typically or potentially used in the development of autonomous transport systems, is as follows:

- Representation of knowledge and reasoning;
- Planning and optimisation;
- Automatic learning;
- Perception;
- Robotics;
- General intelligence.

Thus, concerning the value chain, several critical issues are to be considered from the beginning of autonomous train development:
As it is a disruptive project, it is necessary to involve all the railway jobs by associating them from the beginning to the national agencies of safety.

- Evaluation and modification of current railway procedures: they have been designed for a human operator and will have to be adapted for the autonomous train;
- The evolution of the railway jobs: the arrival of the autonomous train will disrupt the historical functions of rail operators and cause strong evolutions backed by new needs. Impact studies, awareness campaigns, training, recruitment and professional development procedures will have to be carried out. This change will strongly impact the functions/profiles of drivers, controllers, traffic regulators and maintenance operators.

**Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

In the light of the elements mentioned above, we conclude that the European railway industry, thanks to the historical know-how of its leading companies, has a competitive advantage over its international competitors. In a cross-sectoral way, we should also note the large number of emerging start-ups on new technologies (mainly related to AI), which could represent a great asset in the deployment of autonomous systems. In the United States, the big multinationals lead the race and mobilise colossal means. We can mention companies like Google, Amazon, Apple or Tesla.

In Asia, and particularly in Japan, Hitachi is showing interest in gradually rolling out stand-alone systems to improve services, routes and stations (Frost & Sullivan, 2015).

In the perspective of developing autonomous trains by deploying different technologies of artificial intelligence, we can identify a number of structuring issues (barriers and drivers), summarised in the table below:

| Table 29: Barriers and Drivers for developing of autonomous trains. Source: Own elaboration. |
|---|---|
| **Environmental context** | **Drivers** |
| Recyclability of AI components | Energy saving |
| In general, environmental footprint of AI | Better safety against unexpected situations |
| **Organisational and societal context** | Optimization of the current infrastructure |
| Evolution of jobs (need for new skills) | Better lifecycle optimisation, (train maintenance) |
| Acceptability by users | Start-ups positioned on new businesses |
| System certification process involving AI | Strong competition in Europe and around the world |
| Data issues (privacy, confidentiality, commercial information) | around autonomous systems = emulation |
| **Technological context** | Consideration of the strategic importance of the data |
| Cybersecurity | ICT, miniaturisation, embedded systems |
| Maturity of IA technologies | |
| Locks on perception (train in its environment) | |
| Dependability | |

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4.2. Energy Efficiency of propulsion technology in Urban Rail

**Sector/Mode of Transport:** Rail/Rolling stock  
**SCORE:** 4 Europe has a strong competitive advantage in comparison

**Management Summary**

The propulsion technology in urban rail systems – mainly metro, tram and light rail - is very specific compared with other transport modes, including mainline rail:

- traction power has been based on electrical energy for more than a century\(^3\)
- the braking systems produce a lot of energy which is largely recovered
- either the vehicle or the equipment or the infrastructure or the operational rules have to cope with design and operational constraints which are unique for the sector.

Technologies and processes for design, validation, certification, operation and maintenance of urban rail traction power systems have been constantly improved in the past, but they have now to cope with recent or new requirements coming from the public authorities responsible for urban transport which lead to address new key technological concepts - beyond the new generations of semiconductors - which influence drastically the urban rail traction systems and their energy efficiency. These key issues are:

- Universal access to vehicle – leading to “low-floor” light rail - and to stations (escalators, lifts...) – leading to higher power consumption;
- Prohibition of overhead contact lines in some historical areas – leading to alternative solutions;
- New requirements for passenger comfort in terms of HVAC - Heating, Cooling and Ventilation Systems - and internet connectivity – leading to higher on-board power needs;
- Automation of metros – leading to adaptations of the on-board and wayside signaling systems;
- New approaches of mobility in dense conurbations, with rail networks as backbone for motorized travel, and pressure to reduce transport energy consumption in cities – leading to new approaches for managing energy transmission and distribution at city level (the “smart grid” concept).

All these factors contribute to draw more and more attention of the urban rail stakeholders to the energy consumption of the traction systems specifically developed for urban rail systems. The priorities are:

- the reduction of the energy consumption of the traction system and more generally of all on-board systems (for both metro and tram/light rail);
- the recovery of the braking energy (for both metro and tram/light rail); and
- the management of the overall energy consumption in metro systems

In a longer term perspective, the most innovative input for new power equipment design is the new generation of semiconductors, affecting the whole traction systems and related equipment.

The rail industry – both the manufacturers and the urban rail networks operators, with the support of research institutions and public authorities – is investing a lot in research to find innovative solutions to

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\(^1\) Some suburban and regional rail systems can be part of "urban rail", being excluded from the scope of the technical directives of the Fourth Railway Package, but they are not covered by this paper as their characteristics regarding propulsion technology are usually more comparable to conventional rail systems.

\(^2\) The first tram systems have been developed by electricity distribution companies in the third quarter of the nineteenth century, mostly in Belgium and in the Austro-Hungarian Empire.
tackle all above issues. At European level, the European research and innovation project SHIT2RAIL\(^4\) is partially contributing to this research effort, with a current focus priority on (interoperable) mainline rail. Most efforts are supported directly by (individual) manufacturers or operators, hopefully with support from the national or regional authorities.

The EU-transport industry for Urban Rail (represented at EU-level by UNIFE\(^5\) and UITP\(^6\)) is still a leader worldwide in the urban rail sector and especially for automated metro, low-floor light rail and innovative power supply without overhead lines. But they have Asia (Japan, Korea, China) as leading competitors in some areas (like the new generations of wideband electronic components).

**Description of the main concept**

Optimization of energy consumption and of energy management in urban rail systems has always been a target of the rail manufacturing industry and of the urban rail operators (together the rail industry). Contrary to mainline rail, and for environmental and performance reasons (air quality, accessibility, urban integration, noise, aesthetics...), from their creation in the nineteenth century tram and metro systems have been electrified.

Electrical transportation systems are enabling the use of regenerative energy sources as a substitution of fossil energy use. Every measure increasing the acceptance of urban rail is therefore welcome in order to reduce GHG emissions and other disadvantages of individual transport like noise, space and dust. The acceptance can be increased by providing fast and comfortable transport.

Energy consumption of urban rail systems first results from the higher level objective assigned to urban rail systems which is to carry very huge volumes of passengers. However they have also to:

- provide an alternative to the use of private cars in urban areas;
- accompany the huge development of urban areas (urban rail traffic is always increasing);
- and
- serve permanently the needs of their passengers, needs which are changing over time. Customers are always expecting faster trains, more frequent and reliable services, and, especially from the last recent years, more comfortable and accessible trains and stations\(^7\). The most recent trend is for on-board trains and in stations services to serve “connected” travellers.

To achieve their objectives urban rail systems frequently stop (contrary to mainline trains) and spend a lot of time in stations for embarking and disembarking passengers. They do not have a high maximum speed but need high acceleration and deceleration rates to be able to afford an attractive commercial speed despite the dwell time in stations. This high frequency of stops and the power of braking produce a lot of braking energy. In order to avoid losing this energy the urban rail sector has for long and whatever the mode - metro, tram or light rail - introduced technologies allowing recovering and re-using the braking energy. Various technologies are available and benefit from innovative developments.

The urban rail industry had also to find technological solutions for answering requests from public authorities (European Union, Members States or Regional/Local authorities):

\(^4\) www.shift2rail.org
\(^5\) www.unife.org
\(^6\) www.uitp.org - However UITP is a worldwide association representing all local public transport stakeholders.
\(^7\) This explains why metro started soon to be automated and why tram evolved thirty years ago towards light rail.
- Regarding the vehicle, tram and light rail have to be more and more accessible to wheelchairs and other People with Reduced Mobility, which led to the generalization of low-floor light rail largely influencing the design and location of propulsion engines (new running gears).
- Regarding the transmission of electrical energy to the vehicle, in addition to the overhead lines, catenary and pantographs also used by mainline trains, and to the third rail used by some metros, light rail manufacturers are developing power supply systems avoiding overhead contact lines in historical city centers.8
- Regarding the infrastructure, metro systems – guideway and stations - are (most often) built in tunnel. This has many implications in terms of power requirements beyond traction: power for heating, ventilation, cooling and powered equipment on line and in stations. The high volumes of passengers impose large ventilation equipment and many additional powered auxiliaries in stations. As a whole large metro systems consume a very huge amount of power: in Paris the annual consumption of metros, tramways and RER represents more than 1 TWh.9
- The very high level and complexity of energy consumption in metro systems is the reason why energy management in large metro systems requires more and more a holistic approach for optimization, in cooperation with relevant public authorities (the so-called “smart grid”).

As a result of these functional trends, the urban rail industry has constantly been innovative to improve the efficiency of the traction systems and to reduce the on-board energy consumption. Indeed propulsion technologies are foremost contributors to:

- the energy efficiency of the rolling stock: most of the energy consumption of a train is transferred to the wheels by the traction system, therefore the efficiency of these components has a major influence on the global energy consumption of the rolling stock;
- the weight and dimensions of the rolling stock: traction components are adding tons to the weight of rail motor cars, and use a large part of the space left for on-board equipment;
- the noise and electromagnetic emissions: traction systems, converters, gearboxes, cooling systems… are making rolling stock generating noise and electromagnetic fields which have to be made compatible with the signaling and control-command equipment;
- the performances, reliability and availability of the rolling stock.

### 1. Reduction of the energy consumption of the traction system and more generally of all on-board systems (for both metro and tram/light rail) by all means.

Regarding the traction system, the recent innovations always under improvement are as follows:

- Synchronous motors with permanent magnet replacing induction motors.
- New technologies for on-board energy storage (see section 2 below):
  - batteries and super capacitors, which are used not only for braking energy recovery but for catenary-less light rail
  - fuel cells and flying wheels

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8 Metros are fully segregated from any other road or rail traffic and their track access is prohibited to the public. It allows to use in some cases a third rail as an alternative to overhead lines in order to reduce the construction cost of tunnels or elevated structures.

9 More and more cities implementing new light rail systems no longer accept the visual intrusion of catenaries in front of historical monuments or within historical areas, and this new request makes rail manufacturers looking after alternative solutions for collecting traction energy.

• Smart management of energy and of energy savings. The conditions of use of rolling stock are taken into account in addition to the gross efficiency of equipment, e.g.:  
  o On-board energy management systems controlling automatically the use of individual equipment and components in order to optimize the performances and overall energy consumption of the vehicle;  
  o Smart driving assistance systems calculating the most energy efficient driving behavior in real conditions, and able to give instructions to the driver.  
Fully automated metro operation (GOA4, unattended operation with no staff on-board vehicle) also optimizes the propulsion technology efficiency.  
• Use of a new generation of semiconductors called wideband electronic power components, replacing Silicon based components (Insulated Gate Bipolar Transistor).  
• New methodologies for better lifetime estimate, improved design and validation processes of traction systems with high reliability.  
• New simulation methods and static test bench certification speeding up and simplifying the overall validation framework for placing products on the market (e.g. virtual certification).  

2. Recovery of the braking energy (for both metro and tram/light rail)  

In order to better understand this key technological trend it is useful to remind a few features regarding power supply in urban rail systems11:  

• Metro and tram/light rail drive along the line powered by the overhead line or the third rail. The energy is delivered by Traction Power Substations (TPS) which are generally rectifiers distributed on different points of the line in order to ensure a good quality of power with a low voltage drop. These substations can be powered directly by the "national" electrical grid or by an internal electrical network of the train operator or infrastructure manager.  
• Stations and auxiliaries (lights, signaling, escalators, technical rooms ...) are powered by another electrical network which can be independent or connected to the traction network. In fact, energy storage systems can also be used as power suppliers to the station loads and to auxiliaries.  
• When a train is braking, it regenerates energy: the kinetic energy is transformed into electrical energy. This electrical energy is directly consumed by the auxiliaries of the train (heating, air conditioning, lights ... representing 50 to 200kW) and the remaining energy is sent back to the feeder (3rd rail or catenary in most cases). If there is a train accelerating in the area of the braking train (highest is the line voltage, largest is the area), the accelerating train is powered by the braking train. Otherwise the voltage increases and the braking train dissipates the energy in the braking rheostats.  

This kind of braking is generalized to all rolling stocks because of its ease of use in alternative or direct current. No additional component is required because of the natural reversibility of motors and converters by principle or by construction. Moreover the regenerative energy allows improving the energy efficiency of the traction system and it is the main research topic to decrease the consumption of electricity.  

Indeed, braking energy typically amounts to 41% of driving energy in urban rail systems, and although part of it is lost in the braking rheostats – about 10% of the total driving energy - the braking energy which can be recovered amounts to as much as 31% of the total driving energy12.  

11 See OSIRIS Deliverable D4.1_Smart_grid_system_definition_system_studies_and_modeling_technologies_evaluation, section 3.2: http://www.osirisrail.eu/  
12 See Figure 3.1 of the OSIRIS Deliverable D4.1.
The challenge is an absorption of the energy feedback with minimum losses either directly or through energy storage.

Direct recovery by the energy network is possible with new technologies like smart reversible inverters (as HESOP for Alstom). They let the natural exchange of energy between trains and if there is no train able to use the braking energy, the inverters recover the energy and distribute it to the electrical grid or transfer it to the upstream network where it is distributed to other consumers e.g. in stations. This solution captures at least 99% of recoverable energy but it isn't perfect. In fact, lots of auxiliary station networks are independent of the traction network and the unique solution is to sell the energy to the grid operator which will usually buy this energy at a low price compared to its selling price (when the consumption is very high it is possible to sell at a higher price). However if the urban rail operator owns a private medium voltage network which supply all the traction substations, another traction substation (or station substations if they are linked to the same private network) can consume the recovered energy and energy savings can be done.

As part of the OSIRIS project a new type of auxiliary converter has been developed and installed on an ATM metro train in Milan (Line 3) by ALSTOM. The purpose was to reduce the power consumption of onboard systems, including heating, air-conditioning, lighting and the battery charger.

When the network cannot or can only partly absorb the feedback, energy storage may take up a big share of the total.

Lots of storage systems exist and a huge number can be used in urban transport. The best known are batteries (Li-Ion, lead-acid or NiMH), super capacitors and flywheels. Fuel cells are also a possible future technology.

Storage systems are specifically dedicated to power (supercapacitors) or to energy (batteries) or for hybrid (flywheels) use.

The storage system can be on-board or wayside:

- An on-board storage system stores the braking energy and delivers it during the acceleration. Thereby the peak of power at the TPS is limited during the acceleration and line losses decrease. However the train is heavier (the need of more power to move) and the rolling stock has to be studied in order to embark a storage system (problem of space).
- A fixed storage system allows operators to install a higher power or energy system without the problem of space.

An advantage of these storage systems is that they can also be used for catenary-less light rail...

As part of the OSIRIS project, an onboard energy storage system using lithium-ion batteries from SaFT was tested on a tram in Vitoria-Gasteiz (Spain) (the tram manufacturer is CAF). The aim was to capture and store energy during braking, in order to reduce overall energy consumption and cut the power losses from the catenary and substations.

Most of these technologies are not new, but they are regularly improving with new generations replacing the old ones, as examples have been tested during the OSIRIS project for new batteries and a new converter.

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14. See OSIRIS_2nd_Newsletter_20150324
15. See OSIRIS_2nd_Newsletter_20150324
A more disruptive innovation comes with the traction power systems for tram replacing overhead lines, which cover:

- Ground level Power supply by a contact rail (divided in segments shorter than the tram and put under tension only when the tram fully covers a segment). Examples are:
  - APS from ALSTOM\(^{16}\). In operation in Bordeaux (France) since 2003, and now implemented in other cities like Angers.
  - TramWave by Ansaldo STS. Tested in Italy, implemented in Zhuhai (China) in 2014.
- Induction power. The system Primove which is buried is under development by Bombardier in Augsburg and can also be used by electric buses or even trucks and cars.

The biggest disruption shall come in the future with the new generation of wideband electronic components starting to be applied to many sectors and which shall allow for totally new traction systems architectures at a reduced cost.

Other innovation resides in a better cooperation between energy stakeholders, for the implementation either of smart grids at city level or of agreed new validation and certification processes for traction systems and components at microeconomic level.

The silicon based electronic power components (Insulated Gate Bipolar Transistor) have reached the limits of their potential efficiency and performances improvement. A new generation of traction systems based on wideband electronic power components, like Silicon Carbide semiconductors (SiC), Gallium Nitride (GaN) or diamond, would be more efficient (they have very low energy losses), more compact and lighter than Silicon based components. The weight of the propulsion systems could be drastically reduced and their efficiency going beyond the current 85%. In addition, among their advantages, these components are compatible with high functioning temperatures (up to 250°C), which allows reducing drastically the cooling systems and even to adopt natural cooling without pumps or ventilators. Their market uptake is therefore very promising. It shall of course depend also on business cases and production chain. In the case of rail applications, the current leaders are Japanese. Some specific applications should be demonstrated as part of the SHIFT2RAIL Multi-Annual Action Plan, but these technologies shall be frequently used in some years.

Synchronous motors with permanent magnet have better energy efficiency and a higher energy density, allowing for a reduction in volume and weight.

As regards the re-use of braking energy the main expected benefits of the various technologies (converters or energy storage) are a reduction in energy consumption and in some cases new ways of operation (e.g. for tram/light rail). They may also help: increasing the available power when speeding up trains; reducing the peak energy consumption and the losses of the energy network; and increasing the distance between power sub-stations, thereby allowing to save part of them (10 to 20%) or to serve a higher level of traffic.

The new traction power systems for tram without overhead lines shall enlarge the potential market for new tram systems, and may even benefit to other modes of transport.

The energy efficiency of propulsion technology of rail vehicles is no longer limited to the traction power itself but has to be analysed from a more global perspective of the overall energy efficiency of the urban rail networks on their own and of the overall city energy grid.

\(^{16}\) APS: Alimentation Par le Sol.
A holistic approach of the management of energy in metro systems, combined with the reinjection of energy in the grid, shall lead to a better efficiency of the energy transmission and distribution network at the overall city level. The “smart grid” is a high priority in line with the European overall environmental, climate and energy policy.

Many traction systems and components do not benefit from standardized certification and validation processes for putting them into service or place them on the market. New methodologies and processes might not only reduce costs but speed up the market uptake of innovative products.

**Analysis & Assessment of the impact on present industry structures:**

- Wideband electronic power components, like Silicon Carbide semiconductors (SiC), Gallium Nitride (GaN) or diamond: TRL 3 to 6.
- Synchronous motors with permanent magnet: TRL 4 to 9.
- New inverters and converters: TRL 3 to 7.
- New batteries: TRL 3 to 7.
- Smart grid: TRL 6 (but it is largely an institutional issue).
- The new traction power systems for tram without overhead lines: TRL 5 to 9.
- New methodologies and simulation methods: TRL 3 to 6 (it is also an institutional issue).

For all these technologies the roadmap of technology developments is twofold in Europe:

- Individual roadmap of each rail manufacturer and in some cases of rail operators intending to protect their Intellectual Property Rights and to achieve a competitive advantage in front of their competitors.
- Joint roadmap established by all stakeholders. In the case of rail, the two main supports are:
  - The European Technology Platform for Rail, ERRAC, the European Rail Research Advisory Council\(^\text{17}\), which has produced an ERRAC Strategic Rail Research Agenda SRR\(^\text{18}\) and a relevant roadmap; \(^\text{17}\)
  - The European Joint Undertaking SHIFT2RAIL\(^\text{19}\), which is developing a very large specific research program as part of the EU R&I framework program H2020\(^\text{20}\).

However the current priorities of SHIFT2RAIL are more related to the European interoperable railway systems, and it is expected that the next program of SHIFT2RAIL after H2020 shall better take into account the specific needs of urban rail.

- In Europe: all founding members and associated members of SHIFT2RAIL
  - Founding members (apart from the European Commission): ALSTOM, Ansaldo STS, BOMBARDIER, CAF, Network Rail, SIEMENS, THALES, Trafikverket
  - Associated members: AERFITEC, AMADEUS IT Group SA, AZD Praha s.r.o., CFW (Competitive Freight Wagon Consortium), DB (Deutsche Bahn AG), DIGINEXT, EUROC (European Rail Operating community Consortium), Faiveley Transport, HaCon Ingenieurgesellschaft mbH, INDRA SISTEMAS S.A., Kapsch CarrierCom AG, Knorr-Bremse Systems für Schienenfahrzeuge GmbH, MERMEC

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\(^{17}\) [www.errac.org](http://www.errac.org)
\(^{18}\) [http://www.errac.org/roadmap/about/](http://www.errac.org/roadmap/about/)
\(^{19}\) [www.shift2rail.eu](http://www.shift2rail.eu)
\(^{20}\) [https://shift2rail.org/research-development/](https://shift2rail.org/research-development/)
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

S.p.A, SDM (Smart DeMain consortium), SmartRaCon (Smart Rail Control consortium), SNCF (Société Nationale des Chemins de Fer Français - SNCF Mobilités), SwiTracken consortium (Switch Track and Energy), Talgo (Patentes Talgo S.L.U.), Virtual Vehicle Austria consortium+

For more details, see: https://shift2rail.org/about-shift2rail/ju-members/

- Worldwide: Japan, Korea, China…

As described above, there are many different solutions to achieve the overall target of reducing energy consumption in urban rail systems with a focus on traction systems. In fact, each urban rail system shall have to find its most appropriate solution in cooperation with the supply industry.

- Analysis and assessment of the impact of Disruptive Technologies on present value chain

There are no unique selling points for achieving the key technological train of Energy efficiency of traction systems in urban rail. All mentioned ways can be developed in parallel. The OSIRIS project has defined:

- a number of energy and business-related Key Performance Indicators for urban rail systems to allow direct performance comparisons and the benchmarking of technologies to be used by rail operators;
- a series of standardized duty cycles for benchmarking purposes. These will enable urban rail operators to compare the energy consumption of their various systems and support them in decision making as well as optimizing their procurement processes.

The technology which shall have the biggest influence on the dynamics of the value chain is the new generation of wideband semiconductors (SiC) which shall impact all elements of the traction systems, including the related equipment (e.g. for cooling). It is the only really disruptive technology, all others are based on new generations of existing technologies.

The new technologies shall allow to better fit the trend of increase in demand at a reduced cost, and conversely the improvement of traction systems leading to increased performances as well as energy savings shall offer new opportunities for the development of rail systems (new lines or extensions of lines or rolling stock fleets) and therefore attract new customers.

The threats come from the growing quality of the products of the Asian manufacturing industry, especially Japan, Korea and China, which are now challenging the leadership of the European industry.

- Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain

The main drivers are the high sustainability of urban rail systems in comparison with all competing transport modes, and the strong political commitment of the European Union, of the Member States and of most cities in Europe (and worldwide) towards a better management of energy to face the climate and environmental challenges of the next decades and to improve the quality of life of their citizens.

The main barrier is the cost of urban rail systems and the need for financial support from public authorities for the creation or extension or upgrade of urban rail systems. Another barrier is the absence of harmonized validation and certification processes for placing products on the market, and the complexity of the urban rail market which involves a very large number of decision-makers for the
development or improvement of urban rail networks which are always depending on local conditions for optimizing the decisions made.

Cross-sectoral collaborations are essential between manufacturers and between operators. The domains for collaboration are preferably:

- the exchange of experience on demonstrations and experimentations in real applications, offering opportunities for benchmarking to operators and public authorities;
- the harmonization of specifications of products/tools/methods/processes largely shared among the various networks.

The urban rail sector is very dynamic in Europe and Europe has all the required technologies, applications and expertise.

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Rolling Stock in the Railway System – Volume 1, 2 & 3 - La Vie du Rail. Directed by Eric Fontanel and Reinhard Christeller (several authors) with the advice of François Lacôte
See TD3.9 & TD3.10

The global objective of a railway smart grid is to develop the actual unique railway power grid in an overall interconnected and communicating system (Figure 87). This new railway network integrates smart metering, innovative power electronic components, energy and economic management system, energy storage system and local and/or environmentally friendly power sources. This new concept leads to improved and optimized train traffic, energy costs, energy supply security for the railway system, energy efficiency (in term of availability) and environmental impact thereof.
4.3. Effects of digitisation, (UITP)

**Sector/Mode of Transport:** Rail/Rolling stock  
**SCORE:** 3 Europe has a competitive advantage in comparison

**Management Summary**

Digitalisation is the most disruptive trend in the global economy. The digital economy is a new paradigm for the organisation of all economic sectors worldwide, with a scope which gathers all steps of the technological value chain. For the rail sector, digitalisation shall be a technical revolution. The manufacturers shall be drastically affected all along the lifetime of the railway products, whatever the sub-system – infrastructure, trains, and equipment. The operators shall be offered new opportunities to adapt the rail services from their original planning phase to their daily operation with real-time dynamic adaptation in case of incidents. They shall get real-time information coming from both their rail assets and from their customers about the conditions of the components and sub-systems and about the quality of travel services. Operators shall also be able to establish a new kind of individual and “customised” relationship with the customers – especially the “connected” ones.

The impact of digitalisation is very large and this paper shall focus on the impact of the technological changes on the maintenance of the rail assets. The general guideline is that the preventive maintenance (mileage-based and time-based) of the past shall be more and more replaced by a condition-based and predictive maintenance.

The whole railway market is shifting towards remote a monitoring of its key assets. Data analysis and connectivity allow to gradually change preventive maintenance from a systematic approach to on-condition maintenance (Condition Based Maintenance - CBM) and eventually to predictive maintenance, that is a tailored maintenance over the remaining life of key components.

The objective is to bring on the market new and more efficient generations of rail systems serving the various rail market segments: high speed rail; national and regional conventional rail; urban rail – metro, tram/light rail and suburban rail –; and freight. Each segment would benefit from a high-quality reliable rolling stock, intelligent traffic management and control systems, new railway infrastructure, and innovative IT solutions and services, that will radically improve the performances of the systems while substantially reducing the life-cycle cost of rail services. For the local traveller as well as for the EU traveller this will mean 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. For rail in general, this will mean more users and it shall contribute to a modal shift from road to rail supporting sustainable European mobility and the European economy competitiveness.

The European (or more exactly Western) rail transport manufacturing industry – members of the European association UNIFE and the international groups operating rail services - members of the international associations UITP (all local public transport), UIC (international, mainline rail), CER (European, mainline rail) are currently world leaders in the rail sector. European Infrastructure managers (represented at EU level notably by EIM and CER) are also important stakeholders of the European industry.

Manufacturers are providing Rolling Stock (trains, locomotives and their subcomponents: axles, wheels, interiors, HVAC, energy systems, brakes, doors, bogies, ec.), Infrastructure (tracks and  

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21 E.g. Bombardier Transportation is the rail equipment division of the Canadian firm Bombardier Inc.  
22 E.g. the French KEOLIS (SCNF Group), RATP Dev (RATP Group), TRANSDEV or the UK FIRST GROUP PLC or the German DB AG (Deutsche Bahn) owning also ARRIVA (formerly UK).  
23 HVAC: Heating, Ventilation and Air Conditioning.
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electrification), Signalling systems and components, Services (engineering, consulting etc.) or System integration.

According to the UNIFE World Rail Market Study 2014, the rail supply industry today accounts for nearly half of the world market for rail products and for 84% of the EU market for rail supplies and services. The absolute sales of the EU rail suppliers amounted to €47billion in 2014. EU represents the biggest absolute market for rail products and services, with the rolling stock segment representing the largest part of this market. The accessible market is expected to grow with a compound annual growth rate of 2.8%, with major growth markets in NAFTA (3.7%), Asia Pacific (4.2%) and Latin America (5.7%).

The rail supply industry has been the source of major past innovations which are important steps towards an integrated interoperable European rail market and towards the increased development of urban rail systems (especially automated metro and renewal/creation of metro, tram and light rail systems):

- Automatic systems for obstacle detection;
- Medium frequency traction transformers;
- Energy storage technologies;
- Improved regenerative braking;
- Satellite-based positioning systems;
- Hybrid and diesel technologies;
- Light weight materials;
- Track-friendly, low-cost and silent bogies for freight wagons;
- Automated metros;
- Tram systems without overhead lines...

Currently, the industry invests 2.7% of its annual turnover (the EU average for R&D programmes) amounting to some €780 million a year, predominantly in the rolling stock and rail control.

Description of the main concept

An overall vision of the impact of digitalization on the rail sector is provided by the European Technology Platform for rail, ERRAC, in a document called RAIL 2050: “The emergence of enabling technologies, such as artificial intelligence, the “internet of things”, robotics, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2X) communications, autonomous driving and block-chain will provide a wide range of possibilities for innovation in the rail system and to change the way it operates, supporting improvements in rail based logistics and mobility in the short run”.

This ERRAC vision is reflected in the research and innovation initiative taken from 2009 by the railway industry which led to the creation of the Shift2rail Joint Undertaking (in short S2R JU) in 2014.

Shift2Rail is the first European joint undertaking for rail research, which budget over 2014-2020 amounts to €920 million of which nearly half (€450 million) coming from the EU’s Horizon 2020 budget framework. The aim is to set up a European research and innovation programme to integrate new and advanced technologies into innovative rail product solutions. For a very detailed view of the evolution of the rail research covered by the S2R JU and its expected market uptake, the major source of information is the Multi-Annual Action Plan of the Joint Undertaking S2R.

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24 See www.unife.org. The major systems integrators are ALSTOM, BOMBARDIER, CAF, TALGO, SIEMENS and SKODA.
25 About 68% of the global rail supply market is accessible to European companies.
26 16 June 2014: Adoption of Council Regulation No 642/2014 establishing the Shift2Rail JU.
The objective of the MAAP is to understand, specify, agree and update the operational and maintenance needs of operators and infrastructure managers to secure train operators needs for the year 2020 and beyond. The identified needs which are relevant to the current document are:

- LCC aspects, covering traction weight and volume savings; operation cost reductions (including energy and maintenance costs)
- maintenance oriented design, including digital technologies to achieve a more efficient maintenance policy
- spare parts obsolescence management addressed from the design stage
- virtual certification, standardisation of components & qualification to reduce authorisation costs, market analysis and eco-labelling needs and impact maintenance costs.

The digital improvements would mostly impact the Life Cycle-Cost and maintenance cost and organization of the following sub-systems and components of the rail systems:

- Rolling Stock:
  1. Traction system
  2. Train Control and Management System (TCMS)
  3. Running gear
  4. Brakes
  5. Doors
- Signalling and control-command equipment
- Infrastructure
  1. Switches and crossings
  2. Bridges and tunnels
  3. Track
  4. Power supply
  5. Fixed assets (all above)

Each of these sub-systems and components is addressed hereinafter:

1. **Rolling Stock**

Rolling Stock as a global sub-system can also expect a Life-Cycle-Cost (LCC) reduction from virtual certification, higher reliability and lower energy consumption achievable through digitalization.

1.1. **Traction system**

The Traction Drive sub-system is one of the main sub-systems of a train as it moves the train converting energy from an electrical source (directly or via a chemical source) into a mechanical one. The physical domains to master are multiple: electrical, mechanical, thermal, and automatic. A large number of norms and regulations have also to be taken into account for traction systems design, manufacturing, validation and certification. The major innovation shall come from the new Traction Drives using the new electronics materials becoming available, the SiC (Silicon Carbide) technology.

Advanced maintenance services of traction system and components shall be possible through high added value functionalities like remote failure diagnostic and health monitoring which shall help developing predictive maintenance principles. Digitalisation shall support remote data analysis and Condition Based Maintenance (CBM) using existing sensors.

1.2. **TCMS**
The Train Control and Monitoring System (TCMS) is the brain and the communications backbone of the train: it integrates and manages all on-board information, it performs communication between train equipment, vehicles and consists and between train and ground and has a leading role in the integration and interaction between different subsystems of the train. The trend is now towards Wireless TCMS (like in CBTC systems, the Communications Based Train Control and Command systems – CBTC – of automated metros).

Additional technological trends for TCMS are:

- “Drive-by-data” providing a train-wide communication network making new control functions possible, involving interaction between vehicles and train consists, with high safety and reliability levels through very simple physical architectures;
- “Functional distribution architecture”, a new architectural concept based on standard framework & application profiles, allowing distributed computing of end devices distributed along the vehicle meeting;
- “Virtual Placing on the Market” which is a standardised simulation framework in which all subsystems of the train will be simulated, allowing remote and distributed testing including hardware in-the-loop through heterogeneous communication networks;
- “Virtual-coupling” which allows train consists manufactured by different companies and with different interfaces to be virtually coupled, driven together by the leading cabin and sharing the same traffic slot.

1.3. Running gear

The running gear is a large part of the weight of the Rolling Stock (wheels, bogies…) and it conditions the comfort of the train (quality of suspension, emission of noise and vibration). The trend for Digitalisation and Wireless Communications solutions shall allow implementing new sensors and new relevant architectures and functionalities to monitor both bogie and track, and new technologies to control bogies and wheelsets.

1.4. Brakes

Braking technology in urban rail systems has already allowed recovering a very large part of braking energy in metro, tram and light rail systems. For mainline, the technological trend is on safe brake systems with higher braking performance, lower life cycle cost and noise levels, as well as braking energy recuperation.

More precisely the research shall address lighter, compacter and environmentally friendly brake components and a new generation of brake control electronics28 (including new generations of eddy current brakes) for improved adhesion management. Enhanced diagnosis systems shall ease maintenance and make it more cost-efficient.

1.5. Doors

Doors – and to a lesser extent steps and ramps – are the key interfaces between station platforms and trains for passengers. They are opened so frequently in urban rail networks that in the list of

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27 The rail sector shall elaborate on important knowledge and innovative practices on “virtual coupling” coming from European aerospace research projects (RESET, SOFIA, INOUI and ASSTART).
28 Shift2rail shall produce an electronic hardware-software architecture, compliant with High Safety Integrity Level (SIL3-SIL4), particularly oriented to be applied in Brake Control solutions, where the safety functions allocation will be transferred from traditional pneumatic components to electronic modules (up to TRL 4).
operations incidents doors are ranked first. The trend for automated metro is also to implement Platform Screen Doors – PSD – as a support to increased operations performances (mainly for CBTC systems) and for increased travellers’ safety.

New lightweight composite door structures could be made to react faster at existing safety and reliability levels, reducing platform dwell times and increasing overall line capacity. Improved access for passengers and for people with reduced mobility using sensitive edges and light curtains are part of this new development, as well as the integration of digital displays in the door leaf as a contribution to customer-friendly information systems.

Modular door systems would facilitate future evolutions, maintenance and repair activities which would contribute to reduce LCC. A plug and play approach for the different devices would improve the standard of their connectivity, enabling easier obsolescence management and finally widen the range of different configurations.

2. Signalling and Control-Command equipment

A better management of signalling and supervision systems on “static” infrastructure by supporting the development of an intelligent Integrated Mobility Management (I²M) system can enhance the overall line capacity and contribute to life-cycle cost reductions and global reliability of the railway system, while maintaining the highest level of safety. Innovative technologies, systems and applications in the fields of telecommunication, supervision, train separation, engineering, automation and security can enhance the overall performance of all railway market segments. While works shall aim at maintaining the dominance of ERTMS as a solution for railway signalling and control systems across the world they shall also build up on achievements of the automated metro sector (lines equiped with CBTC systems).

LCC shall be reduced with savings in energy consumption by introducing an appropriate Automatic Train Operation (ATO functionalities with Grade of Automation from 2 to 4) and Intelligent Traffic Management in all rail transport market segments.

Maintenance cost shall be reduced by reducing as much as possible the number of electronic and mechanical components laid down along the rail lines and concentrating them in a limited number of easily accessible areas. Another trend is virtual balises which could allow lines with no track circuits. A significant reduction of the number of traditional train detection systems (e.g. track circuits) can be expected using a multi-sensor positioning concept using the Global Navigation Satellite System – GNSS – technology (and EGNOSS and GALILEO satellites).

GNSS can also support methods and tools (such as drones) for surveys along the tracks (lines/stations) and for the creation of Digital track maps.

A larger introduction of auto-diagnostic functions to detect the status of more critical components will allow a predictive (and optimised) maintenance.

Another new concept is virtual coupling of train consists. Virtual coupling makes infrastructure managers and railway undertakings capable of operating physical trains much closer to one another (inside their absolute braking distance) and dynamically modifying their own composition on the move.

Another trend is improvement of Cyber-security. The main goals of cyber-security are Security and safety improvement and Cost reduction. Another goal is the standardisation of the security system at European level for reducing the infrastructure and maintenance costs of railways operators and improving compatibility and interoperability. This will apply to all new ICT used in railway (e.g.: traffic management, interlocking, urban signalling communication, …).
3. Infrastructure

The demand for growth in transport is tremendously speeding up and the rail sector has to deliver increased productivity to fulfil growth demands across all modes in freight and passenger services estimated as 80% and 50% respectively by 2050. The trend is towards innovative design and optimisation of core infrastructure elements as well as improvement in the management of the railway system by adopting a holistic, system-wide approach.

Currently asset maintenance activities predominantly follow costly time-based regimes that often fail to define and target the root causes of degradation. The target is a step change in the way the European rail network is developed and operated with a focus on risk and condition-based lean approaches to optimise Reliability, Availability, Maintainability, Safety (RAMS) and lifecycle costs.

The focus of new technologies taking advantage of digital tools which are mostly impacting the maintenance cost is as follows:

3.1. Switch & Crossing Systems

New Switch & Crossing Systems would deliver new methods for directing trains to change tracks.

3.2. Bridges and Tunnels

Proactive Bridge and Tunnel Assessment, Repair and Upgrade would improve inspection methods and repair techniques in order to reduce costs, improve quality and extend the service life of bridges and tunnels if possible. Different options need to be considered at each stage of the asset lifecycle, based on the maintenance strategy and on the timing of renewal and whether operational limitations may be required.

Data input includes direct information on the asset which could also be used for benchmarking.

What shall be developed are:

- innovative tools and techniques for capturing information on the current status of assets in a non-intrusive and fully integrated manner (focus on asset status data collection organised around the different technical systems of the railway);
- innovative system for the management, processing and analysis of railway data;
- Intelligent Asset Management Strategies (IAMS) addressing a holistic, whole-system approach of asset management employing above collected and processed data and putting long-term strategies in the context of day-to-day execution of the maintenance and other maintenance activities.

These options need to be considered at each stage of the asset lifecycle, based on the maintenance strategy and on the timing of renewal and whether operational limitations may be required.

Data input includes direct information on the asset which could also be used for benchmarking.

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29 Lean means creating more value for customers with fewer resources.
3.3. Track

Approximately 25% of the annual operational cost of High Speed infrastructure is incurred by maintenance. For conventional mixed traffic track this ratio is higher due to older infrastructure and accelerated deteriorations (due to increased usage). In addition, track related installation costs are a significant portion of total installation costs, and direct, secondary and long-term costs related to malfunctioning track structures are massive.

The age of the current rail infrastructure is not the only cause of this massive spending on maintenance. Another reason is that assets of the rail infrastructure have an expected life time of more than 30 to 50 years. Improving the situation requires that each maintenance step during the life time needs to be recorded in order to monitor its effect. The gained knowledge will be used for decisions in the future.

Future demands on railways will drastically reduce time for maintenance in track, while at the same time, a significant increase in maintenance levels and improved maintenance procedures will be needed to withstand the increased operational demands. Objectives regarding maintenance are improving: evaluation of needs; decisions on required actions; performance of these actions; and coordination of maintenance actions.

Focus shall be on key operational parameters to measure and analyse and on models to predict deterioration, establish technical limits for acceptable deterioration levels, evaluate technical feasibility of improved maintenance procedures, and make consequence analyses of different maintenance scenarios.

In that regard, Track System can be seen from two perspectives:

- Optimised Track System, in order mainly to reduce the maintenance costs of the track;
- Next generation of track system, in order to achieve ambitious long-term objectives reducing the LCC over a far larger lifetime.

3.4. Power Supply

The digital economy shall support the global objective of a railway smart grid integrated in an overall interconnected and communicating system covering the whole city territory and even a larger territory in case of multimillion population conurbations (nationwide power system). This new concept leads to improved and optimized energy transmission and distribution at city-wide level.

3.5. Fixed assets

The current situation of railway maintenance is characterised as follows:

- The majority of monitoring and measuring systems are designed as independent tools thus making difficult the fusion of information and its integration in the maintenance process.
- A huge number of individual information systems is currently available in the EU railways, each of them dealing with individual and isolated areas of the maintenance process thus not exploiting the potentiality of big data analysis.
- Research and innovation results are showing that maintenance performances are strictly linked to many heterogeneous parameters, most of them not yet taken into account in the maintenance process.
- Typically applied maintenance is still periodic preventive maintenance based on good practices established a long time ago, simply integrated by targeted interventions when faults appear.
• Stakeholders’ environment is becoming more and more complex due to the increasing amount of parties – often with conflicting priorities – involved in infrastructure operation and maintenance.

As the European railway passenger and freight traffic continues to rise (passenger 34% and freight 40% in 2030 compared to a 2005 baseline), the access time to bridges and tunnels for inspection and repair is reducing. However, by performing fewer inspections or reducing the quality of the inspections, structures deteriorate at faster rates. This is due to delayed detection of damage, leading to more extensive time and cost consuming repairs in the long run. This becomes critical and severely impacts track availability due to extended track closures. With enhanced inspection methods and techniques, 50% reduction in inspection costs could be achieved whilst improving the quality of the inspection and rationalising the costs for corrective maintenance actions.

Even if many of the existing structures are close to or over the end of their service life, it is not economically feasible to envisage their replacement on a large scale since new standard bridges cost between 0.5-2M€ each. Similarly for the replacement of existing tunnels, apart from economic considerations, is not always a viable option due to the lack of space especially in densely populated areas. In view of this, the proactive and effective maintenance and upgrading of these structures to extend their service life is seen as a major priority to facilitate Europe’s rail transport ambitions.

The novelty and changes depend upon the sub-system.

**Traction system**

Advanced semiconductor technology has always been a key component for the traction system. Former steps from line commutated thyristor converters to gate-turn-off thyristors and also from bipolar technology to insulated gate bipolar transistors (IGBT) have been the enablers for step changes in performance of traction drives, which already offer a good energy efficiency (up to 85%). Today the new emerging technology is the Silicon carbide (SiC) semiconductor technology candidate to replace the existing Silicon (Si) Technology. The SiC semi-conductors have very low losses and allow very high energy efficiency.

The Silicon technology has a low reliability and no capability to predict life time of semi-conductors and traction components in real train operational conditions, which shall change with the SiC technology.

SiC technology would allow replacing heavy and very large traction equipment by smaller, lighter and much more efficient transformers and motors and simpler and cheaper cooling systems.

**TCMS**

TCMS is currently based on specific – and therefore expensive - hardware and software30 which have relatively poor performance and are bottleneck for deploying new demanding systems onboard. The increase in information volumes and the introduction of new functions and passenger oriented services require today an additional network often based on Ethernet: Ethernet brings higher throughput and reduced material cost31 and is more and more deployed in railway factory automation. The Ethernet technology is accompanied by Internet Protocols (IP) allowing a seamless integration of trains into the operator’s infrastructure including control centers, workshops and offices, through an appropriate and standardised train-to-ground link.

The existing technologies should be replaced by Wireless TCMS.

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30 The Multifunction Vehicle Bus (MVB) and the Wire Train Bus (WTB).
31 Through the new Ethernet Train Backbone (ETB) and Ethernet Consist Network (ECN) buses.
Running gear

The novelty is an improved ride and curving performance of the running gear and wheelsets leading to higher reliability/availability of the vehicles and significant savings in wheelset maintenance and longer life together with lower energy consumption.

Signaling and control-command

Many European railway lines – both for mainline and urban rail - are very busy today and have a problem to handle the requested capacity. New lines are built and tracks added to existing lines, but this is slow, expensive and will not create the needed capacity in the near future.

The new signaling and control-command systems and Virtually Coupled Train Sets – VCTS- represent a total deviation from the traditional railway operational concept.

Cyber-security

Nowadays the wired and wireless networks used by railways operators are usually heterogeneous, not protected well enough and they don’t fulfill the usual cyber security requirements in term of sustainability, protection and attack detection. The quick evolution of the telecommunications means, the threats and the sustainability aspects have not been taken into account because of the obsolescence of cryptographic techniques and of the amount of manual maintenance operations (the update of the encryption and authentication material still requires the manual intervention of operators on trackside and mobile devices).

In addition there are many devices and rooms which are not secured. The access protections to trains and shelters are usually mechanical (keys, padlock or even a common key for many devices…). The profile selection is usually very poor and when this feature is provided it is usually based on the user name.

The new technology would replace the existing access protection systems and better protect existing and future wireless networks from cyber threats.

Infrastructure

Switch and crossings

A number of key components within the traditional railway system are particularly vulnerable to failure, the consequences of which are profound to the overall performance and safety of the railway infrastructure. One such element is Switch and Crossing (S&C) assemblies the fundamental design principles of which have remained unchanged since their inception, and currently account for 25-30% of all infrastructure failures on most European railway networks. The duty cycle on rails are arduous and complex and advances in rail steel technology needs to be developed to resist abrasive wear and rolling contact fatigue.

The innovative approach is to adopt the growing trend of blending mechanical, electro-mechanics, digital control systems and electronic design elements into one integrated S&C system. By focusing on the development of a cross-functional integrated system that uses modern technology in innovative ways for the S&C operating system, it opens new opportunities for infrastructure maintainers to provide in-time preventative maintenance that will increase system longevity and availability and therefore service revenue and reduce manual intervention. New designs will also consider interoperability and inter-changeability needs of the European railway systems.
Track

In the current situation the track maintenance does not easily deal with rail crack detection (also cracks not located in the rail head), broken fasteners and deteriorated rail pads, cracked sleepers, fouled ballast, improper track stiffness, wrong stress-free rail temperature etc. The novelty shall be monitoring systems able to output data that are more relevant and better harmonized with numerical simulations of further degradation, that better relate to the current condition of the track and reduce traffic disruptions.

Infrastructure, Intelligent Asset Management

Digital technologies shall allow Intelligent Asset Management, which covers three complementary technologies:

- **Dynamic Railway Information Management System (DRIMS)**, focusing on: interfaces with external systems; maintenance-related data management and data mining and data analytics; asset degradation modelling covering both degradation modelling driven by data and domain knowledge and the enhancement of existing models using data/new insights;
- **Railway Integrated Measuring and Monitoring System (RIMMS)** focusing on: asset status data collection (measuring and monitoring) and processing and data aggregation producing data and/or information on the measured/monitored status of assets;
- **Intelligent Asset Management Strategies Demonstrator (IAMS)**, concentrating on: decision making; validation and implementation of degradation models based on the combination of traditional and data driven degradation models and embedding them in the operational maintenance process based upon domain knowledge; system modelling; strategies and human decision support.

Many of the existing structures were built to codes which did not take into account fatigue loading. The need for inspection and strengthening due to bigger traffic loads are increasing, whilst the ability to justify the pertinence of the calculations is becoming harder. As in other sectors, there is a need to use numerical simulation techniques that are closer to reality, coupled with physical inspection and maintenance data with the aim of better managing uncertainties and reinforce the administrative upgrading approaches and design of future structures.

For all assets, ability to rationalise and remove non-critical requirements from ageing codes and standards is a key requirement. This coupled with improved inspection and maintenance techniques will reduce the implementation of non-standard and expensive solutions within the rail industry, leading to the optimisation of the future structure design and operation. A novelty is that assets like tunnels and bridges shall be shown to be safe through calculations without any need for physical inspection.

The complexity of intelligent maintenance covers the interests of those parties involved in the rail infrastructure system. For the infrastructure manager, intelligent maintenance results in long-term preservation of assets (expressed in RAMS requirements) at minimal life cycle cost, while for the operator, intelligent maintenance leads to an available and reliable traffic system. For the maintenance contractor, intelligent maintenance leads to effective and efficient maintenance processes, adequate working methods, and purpose fit logistics, tools and equipment.

A large proportion of the cost of the European Rail Infrastructure is for maintenance. Due to rising pressure of utilisation of railway infrastructure for passenger and freight transport; environmental and safety regulations, increasing maintenance requirements cannot be met without a substantial shift in maintenance strategies. This shift and tailor made maintenance approach can only be reached with innovative tools for information management and decision support. A scalable framework for asset management systems, containing the static and dynamic data from all relevant components of the rail infrastructure.
infrastructure will enable improved lifecycle management, efficient maintenance strategies and adequate operations planning which includes logistic preparation, deployment of staff, tools, equipment and plant and possessions.

The benefits of the application of IAMS come from its holistic, whole-system approach.

Decision making processes will become more transparent, controllable and their results will be directly accessible by railway service providers and customers.

**Entire railway systems**

Wireless technologies shall drastically reduce the cabling on-board trains and on the wayside. New sensors shall replace sensors produced in small and expensive series by new standardised sensors fit for purpose that can be produced in large series at a lower cost.

**Traction system**

New SiC semiconductors have much superior characteristics than existing Silicium technology at high temperatures and significant lower switching loss. This can result in simplified cooling components and in general a much compacter design of the traction system overall with huge advantages in terms of LCC and O&M cost. This new technology shall benefit with relevant solutions to all categories of rail systems, from High Speed Train to metro, tram and Light Rail.

The potential is in:

- **Reduction in capital costs** (Rolling Stock): the traction system validation and certification costs could be reduced by around 40% through simplification, harmonisation of rules and shifting from “on site” certification tests to simulations and/or static bench tests;
- **Reduction in maintenance costs** (Rolling Stock): high reliability and “maintenance oriented design” components and traction sub-system hardware completed by smart Maintenance onboard software. Contribution to the reduction of the maintenance costs (Rolling Stock) in the range of 5% for the traction drive;
- **Reduction in Energy consumption**: higher energy efficiency technologies. Significant weight reductions will also contribute to reduce consumption and thus CO2 emission to progress on this environmental domain.

**TMC**

Tangible benefits expected for the end user of TCMS are in particular:

- Overcome drawbacks caused by physically coupled trains to be overcome;
- Take advantage of the important knowledge and innovative practices on “virtual coupling” coming from European aerospace research projects (RESET, SOFIA, INOU and ASSTAR);
- **An increase of operational reliability** (less service disruptions) through more robust systems based on less physical components, enhanced validation and debugging concepts, and more flexible processing of information;
- **A potential huge capacity increase** because of trains failing less often in service and by making it possible for units to be coupled and decoupled in a very flexible way;
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

- A substantial LCC reduction through simpler authorisation, lower physical complexity of systems, increased reliability …;
- Additional performance and services coming from fail-safe functions, flexible coupling of trains, train-to-train and train-to-ground communications …
- Take advantage of achievements in CBTC systems, the Communications Based Train Control and Command systems – CBTC – of automated metros.

Running gear

The potential of the new running gear is as follows:

- Increase of operational reliability (potentially up to 20%) due to standardized sensors, health monitoring functionality, and extensive use of mechatronic solutions, as well as the reduction in wear, improvement in riding quality, reduction of in-service failures and track interventions;
- Reduction of life-cycle costs (potentially up to 50%), due to weight reduction, less operational, maintenance related costs, as well as active system control. Reduced maintenance costs around the wheel / rail interface can be achieved due to lower wear rates delivered by active suspensions and lower weight and improved wheelset materials.
- Increase of capacity (potentially up to 30%): thanks to the reduction of the total weight of a bogie by up to 20%, the new generation of vehicle shall allow higher payload.

Signaling and control-command

Virtually Coupled Train Sets – VCTS- could increase line capacity by at least 100% for mainline (depends on existing infrastructure, traffic patterns and train characteristics) without building new tracks, and do this faster and with less investment and lower maintenance and operational cost, by improving the technical systems (mainly signalling).

This is a total deviation from the traditional railway operational concept.

Cyber-security

The standardisation of the Cyber-security features and of the automation and remote management of maintenance operation shall significantly reduce the maintenance cost of wired and wireless systems.

The development of Centres for Excellence in Railway Training – CERT – and of specifications of disaster recovery management plans shall increase a lot the sustainability of the railway systems in degraded situations..

Infrastructure

The expected impact of all actions presented in SHIFT2RAIL on infrastructure is a 100% Capacity Increase, a 30% Reduction in LCC and a 50% Increase in Reliability & Punctuality.

Switches & crossings

The next generation of Switch & Crossing systems, with improved sensor capabilities for self-diagnostics and the ability to self-adjust, self-correct, self-repair and self-heal shall allow increasing capacity, while reducing maintenance needs, traffic disturbances and life cycle costs. The market can expect:

- A significant enhancement of Reliability, Availability, Maintainability and Safety (RAMS) performance;
- **Intelligent asset monitoring** reducing the frequency of manual inspection and maintenance activities and enabling timely and focussed maintenance interventions (predictive maintenance);
- **Increased network availability** through enhanced, predictive maintenance capabilities reducing disturbance of operations;
- **Extended asset operational life** through enhanced, whole system S&C design and materials selection;
- **Low cost solutions for maintenance and renewals** whilst considering **24/7 working and increased safety** for track workers.

**Track**

The development will set out from developments in recent years (see e.g. INNOTRACK, D-RAIL, Capacity4Rail and other EC funded projects).

Apart from large savings in maintenance costs, another potential for the market is a significant decrease in the time spent in large track works most often involving shutting down traffic for a considerable amount of time. What can be expected are less maintenance, improved precision in identifying exact maintenance targets, and improved installation methods.

The potential economic savings resulting from an optimization of the current track system are significant, knowing that the maintenance costs of the track represent about 50–60% of total maintenance costs for railway infrastructure, and that track related installation costs are a significant portion of total installation costs.

The future generation of track systems offers however a much more important potential: an increased lifetime of track by 150%; a decreased traffic disturbance due to track maintenance and faults by 75%. Developing and deploying seamlessly integrated tools shall provide the infrastructure manager with means to optimize a pro-active management plan from a system perspective.

**Power supply**

The novelty introduced by innovation in smart metering, power electronic components, energy and economic management system, energy storage system and local and/or environmentally friendly power sources shall allow to develop a „railway power smart grid“ as part of a city-wide interconnected and communicating smart power system. This new concept leads to improved and optimized train traffic, energy costs, energy supply security for the railway system, energy efficiency (in term of availability) and environmental impact thereof.

**Analysis & Assessment of the impact on present industry structures:**

Most of the current technologies which are covered by the targeted innovative maintenance concepts are at applied research activities levels ranging from TRL 1 to TRL2 (Principles observed and and formulation of top levels requirements and of the possibility of applying them) or in some cases TRL3 (experimental proof of concept already developed). What is proposed in Shift2Rail is to test concepts and tools at TRL3 and TRL4 (including lab prototypes) and produce tests at TRL5 (for virtual validation and certification) so that the successful concepts are brought up to TRL6 (technology demonstrated in relevant environment) or TRL7 (system prototype demonstration in operational environment).

The roadmap of technology developments for the next years is extensively described in the 800 pages of the Multi-Annual Action Plan of Shift2rail (S2R MAAP). The works under this Shift2rail programme shall produce “Technology Demonstrators” for all the innovative technologies which have been described above.
In Europe: these companies are the 28 founding members or associated members of the Shift2rail Joint Undertaking (S2R JU) as well as the numerous members of UNIFE. S2R JU members are as follows: the European Union, represented by the Commission, and Aerfitec consortium, Alstom Transport SA, Amadeus IT Group SA, Ansaldo STS S.p.A, AZD Praha s.r.o., Bombardier Transportation GmbH, CFW consortium, Construcciones y Auxiliar de Ferrocarriles, Deutsche Bahn AG, DIGINEST, EUROC consortium, Faiveley Transport, HaCon Ingenieurgesellschaft mbH, Indra Sistemas S.A., Kapsch CarrierCom AG, Knorr-Bremse GmbH, MER MEC S.p.A., Network Rail, Siemens Atkiengsellschaft, Smart DeMain consortium, SmartRaCon consortium, SNCF, Railenium SwiTracken consortium, Patentes Talgo S.L.U., Thales, Trafikverket, Virtual Vehicle Austria consortium+. UNIFE members and associated members are presented on pages 99 to 102 of the UNIFE Annual Report 201732

Worldwide: these companies are Japanese, Korean or Chinese in most of the cases.
- Japanese companies are well known (Hitachi, Kawasaki, Mitsubishi, Toshiba etc.). An agreement has been signed on 8 December 2017 between the EU and Japan (EU-Japan Free Trade Agreement).
- China is hosting the largest Rolling Stock supplier in the world (CRRC) and the very big companies CREC (infrastructure) and CRSC (signaling). In September 2015, a Memorandum of Understanding was signed on the ‘EU-China Connectivity Platform’ to enhance synergies between China’s One Belt One Road” initiative and the EU’s connectivity initiatives (TEN-T policy). However the progress is slow.
- In Korea, companies like Samsung or Hyundai are successful competitors to the EU industry.

There are different technological developments paths for some technologies, but they are almost all covered by the various research developments already covered by Shift2rail. Those which are not covered shall be proposed for the potential Shift2Rail 2.0, for which UNIFE Research & Innovation Committee members identified the following nine Key Enablers: automated rail transport, mobility as a seamless service, digitalisation, towards an efficient zero emission railway, maintenance of the future, enhancing the security and the protection of the rail system, optimized infrastructure, digitization of the supply chain (Industry 4.0) and new certification framework.

Analysis and assessment of the impact of Disruptive Technologies on present value chain

There are no “unique selling points” for the technologies presented above, which are subject to competition rules. However there are sub-groups of UNIFE members which are focusing on some specific markets. This is for example the case of:

- UNISIG (Alstom, Ansaldo STS, AZD Praha, Bombardier, CAF, MerMec, Siemens and Thales) in charge of monitoring the development of ERTMS;
- ERWA, the UNIFE Railway Wheels Committee, which currently comprises nine companies (Bochumer Verein Verkehrsstechnik, BONATRANS Group, CAF MiiRA, GHH Radsatz, Lucchini RS, Lucchini Sweden, Lucchini Unipart Rail, Lucchini Poland and LBX). All of them produce railway wheels and wheelsets in eight different European countries with deliveries to five continents.

All steps of the value chain are impacted by the technologies, from the initial concept to the construction, operation and maintenance of components and sub-systems:

http://www.unife.org/component/attachments/attachments.html?id=886&task=download
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

- initial concept and design of a new product or sub-system,
- detailed and final design,
- component/sub-system construction and/or implementation,
- system integration, until the system validation and acceptance,
- system operation,
- component, sub-system and system maintenance after they have been placed on the market or put into service.

All innovations presented above can have a positive impact on the level of demand, as they improve the performances, reliability, availability and therefore attractiveness of the rail systems. The savings in investment, operations and maintenance costs shall also allow increasing the level of supply (e.g. new trains, more trains, higher commercial speed etc.) at more competitive LCCs for the benefit of current and new customers and of European citizens as a whole (due to the sustainability of rail in comparison of other mobility modes).

On the manufacturing side, the incumbents are supporting the emergence and involvement of Small and Medium-sized Enterprises (SMEs) in the supply chain. One third of the membership of UNIFE is made of SMEs and UNIFE is permanently vocal in the support of the European Commission, European Parliament and European Council to SMEs and to reinforce skills development to overcome the shortage of skilled labour.

- Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain

On the supply side (the manufacturers), the drivers are mainly research and innovation, cooperation for developing standardization and common specifications, sharing data and experience.

On the demand side (the operators), the drivers are the cooperation:

- between the operators and the rail industry for delivering data, proposing test sites and suggesting protocols for testing components or sub-systems;
- between the operators for exchanging data and benchmarking information about the various technologies;
- between the industry and the public authorities at all level, in order to get additional funds and financing for developing innovative solutions (from research to operations), and in order to help overcoming where appropriate some barriers impeding or slowing the implementation of the new technologies;

Many institutional levels are involved in the development of rail systems, at local, national and European levels and their cooperation has to take into account the principle of subsidiarity: specific incentives must be developed at European level to facilitate the cooperation between the numerous legitimate institutional actors, especially towards harmonization and standardization where relevant.

Barriers are multiple and they maybe technical, institutional, social, environmental or financial:

- Legacy rail systems in most of EU countries have very different types of assets, and the lack of harmonisation is an obstacle for interoperability (mainline) for a competitive and attractive market (all rail segments).
- The objective of a Europe-wide interoperability of rail systems has to face the very different conditions of use of the rail infrastructure for environmental reasons (climatic conditions in Northern versus Southern Europe) or for business reasons (different rail market segments, different performances required between rail segments, different
performances required within a given rail segment for various territories at local, national or European level).

- Regulatory barriers exist between countries for introducing new products and techniques – i.e. national notified rules; national product acceptance processes; national standards; and specifications.
- Interfaces with other transport modes and other sectors are not well developed, i.e. energy interfaces with public grids including contractual conditions.
- On the political level, it is difficult to raise a long-term vision of rail needs, which reduces the potential uptake of innovative solutions.
- On the economical level, there is a lack of (or restricted) investment in the rail systems, due to their high cost and to the limitation in budgets of relevant institutions. Some existing contractual agreements framework can restrict the uptake of new technologies.
- On the competition side, rules enforcing the choice of the cheapest solutions are a barrier against the choice of the optimised LCC option.
- Some resistance to change is due to culture & competence of several stakeholders (from customers to authorities and railway companies, including their employees).
- Many different ways of working are used across Europe, which increases difficulty in making a universal incremental change or step-change.
- The expertise in rail excellence is ageing and retiring (or already retired), with some competences difficult to sustain for lack of attraction of the rail sector for students.

Cross-sectoral collaborations are already in place, but additional ones are necessary to overcome the existing barriers especially regarding:

- standardization and harmonization of specifications used along the value chain;
- cooperation between the different institutional levels within Europe and within countries.

Europe is still a world leader for all rail technologies, but has to face an increasing competition from countries which invest much more in the development of rail systems (especially China) and therefore are offered many more opportunities to develop their skill and competitiveness.

References

UNIFE World Rail Market Study 2014

RAIL 2050 – ERRAC

SHFT2RAIL Multi-Annual Action Plan (MAAP)

UNIFE Annual Report 2017


A Roadmap for Digital Railways.pdf rev - CER, CIT, EIM and UIC


Jet Engines That Know When Something’s Wrong—And Then Fix It - Benjamin D Katz - 5 février 2018

ANNEX: The Vision of ERRAC on Digitalisation

- Digitalisation is the instrumentation of assets, processes and personnel with powerful Information and Communications Technology (ICT) capabilities, able to sense, detect, process, receive, transmit and analyse digital information across secure, reliable and ubiquitous networks, making them all participants of a global “internet of things”;
- Distributed cognitive computing: endowing machines with the ability to become aware of and understand their surroundings, to recognize patterns, to generate meaningful insights from large amounts of distributed data, and to learn;
- Robotics: endowing machines with the ability to perform goal-oriented tasks autonomously;
- Taking into account data privacy management, relevant information is shared across the industry as a part of the data economy, enabling new services and applications for the benefit of the railway and its customers;
- Rail manages a growing volume of data contributing to the data economy. Collection, analysis, interpretation and prediction are automated to provide consistent up-to-date information, supporting fast, well-informed decisions and business benefits;
- This is achieved through a robust, resilient and secure self-diagnosing and self-healing information architecture;
- Intelligent trains are aware of themselves, their passengers/loads and their surroundings, know where they need to be and when, and can adjust journeys automatically to meet demand. In addition, they intelligently feed information about the infrastructure to support prescriptive maintenance;
- A network of fully-intelligent trains can be self-regulating in traffic, negotiating vehicle-to-vehicle and vehicle-to-X to determine movement priority and resolve potential conflicts at junctions in the network, and reacting to unexpected situations. The trains are also aware of and able to take account of the status of other transport modes.
- Combinations of autonomous, intelligent and highly responsive vehicles are able to communicate with each other and with the intelligent infrastructure, ensuring safe and reliable operations, while running closer together and contributing to reduce life-cycle costs substantially. This constitutes a successful deployment of the next generation of the traffic management systems such as European Railway Traffic Management System (ERTMS) and mass transit Communication Based Train Control (CBTC).
- Distributed operation management of autonomous trains allow for adaptive and accurate adjustments to transport demand patterns, dramatically increasing the capacity and flexibility of the rail transport system for all types of operations: urban rail, high speed, freight, rural and mass transit system.
- Fully automatic train operation, autonomous vehicles and intelligent remote-controlled systems guarantee an unprecedented level of safety.
- Autonomous operations also enable new types of mobility on rail, such as self-operated light pods/shuttles providing seamless interconnection across infrastructures.
- In urban areas, metros and light rail are the core of public transport for large volumes of passengers, complemented by a network of bus services and shared mobility options such as taxis, car-sharing, cycle-hire, ride-hail systems and individual vehicles/shuttles to take care of the last mile. Rail stations have turned into multimodal smart hubs which also include storing and charging facilities for electric vehicles of all sizes and sorts. For trips up to 1000 km, rail journeys connecting the major urban areas in Europe have become the norm.
4.4. Hydrail: hydrogen-powered trains

Sector/Mode of Transport: Rail/Rolling stock
SCORE: 2 Europe has neither a competitive advantage nor a competitive disadvantage

Management Summary

One of the most promising alternatives for diesel traction in the rail sector is the introduction of hydrogen fuel cells. Two regions in the world are currently leading in hydral developments: Europe and China. Nevertheless, it is difficult to determine which region is ahead of the other. In Europe, current developments of regional trains, with relatively high autonomy and speed (i.e., 1000 km and 140 km/h), are only concluding the trial phase and commercial services are expected in 2021. On the other hand, in China, urban applications of rolling stock with lower autonomy and speed (i.e., 100 km and 70 km/h) are reported to be in the operational phase since 2016.

Description of the main concept

The main energy sources for rail vehicles are either diesel or electricity. Even if the proportion of electric traction is high in some regions of the world (e.g., 80% in Europe), the majority of the worldwide energy demand for railway motive power is currently supplied by diesel (IEA/UIC, 2016). Nevertheless, diesel motors have problems such as low energy efficiency, CO2 and NOx emissions, heavy noise, and vibration. One of the most promising alternatives for diesel traction in the rail sector is the introduction of hydrogen fuel cells. Fuel cells generate electricity through a chemical process without explosion, noise and vibration. The railway vehicles powered by fuel cells have lower carbon dioxide emissions and lower energy consumption due to the high-efficiency of fuel cells. Moreover, the overall system has a long-life cycle and high reliability.

The term Hydrail, as a short form of hydrogen rail, has been coined to describe hydrogen-based rail vehicles. Hydrogen not only represents a clean energy source for mass transit that is better for the environment than diesel, but it is also less costly than building the overhead catenary infrastructure required by electric trains. Indeed, using hydrogen eliminates the need to electrify rail track networks that deliver electricity to locomotives in distant places. Other than the installation of hydrogen refueling stations, no additional infrastructure needs to be built, as the track system already exists. As hydrogen-powered vehicles are energy-autonomous, they can provide flexibility to railway networks that are either partially electrified or not electrified at all.

The dependence of an external source of energy can be taken further by combining hydrogen propulsion with energy storage systems and regenerative braking. The use of lighter materials, such as functionally-graded composition materials and multi-material assemblies, can also help to reduce weight and, therefore, reduce energy consumption.

According to Hydrogen Council (2017), by 2030, one in ten trains sold for currently non-electrified railways could be powered by hydrogen; and, by 2050, one in five trains running on non-electrified railways or one in ten trains overall could run on fuel cells. Hydrogen Council also estimates that hydrogen-powered trains have the potential to replace around 20% of the world’s diesel trains by 2050.

Analysis & Assessment of the impact on present industry structures

The recent Shell Hydrogen Study (see: Shell, 2017), which explores hydrogen as a future energy source for transport, show that hydrogen fuel cell systems are suitable for virtually all means of transport, but their technological maturity varies according to the means of transport and the way in which they are used.

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33 As hydrogen and oxygen can be combined to produce electrical energy and water without contamination at the point-of-use.
which it is used. In mobility applications of hydrogen, the longest and most extensive operational experience that is available relates to the bus segment. The technological components and operational experience developed and acquired in this segment have been somehow transferred to light rail vehicles. The study estimates that whereas urban rolling stock powered by hydrogen has already reached a relatively high technology readiness (TRL 7), the technology for shunting locomotives is still lagging behind somewhat (TRL 6 to 7). Conventional intercity passenger trains have also achieved a high technology readiness (TRL 7). A comparison with other transport modes is presented in the next Figure:

Figure 30: Technology readiness levels of mobility applications for hydrogen/fuel cells. Source: Shell (2017)

To date, there are demonstration projects for intercity trains in Germany, urban rail vehicles in China and shunting locomotives in the US. The remaining of this section gives an overview of the recent developments around the world for the three major regions: Europe, Asia and North America. Most of the information comes from internet sources which are cited in footnotes and referenced further in the references section.

Europe:

The European Rail Research Advisory Council (ERRAC), as a European Technology Platform and an advisory body to the European Commission and all European stakeholders, published in 2016 the sectoral technology and innovation roadmaps on common European R&D (see: ERRAC, 2016). These roadmaps intend to implement the Strategic Rail Research and Innovation Agenda (SRRIA). Regarding innovative propulsion systems, the roadmaps consider the implementation of hydrogen fuel cells (including the aspects of hydrogen production and storage) as a priority for research and innovation in the European railway sector (horizon 2015-2040), as well as onboard energy storage equipment and regenerative braking (horizon 2025). The application of fuel cells in the European railway market is, nevertheless, not foreseen before 2050 (ERRAC, 2011). The main problem being the production and storage of hydrogen and the high operation cost of the technology. Reliability, Availability, Maintenance and Service (RAMS) characteristics are seen as a critical point for applications in the railway domains.

It is important to note that hydrail can significantly contribute to the environmental and sustainability targets proposed by the ERRAC for the European railways (ERRAC, 2011):
Climate protection: By 2030, the European railways will reduce their specific average CO2 emissions from train operation by 50% compared to 1990. By 2050, the European railways will strive towards carbon-free train operation and provide society with a climate neutral transport alternative.

Energy efficiency: By 2030 the European railways will reduce their specific final energy consumption from train operation by 30% compared to 1990. By 2050, the European railways will strive towards halving their specific final energy consumption from train operation by 2050 compared to 1990.

Exhaust emissions: By 2030, the European railways will reduce their total exhaust emissions of NOx and PM10 by 40% compared to 2005. By 2050, the European railways will strive towards zero emission of nitrogen oxides (NOx) and particulate matter (PM10) from non-electric trains.

Another European initiative that is worth mentioning is the Hydrogen Trains Workshop (15 May 2017) organised by the European Fuel Cells and Hydrogen Joint Undertaking (FCH JU), Shift2Rail Joint Undertaking (S2R JU) and Hydrogen Fuel Cells and Electro-Mobility in European Regions (HyER). Participants concluded that hydrogen is a key alternative for decarbonising the rail sector but one of the challenges to address is to break the silo approach and combine funding sources. In this regard, a support programme for a large-scale deployment of fuel cell regional trains, including infrastructure with large scale storage of hydrogen, compression and fuelling stations would help to bring their total cost of ownership (TCO) down. It was identified that for regional trains, the challenge is to bring the TCO closer to the one of diesel trains (infrastructure and rolling stock). It is important to point out that, in the view of Hydrogen Council, hydrogen fuel-cell trains are already cost competitive with diesel trains from a TCO perspective (see: Hydrogen Council, 2017).

European developments at the country level:

At the European level, Germany is leading in hydral demonstrations with a regional train prototype that uses a fuel cell.\(^{34}\) The train, called the Coradia iLint and manufactured by Alstom (based on a previous diesel design), performed initial trials in early 2017 at 80km/h to confirm its stability and braking power. Subsequently, tests were completed at its maximum speed of 140 km/h. Line trials are expected to begin in spring 2018 and commercial services in 2021. Trains will be capable of operating up to 1000 km on a single tank of hydrogen with the refuelling process taking less than 15 minutes. A fleet of 14 Coradia iLint trains is expected to replace diesel trains on non-electrified routes in northwest Germany from 2021 onwards. There is a potential for the delivery of 30 further trains to other German regions that have also shown interest in this technology. On the other hand, Siemens has also announced to be working on the development of Mireo, a modular commuter train platform designed for speeds of up to 160 km/h using a fuel cell engine. Thanks to a lightweight design, energy-efficient components and intelligent onboard network management, Mireo would consume up to 25% less energy than trains with similar passenger capacity. The first line trials of the fuel cell-powered train are planned for 2021.\(^ {35}\) According to Railcolornews,\(^ {36}\) Siemens has currently two orders for its new Mireo platform train.

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Beyond Germany, the Netherlands also wants to test run the Alstom’s Coradia iLint train (in 2018), once full safety is demonstrated from the German tests. The Netherlands wants to determine whether a hydrogen-powered train will prove to be a cheap and sustainable alternative for the diesel trains now operating in two northern provinces where the rail network is not equipped with electric overhead lines. According to Smith (2018), Alstom sees significant opportunities for hydrogen applications in Britain (where there are currently 3003 DMU cars in service), Denmark (where there are 1000), the Netherlands (where there are 351) and Norway (where there are 95). Critically, it is targeting new rolling stock tenders rather than projects to retrofit existing vehicles.

In Spain, Ferrocarriles de Via Estrecha (FEVE) unveiled, in 2011, a tram powered by two hydrogen fuel cells that can carry between 20 and 30 passengers at up to 20 km/h. FEVE is also actively working on a narrow-gauge hydral train to connect the Northern provinces. RENFE (state-owned company that operates freight and passenger trains) and Alstom have recently participated in an EU proposal to the LIFE call to test the use of Hydrogen trains (FEVE 3100 model) in the national railway infrastructure relative to technical and economic viability (IEA HIC, 2017).

Studies have been carried out in other European countries. Denmark has been looking at a wind-to-hydrogen commuter rail line to link two cities since 2006. In 2012, a first hydrogen passenger train completed a pilot trip UK. In the UK also, a study between Fuel Cell Systems Ltd, the University of Birmingham and Hitachi Rail Europe concluded that hydrogen fuel cell technology can be successfully retrofitted to extend the life of existing rolling stock. It also established that fuel cells can provide a clean alternative for the next generation of self-powered regional trains in the UK. In Latvia, Latvian Railways (LDZ) signed, end of 2017, a memorandum of understanding with the manufacturer CZ Loko (Czech Republic) on the development of hydrogen fuel-cell powered shunting locomotives.

### Asia:

In China, the province of Qingdao deployed, in March 2016, its first fuel cell tram, which runs at about 70 km/h for about 100 km. Part of the route has been fitted with DC overhead electrification, but elsewhere the trams are powered by hydrogen fuel cells. The fuel tank can be recharged in around 3 min. CRRC Qingdao Sifang assembled the trams under licence from Škoda. In October 2017, a China-made (CRRC Tangshan) tram powered by hydrogen fuel cells entered into commercial operation in Tangshan. It can be refilled with hydrogen in 15 minutes and can run for 40 km at a maximum speed of 70 km/h. The city of Foshan has signed a contract for eight hydrogen-powered trams with Qingdao Sifang. The trams are expected to be operating by 2018 on the 7 km network, on which there are ten stops and one refuelling station. Each tram can be refilled with hydrogen in 3 min, which allows it to then run for 100 km at speeds as high as 70 km/h.

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39 See Fuel cell systems: Team shows fuel cells can be used to power UK trains. http://www.fuelcellsystems.co.uk/team-shows-fuel-cells-can-used-power-uk-trains/


In Japan, back in 2006, two companies were in battle for the honour of running the first fuel-cell locomotive on a passenger line: the East Japan Railway Company (EJRC) and the Tokyo’s Railway Technical Research Institute (RTRI) (see: IEEE Spectrum, 2006). Leading the way, the EJRC announced, in April 2006, to have scheduled basic performance and safety tests on a hybrid model using fuel cells and diesel engines in July 2006 and planned running tests on an actual service line in April 2007. Surprisingly, the company does not seem to have communicated further on the issue after that. According to Hoffrichter (2013), issues such as the equipment size, costs, and fuel cell lifetimes prevented the project from going commercial. On the other side, RTRI has announced to have begun test runs on a hydrogen-powered train only in August 2017. The first production-model trains are expected to be used in rural areas currently served by diesel trains.

North America:

In the US, a public-private consortium (in collaboration with BNSF Railway and the U.S. military) developed, in 2009, a prototype PEM-based fuel-cell hybrid switcher locomotive.

In the light of this evidence, we can conclude that there are two regions leading in hydrail developments: Europe and China. Nevertheless, it is difficult to determine which region is ahead of the other. In Europe, current developments of regional trains, with relatively high autonomy and speed (i.e., 1000 km and 140 km/h), are only concluding the trial phase and commercial services are expected in 2021. On the other hand, in China, urban applications of rolling stock with lower autonomy and speed (i.e., 100 km and 70 km/h) are reported to be in the operational phase since 2016.

- Analysis and assessment of the impact of Disruptive Technologies on present value chain

Given the low anticipated rail fuel cell volumes, hydrogen trains are expected to use the same heavy duty stacks and storage tanks used for buses and lorries (Hydrogen Council, 2017). Hence, cost reductions will be mainly driven by developments in the automotive sector. Some companies from the automotive supply chain are developing fuel cell technologies, in part to understand better the methods by which they can be produced, but also with the intention of supplying other types of vehicles (E4tech, 2015). A coordinated effort is, therefore, required to catalyse improvements in both industries. This need for coordination and collaboration is not only essential for the automotive and railway supply chains, but should also be extended to the hydrogen industry. As stated earlier, the silo approach should be broken as combining efforts might allow to take maximum advantage of the benefits.

In this respect, it is worth noting that Europe has lagged behind Asia and North America in developing hydrogen fuel cells for automotive applications. Indeed, the vast majority of hydrogen fuel cell vehicles on Europe’s roads today rely on fuel cell stacks from overseas companies (Japan, Canada and the United States) and the same is true for the railway sector. European rolling stock manufacturers have mainly used overseas fuel-cell technologies in developing hydrogen-powered trains. For instance, Alstom uses technology from the Canadian Hydrogenics with whom they have agreed on a 10-year deal for the fuel cells for the Coradia iLint train (including the supply of fuel cell systems, service and

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D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

maintenance). Similarly, Siemens signed a multi-year development agreement with the Canadian Ballard for fuel cell engine of the Mireo platform train.46

This reliance on foreign technology is not only specific to the European industry. Chinese hydrogen-based railway developments are also based on foreign technology. Ballard has gained sizable orders of fuel cells for trams, trains and buses in China. In 2015, Ballard signed a framework agreement with CRRC Tangshan for the development of a new fuel cell module for tram or ground transport vehicle applications. Later the same year, Ballard signed a joint development agreement and a supply agreement to develop and commercialise a fuel cell for integration into the trams manufactured by CRRC Qingdao Sifang.47 Ballard further announced a license and supply agreement to support the deployment of fuel cell-powered buses in the cities of Foshan and Yunfu, after an earlier agreement for the delivery of power modules for use in fuel cell buses to be deployed in Yunfu and Rugao (E4tech, 2015).

Beyond the fuel cell technology, another critical issue from a value chain perspective is the supply of hydrogen for refuelling at a depot scale. For hydrogen to be a viable fuel for rail in the medium term, infrastructure for fuel production, storage and distribution is required. Providing fuel for a full fleet of hydrogen-powered trains creates new challenges. As hydrogen can be either produced on-site or delivered from a different facility (off-site production), decisions on the procurement scheme are crucial. Engaging in production is not the same as choosing the delivery of hydrogen from an external supplier. In Germany, for instance, dedicated hydrogen refuelling facilities will be installed by the gas supplier Linde Group and funded with the aid of a grant (around 80%) from the German federal government's National Innovation Programme for Hydrogen and Fuel Cell Technology. It is expected that, in a later phase of the project, hydrogen will be produced on-site using electrolysis with a wind turbine providing power for the process.48 Large scale depot refuelling imposes significant new challenges that need to be understood by actors in the supply chain. Unfortunately, the issue has not yet been broadly tackled by specialised literature which has mainly focused on refuelling for cars. This has been recognised by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) who funded the NewBusFuel study (2015-2017) with the aim of resolving the knowledge gap for establishment of large-scale hydrogen refuelling infrastructure for fuel cell buses. The insights and recommendations provided by the study can certainly be transferred to the rail sector (for details, see Reuter et al. 2017).

- Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain

The table below presents the main drivers and barriers related to the adoption of hydraid by EU manufacturing businesses.

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Drivers</th>
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<tr>
<td>Environmental context</td>
<td>• Recyclability of components (both fuel cells and energy storage devices)</td>
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<tr>
<td>• Environmental and sustainability targets for transport</td>
<td></td>
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<tr>
<td>• Policy incentives pushing towards hydrogen deployment</td>
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Organisational and societal context

- Safety and security concerns (an incident can damage the public acceptance of hydrogen/fuel cell vehicles)
- Public resistance to hydrogen infrastructure developments (e.g. pipelines for distribution)
- Regulation (e.g. incident risks in confined environments such as metros or tunnels), railway standards and safety regulations
- Costs and implementation of infrastructure and logistics for hydrogen production and provision
- Overall cost per kW produced by fuel cells
- Recycling and disposal costs
- Lack of hydrogen distribution infrastructure
- Environmental awareness
- Security of energy supply concerns
- High cost of overhead catenary infrastructure

Technological context

- Concerns about energy autonomy
- Reliability level required by railway systems
- Lifetime and maintenance requirements
- Concerns about traction power (e.g. for freight large fuel cells will be required)
- Onboard weight and space requirements
- Environmental awareness
- Security of energy supply concerns
- High cost of overhead catenary infrastructure

Figure 31: Barriers and Drivers for developing of autonomous trains. Source: Own elaboration

References


D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry


D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry


5. **Shipbuilding**

The following key technological trends and innovative concepts have been assessed in terms of their impact in the current value chains and the success factors for implementing new technologies:

- **Electrical propulsion & hybrid power supply**
  Electric propulsion systems and hybrid systems applied in vessels. How competitive is European shipbuilding sector in this technology?

- **Deep sea mining vessel or production support vessels (PSV) as new ship type development**
  Which basic and complement technologies are required to operate and maintain autonomous vessels while decreasing the time, ships need to stay in the harbour?

- **Advanced emission abatement technology for shipping addressing the introduction of Emission Controlled Areas (ECAs) for NOx and SOx and of the global sulphur cap for ship fuel**
  Advanced emission abatement technology for shipping addressing the introduction of Emission Controlled Areas (ECAs) for NOx and SOx and of the global sulphur cap for ship fuel

- **Smart ship**
  The innovative concept of the new generation of the ship using a range of technological solutions
5.1. Electrical propulsion & hybrid power supply

**Technological solution:** Electric propulsion systems

**Sector/Mode of Transport:** Shipbuilding

**SCORE:** 3 Europe has a competitive advantage in comparison

**Management Summary**

Historically, the propulsion system of the ship and the ship's power supply system were separate systems. The propulsion system in the classical system consisted of an internal combustion engine, propeller shaft and propeller. In turn, the classic power supply system consisted of a combustion engine and a direct or alternating current generator (power generator) and a main switchboard. The search for more optimal technical solutions for the indicated systems was associated on the one hand with adapting both systems to the needs of different types of ships and associated navigational and maneuvering abilities, and on the other with lowering the operating costs of the ship and reducing exhaust and heat emissions.

For the European shipbuilding industry, which has a competitive advantage in the construction of technically complex vessels, in the sectors of specialized vessels (high-value ships such as ferries, cruisers, offshore service vessels), the key was the development of technologies necessary for the further development of the electrical propulsion & hybrid power supply system that can evolve in the future in the electrical propulsion & electrical power supply integrated system.

Applied already in ships built in Europe, the electrical propulsion & hybrid power supply system allows European suppliers of these systems and production shipyards to build specialized units in ship sectors where European shipbuilding has gained a competitive advantage in recent years. The next generations of propulsion & powering systems using new technologies necessary for their construction and use on sea-going ships allow for the supply of personalized integrated propulsion & powering systems to ship-owners, meeting the postulate of adjusting the European shipbuilding offer to the expected demand from ship-owners.

The implementation of the integrated electrical propulsion & hybrid power supply system by European Tier 1 suppliers, in cooperation with ship-owners and shipyards, strengthens cooperation in the triangle of the ship-owner, suppliers and shipyards where this cooperation is often transformed from typically commercial to capital to establish permanent organizational and capital links in the ship's formation processes, from the concept to the handing over of the vessel to operation strictly as it is expected by the ship-owner. The implementation of the demand for specific ships by the European shipbuilding industry strengthens the position of this sector on the global market of specialized vessels such as: ferries, cruisers, service and task vessels, offshore constructions. This is especially true for European Tier 1 suppliers of systems and European suppliers of integrators of various ship systems.

It should be noted here that another factor strengthening the competitive position of European shipbuilding related to the implementation of the integrated system of electrical propulsion & hybrid power supply is the fact that the system meets not only increasingly stringent environmental requirements in force in the EU at the same time becoming more and more ecological awareness of European ship-owners.

**Description of the main concept**

Figure 32 presents a ro-ro ship, on which the part of the ship in which the propulsion and powering systems are located is indicated. As indicated in the management summary, the evolution of ship's structure resulting from the requirements of ship-owners and environmental restrictions has led to the
construction and implementation of a group of integrated propulsion & powering systems, which create the following solutions:

- Electrical propeller & electrochemical power system,
- Electrical propulsion & hybrid power supply,
- Hybrid propulsion & hybrid power supply,
- Electrical propulsion & hybrid power supply,
- Hybrid propulsion & DC hybrid power supply.

Figure 32 Ro-ro vessel with an indication of the location of propulsion and powering systems.


The propulsion & powering system that is essential for the competitiveness of European shipbuilding is the Electrical propulsion & hybrid power supply system. This is due to the fact that this system is optimal for the types of ships under construction which European shipbuilding has a strong competitive position on the global shipbuilding market. These are cruisers, ferries, tugs, service ships for the maritime mining industry, and small short sea shipping vessels. Figure 33 presents the Electrical propulsion & hybrid power supply system with an indication of the direction of its further evolution.

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Integrated Electrical propulsion & hybrid power supply system presented in Figure 33 was originally used on submarines. For more than ten years, this system has been developed in the direction of increasing its efficiency, reducing operating costs, reducing emissions and heat as well as the autonomy of processes implemented by the system. Currently, it is used on many ships built in Europe characterized by high added value: cruisers, ferries and ro-ro vessels, service ships, tugs where the system is constantly improved while building new ships.

The implementation of new technical solutions and the application of new technologies in the Electrical propulsion & hybrid power supply system concern such areas as:

1. Power generators.
2. Electric power system.
3. Control and management of the system.

The fourth area of the system which is the propulsion is in principle not subject to technological changes at this stage. Of course, research activities related to increasing the overall efficiency of propulsion systems are continuing by reducing losses between energy supplied to the system and energy converted into work, but the technologies used to build propulsion systems do not change. The complex systems of electric motors and propulsors currently used on many specialized ships are subjected to improvements, but the technologies used for their construction and operating principles do not change.

Ad 1 – 3.

The basis for the production of electricity on sea-going vessels are power generators. When propulsion and powering systems were separate systems, the produced electricity served to supply all ship systems and subsystems necessary for its proper operation. Replacing the traditional mechanical propulsion system consisting mainly of the main diesel engine, propulsion shaft and propeller, propulsor system with its own electric motors has led to the situation where the propulsion system must also be supplied with electricity from power generators. In practice, for many types of ships, this
meant combining propulsion and powering into one system. A system with high flexibility in the use of electricity produced and thus optimization of fuel consumption.

In the 1990s, due to the tightening environmental regulations in the field of exhaust emissions as well as postulates from ship owners (demand), work on changes in the construction of power generators began in the shipbuilding sector, focusing on the optimization of combustion processes and, from the beginning of the 21st century, on the use of different fuels for combustion other than traditional diesel fuels and on the storage of surplus energy produced in order to use it at times of increased demand of ship's systems on it.

As a result, using the research of the R & D sector and new combustion technologies allowing using a different fuel than the traditional one, an electric-hybrid system was constructed and started to be used on specialized ships, such as: ferries, tugs, offshore service ships. This system is the subject of research in the R & D sector, which allows for constant changes in technical solutions where new technologies are gradually implemented for sources of energy needed to operate systems. The basic configuration of the system, where different technical solutions are used, are:

1. Power generators where the combustion engine is an engine (variant):
   - powered by diesel oil,
   - powered by compressed natural gas (CNG),
   - powered by liquid natural gas (LNG),
   - dual fuel, which is adapted to the combustion of both diesel and natural gas.

2. Batteries charged from:
   - power generators,
   - land-based energy charging points,
   - solar batteries installed on the ship.

3. Control and management of the system:
   - main switchboard,
   - automatic control of the operation of individual devices,
   - automatic control of the operation of the entire production and electricity consumption system,
   - intelligent control and production management systems and energy consumption.

Forecasted directions of technological evolution of the Electrical propulsion & hybrid power supply system:
   - replacement of power generators with fuel cells,
   - new generation batteries with a much higher energy capacity that allows for the abandonment of power generators on vessels sailing on closed waters at small distances, eg double-end ferries.

The essence of the integrated Electrical propulsion & hybrid power supply system is that it is subject to continuous evolution where, as discussed above, new technical and technological solutions are implemented that allow for continuous optimization of the operating costs of the system and thus the ship.

The current level of technological advancement and technical and production potential of the European shipbuilding sector allows us to meet the demand from ship owners on ships with an integrated Electrical propulsion & hybrid power supply system. As indicated earlier in the part of the SCORE project "D2.1 Technical Analysis", the correlation of the development strategy of the European shipbuilding sector with the EU 2020 Strategy enabled the sector to reach a global level in technologies used in the production of ship systems and ships as a whole and the potential to meet the demand for modern very complex ships in selected sectors indicated in "D2.1 Technical Analysis".
Analysis & Assessment of the impact on present industry structures

Introduction of the integrated Electrical Propulsion & Hybrid Power Supply to the operation was a response of the shipbuilding sector to a specific demand from ship owners, where the key issues were reducing the costs of vessel operation (lower fuel consumption, reducing ship crews) and reducing greenhouse gas emissions and environmentally harmful compounds chemical. The implementation of the postulates offered by ship owners led to the implementation on ships of variously configured Electrical Propulsion & Hybrid Power Supply system's adequately to the nature of the ship's operation and its tasks.

The implementation of the Electrical propulsion & hybrid power supply system was possible due to the high technological advancement and reliability of technical solutions, which together meets the condition of system efficiency at the level expected by ship owners and ship users. Table 1 presents the TRL level for the system as a whole and its key elements.

Table 1 TRL of the system as a whole and its individual components

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<th>TRL reasons</th>
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<td>8</td>
<td>The system is used on various types of ships with the efficiency level postulated at the design stage and then integrated on a specific ship</td>
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Key elements Electrical propulsion & hybrid power supply system

Power generators where the internal combustion engine is:

- powered by diesel: 8 A classic internal combustion engine with a high level of reliability
- powered by compressed natural gas (CNG): 8 Internal combustion engine with CNG combustion technology tested in the operation of the ship; construction technology of tanks as well as the system of pipelines and power control devices tested in the operation of the ship
- powered by liquid natural gas (LNG): 9 Combustion engine with LNG combustion technology tested in operating conditions; construction technology of tanks as well as the system of pipelines and power control devices tested in the operation of the ship
- dual-fuel, which is adapted to the combustion of both diesel and natural gas: 9 An internal combustion engine adapted for the combustion of diesel oil and natural gas, tested in the ship's operating conditions; tank construction technology for both types of fuel and pipeline systems as well as fuel change systems delivered to the engine, tested in the operation of the ship

Charging the battery with power generators: 8 Proven and used for a long time battery charging technology in the operating conditions of the ship

Charging the battery with land-based energy charging points: 8 Proven and used, but not for a long time, battery charging technology in the operating conditions of the ship but on a small number; it still requires an analysis of efficiency and reliability in the long run

Charging the battery with solar batteries installed on the ship: 8 Proven and used for a long time battery charging technology in environments other than a ship; recently used on ships; it still requires an analysis of efficiency and reliability in the long run

Control and management of the system:
- main switchboard: 8 Proven and used technology of the central collection point of produced / stored electricity and its distribution to the
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

automatic control of the operation of individual devices, 9 Proven and used technology in ship’s operating conditions

automatic control of the operation of the entire production and electricity consumption system, 9 Proven and used technology in ship’s operating conditions

intelligent control and production management systems and energy consumption. 7 Recently, systems that are tested and used in the operation of the ship, being an extension of the technology of automation control of the operation of the subsystem of the electricity production / storage system and its distribution; their essence is to bring autonomy to the Electrical propulsion & hybrid power supply system thanks to the use of intelligent control systems and management of the analyzed system

Directions of technological evolution of selected system elements

- fuel cells instead of power generators 7 Technology tested in other industry sectors for several years in the ship’s environment; introduction of fuel cells on ships instead of power generators will depend only on the economic efficiency of fuel cells
- new generation batteries with a much larger energy capacity that allows for the abandonment of power generators 6 Future technology that will allow the abandonment of power generators and fuel cells or leave these devices as an emergency technology for the production of electricity; the shipbuilding sector has the potential to introduce a new type of batteries that will be developed and tested by the R & D sector

Sources: own work

When analyzing the degree of advancement of individual technologies used in the Electrical Propulsion & Hybrid Power Supply system expected for future use, it can be stated that they are part of the EU 2020 Strategy, especially meeting milestones included in EU programs concerning new technologies and environmental programs forcing new proecological technologies and technical solutions such as \textsuperscript{50,51,52,53}:  

- automation and robotization of technical processes in production and transport,
- intelligent control systems being the stage of creating "artificial intelligence", which will manage processes, production, devices or means of transport,
- low-emission and resource-efficient propulsion systems,
- low-emission and resource-efficient electricity production and storage systems,
- electromobility.

According to Table 1, the directions of the technological evolution of the Electrical propulsion & hybrid power supply system are:

- replacement of power generators with fuel cells,

\textsuperscript{51} LeaderSHIP 2020 The Sea, New Opportunities for the Future Brussels, 20th of February 2013
\textsuperscript{53} WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, EUROPEAN COMMISSION Brussels, 28.3.2011
the use of new generation batteries with a much larger energy capacity that allows for the abandonment of power generators on ships used in closed waters,

improving the technology of intelligent production management systems and electricity consumption as a component of construction and handing over for operation, in stages, of remote controlled vessels, and ultimately autonomous vessels,

i.e. new technical solutions where the applied technologies are developed by the European R&D&I sector, which is a key element of the EU 2020 strategy.

The main suppliers of Electrical propulsion & hybrid power supply components are generally enterprises that are Tier 1 suppliers in the ship value chain. For the most part, they are global players in the global market of system and component suppliers, where a significant part of them has its main headquarters in Europe. Below are the main players on the market of equipment and systems with the country of the company's headquarters given in brackets:

- Caterpilar Marine Power System (Germany),
- GE Power Conversion (France),
- Hynday Heavy Industries Engine & Machinery Division (South Korea),
- MAN Diesek & Turbo Germany),
- Rolls-Royce Marine (United Kingdom),
- Schneider Electric (France),
- Siemens Marine Solutions (Germany)
- Wartsila (Finland),
- ZF Fridrichshafen AG Marine Propulsion System (Germany).

The above list clearly illustrates the competitive advantage of the European shipbuilding sector in the supplier sub-sector as most suppliers of system components as well as complete Electrical Propulsion & Hybrid Power Supply systems are European companies that are the main players in the global market of the analysed system. What is important, they are the regular players on these markets. These enterprises have developed a significant competitive advantage on the market and thanks to the development and implementation of new technologies in the production of ship equipment and systems, they are and will be in the next years global leaders in the supply of next generation components as well as complete Electrical propulsion & hybrid power supply systems.

- **Analysis and assessment of the impact of Disruptive Technologies on present value chain**

Figure 34 presents the scheme of implementation of new technical solutions using new technologies in the value chain of the shipbuilding. The integrated Electrical Propulsion & Hybrid Power Supply system, implemented over the last few years, is part of the continuous increase in the added value of the ship's production, added value for both the shipowner and the shipbuilding sector. According to the schemes in Figure 34, system components are manufactured by Tier 2 suppliers (Part II) and the integration of the system as a whole is made by the Tier 1 suppliers (Part II), who assemble the entire system on ship in shipyards (Part III).

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Figure 34 The scheme of system of implementation of new technical solutions using new technologies in the value chain of the shipbuilding

Source: own study; the figure used in D2.1 Mapping of the current status of dynamics of value chain of European transport manufacturing industry, chapter 5

The integrated Electrical propulsion & hybrid power supply system is a system where new technologies do not cause rapid, revolutionary transformation and are technologies that improve this system continuously increasing the efficiency of the value chain, successively creating added value from Tier 1 and 2 suppliers who, on equal to ship-owners, are significant beneficiaries of the implemented solutions.

In the context of the value chain created in the ship's production process, from materials to the finished ship for the ship owner, it should be pointed out that the evolution of Electrical propulsion & hybrid power supply is a process that requires close cooperation of suppliers - system and system components manufacturers with ship-owners who, on equal to suppliers, are the beneficiaries of the value added arising in the ship's production value chain. This creates a situation that has in the past been a factor in creating a clustered system of business dependencies in the value chain where the "win-win" principle applies.

The principle of a cluster system of enterprises in production and service processes, widely introduced in the European maritime economy, gave it a strong position in the global maritime economy. The authors of the study *The role of Maritime Clusters to enhance the strength and development of European maritime sectors* explain the important advantages of a cluster enterprise system in

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55 *The role of Maritime Clusters to enhance the strength and development of European maritime sectors*, Report on results, Commissioned by the European Commission (DG MARE), November 2008
production and service processes. The authors point to the fact that the European shipbuilding industry has achieved the highest global financial turnover over most of the last decade. This illustrates how important for European shipbuilding is a cluster-based system of operation according to the "win-win" principle combined with the ability to absorb new technologies arising both within and outside the shipbuilding sector in the European and the global R&D&I sector.

The cluster ship production system in Europe, within the meaning of the set of processes ranging from processing the raw material to a finished ship built in accordance with the shipowner's order, favours the innovation of the shipbuilding sector. Referring to the Electrical propulsion & hybrid power supply system, it should be pointed out that its continuous improvement through the use of new technologies increases the added value of which suppliers, shipyards and ship-owners are beneficiaries. As a result, the shipbuilding sector in Europe represents a potential that is able to meet the demand from ship-owners for new generations of the Electrical propulsion & hybrid power supply system equipped with new technical solutions presented in Table 1.

- **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

As previously indicated, the key success factors for implementing new technologies in the Electrical propulsion & hybrid power supply system are:

- EU policy in building a pro-innovative European economy as a key to improving the competitive position of the European economy,
- environmental policy of the EU and a number of European countries aimed at minimizing greenhouse gas emissions, heat and harmful chemical compounds,
- demand from ship-owners focused on continuous reduction of operating costs of vessels, both those related to the operation of technical systems of the ship as well as the direct and indirect costs related to the size of crews,
- wide use by Tier 1 and 2 suppliers as well as the shipyards of new technologies and new technical solutions developed by both the European and American and Asian R&D sector for various sectors of the economy where the shipbuilding sector absorbs new technologies and new technical solutions in the ships production.

As previously indicated, lasting for several years evolution of the Electrical propulsion & hybrid power supply system, aimed at continuous improvement of its efficiency and reducing emission and ultimately reaching the Electrical propulsion & electric power supply system, is a process that does not show barriers in the area of technology, technical solutions, EU development policy or restrictions on the part of ship-owners. It is also important that a number of technical solutions used and planned for use in the Electrical propulsion & hybrid power supply system are solutions implemented also in the production of other means of transport. There are two reasons. One is the versatility of the technologies so that they can be used in various sectors of the economy, or, referring to the SCORE project, the production of various means of transport. Example is the hybrid propulsion and power generation system currently used in the production and operation of cars. The implementation of this system in shipbuilding is an example of cross-sectoral cooperation and cross-sectoral technology flows. Another example are fuel cells. This is the technology developed by car manufacturers, Tier 1 and 2 suppliers in shipbuilding or companies in the aircraft production sector. Example of the development of fuel cells is a classic example of intersectorial cooperation that is beneficial for everyone due to the principles of creating benefits for each stakeholder.
References

The role of Maritime Clusters to enhance the strength and development of European maritime sectors, Report on results, Commissioned by the European Commission (DG MARE), November 2008.


LeaderSHIP 2020 The Sea, New Opportunities for the Future Brussels, 20th of February 2013


WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, EUROPEAN COMMISSION Brussels, 28.3.2011,


5.2. Deep sea mining vessel or production support vessels (PSV) as new ship type development

**Sector/Mode of Transport:** Shipbuilding

**SCORE:** 3 Europe has a competitive advantage in comparison

**Management summary**

Deep sea mining is regarded as potential for new sources of metals and rare earth elements and covers the technology-intensive processes of exploration, exploitation, extraction, mining and processing. Commercial deep sea mining is still in the early beginning in international seas and within Exclusive Economic Zones (EEZs) of many coastal nations. It is legally organised by the International Seabed Authority (ISA), under the U.N. Convention on Law of the Sea (UNCLOS).

Specifically high-technology designed deep sea mining or production support vessels (PSV) vessels play a crucial role in the process as it serves e.g. as dispatching system, storage buffer, preprocessing facility like for dewatering and accommodation – and present a mix of drilling vessel, bulk carrier, tanker, and offshore construction vessel.

Recently, the first deep sea mining vessels has been built by the Chinese shipyard Fujian Mawei Shipbuilding and is equipped by Rolls Royce diesel engines. The vessel is expected start operating in 2018. Based on the advance made in economically viable deep sea mining, these specific vessel types has been considered as an opportunity for the European shipbuilding companies to gain a high market share in such a niche market – comparable to other niches like cruise shipbuilding and emission abatement technologies.

**Description of the main concept**

Today, deep sea mining is regarded as important potential of new sources of metals and rare earth elements comprising technology-intensive processes of exploration, exploitation, extraction, mining and processing. Since the turn of the millennium, a number of parameters have pushed deep sea mining from a theoretical and scientific approach to a feasible option of primary production.

A rising worldwide demand for these sources like inter alia for manganese nodules, copper, cobalt, nickel, lithium, silver and other rare earth and metals derives inter alia from emerging countries, new technologies and renewable energies. An electrified and digitalised but also sustainable society demands metals and rare earth which are currently still covered by mining from land sources and to a small but growing degree by recycling processes. As deep sea mining is considered to may cause harmful ecological impacts, extensive work has been done for mapping ocean floor eco-systems and to analyse and develop processes to minimise negative impacts on the environment.

Legally the exploitation of deep sea mining sources outside national responsibilities is regulated by the International Seabed Authority (ISA) which was established in 1994 under the U.N. Convention on Law of the Sea (UNCLOS). ISA shall ensure severe rules and procedures in order to avoid and control pollution and other risks to the sensible marine environment systems – and to provide an environmental friendly legal framework.

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56 [http://www.xinhuanet.com/english/2017-09/21/c_136627203.htm](http://www.xinhuanet.com/english/2017-09/21/c_136627203.htm)

57 [Feasibility of Deep-Sea Mining Operation within Norwegian Jurisdiction, Norwegian University of Science and Technology (NTNU), Trondheim, 2016](https://www.ntnu.no/en/)

58 [https://www.isa.org.jm/authority](https://www.isa.org.jm/authority)
Technically, substantial challenges like an increase of economical efficiency, optimisation of environmental sustainability, energy provision and the development of intelligent systems for largely autonomous production processes are still to be successfully tackled as preconditions for an overall economic viability but also sustainability of deep sea mining. However, essential technological progress like in the offshore oil and gas industries exploiting sources from ever deeper sea contributed to the fact that a number of the technical challenges in deep sea mining have been solved already.

This situation of technological advance and feasibilities as well as the potential to achieve an economic viability has triggered a motivation of the business sector and the national governments to strongly support the development of the deep sea mining industry. Therefore, provided that the environmental related risks and concerns will be successfully tackled and economical and financial issues overcome, deep sea mining is expected to become commonly acknowledged as an alternative for the provision of metal and rare earths in the long-run.\(^59\)

The required type of vessels have an essential role for the deep sea mining development as it has to support the surface as well as the subsea mining operations. The current vessel types belonging to the fleet group of mining vessels were built in the mid-eighties and before and had a maximum of about 6,500 DWT.\(^60\) The new required vessel type is a kind of combined drillship, bulker and offshore construction vessel offering also refinery and processing facilities. The current vessel built by Fujian Mawei Shipbuilding fulfils these requirements and has been declared as the ‘world first deep sea mining vessels’ which is expected to become operational in 2018. The dimensions with a length of 227 m, a width of 40 m and 45,000 DWT clearly outperform the vessels currently under the heading of ‘mining vessels’. The vessel provides advanced technologies for working depths of 2.5 kilometers, and comprises also deep sea mining robots, a deep sea lift system, a water-storage system and a cargo-loading system. Accommodation and working areas are provided for 200 people. Costs running up to around 500 million U.S. dollars and the vessel is ordered by a Canadian mining company to be used for deep sea mining for metal ore in the West Pacific.

The current market prospects are considered as quite positive even if market potentials are hardly to assess. Shipbuilding is a diverted demand for shipping operations and shipping in turn is a diverted demand for global trade or in this specific use case for the feasibility of a further positive deep sea mining development in terms of economical, environmental and political feasibility. In a recently finalised study on new trends in globalisation in shipbuilding and marine supplies or the European Commission on the development of shipbuilding it has been acknowledged that then potentials of blue growth markets like deep sea mining offers shipyards and its supply industry access to new markets and market niches.\(^61\) Based on the technological strengths of the European shipbuilding sector opportunities particularly in pre-mature markets exist which needs to be strongly supported by research and developments strategies. The study estimated an annual potential of 5-12 bn from 2025 for the shipbuilding and supply sector related to deep sea mining or production support vessels (PSV) vessels and technologies. This indicates that in this total context also deep sea mining vessel will show a high technology based market potential.

Analysis & Assessment of the impact on present industry structures:

The current situation in the development of deep sea mining vessels is dominated by the first deep sea mining vessels built by Fujian Mawei Shipbuilding and to be operated by Nautilus Minerals Inc. The vessel is to be deployed for the Solwara I project aiming at exploiting of seafloor massive sulphide

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59 Blue growth – scenarios and drivers for sustainable growth from the oceans, seas and coast, Ecory, a.o., Rotterdam, 2012

60 ISL Fleet Database, Bremen, 2017

sources in a volcanic surrounding. The Solwara 1 project has been running for many years and a number of financial and economic problems have not been solved while concerns on negative environmental impacts are still present. However, the Solwara 1 project has been considered as a crucial reference project for the future development of deep sea mining in terms of economic viability and environmental sustainability.

So, even if the first deep sea mining vessel acting as benchmarking for this new market niche can be regarded as TRL8, the maturity of the deep sea mining market is still to be assessed as pre-mature showing opportunities for the actors involved and hence for the shipbuilding sector but also essential threats that require innovative and technologically based solutions. Thus, designing deep sea mining support and production vessels has been targeted in a number of EU projects dealing like ‘MIDAS’, ‘Blue Alantis’ and ‘Blue Nodules’. A remarkable conclusion from the MIDAS which tackled the issue of environmental risks and impacts from deep sea mining is that there are numerous companies in the offshore sector which could contribute to the further development from their knowledge and technological know-how and which are moreover obviously interested in this market. However, given the uncertainties of environmental hazards they have preferred to be only in a observer that in a driver seat position. Hence, given the existing uncertainties in the deep sea mining sector, rather scenarios are more adequate than a roadmap.

Given the role of the Solwara I project, a potential scenario deals with the economical failure of the project which leads to a stop or to a delay in commercial exploitation of deep sea mining of at least 20 years depending on the technological advance.

An alternative scenario is defined by the assumption that ongoing projects in deep sea mining will be successful, the current geo-political situation with the U.S and China as economical world leaders with lower ambitions in environmental protection and the strategic role of deep sea raw materials. Such a framework provides the potential of having a deep sea mining market clearly dominated by the U.S and China – both strongly supporting their national companies politically and economically. This would have a negative impact on EU companies involved in this sector and their market shares due to the fact that the EU shows disunity in terms of a common industry policy and foreign affairs.

A positive scenario for the European deep sea mining sector assumes that deep sea mining becomes commercially viable and ecologically sustainable – and that the European companies are able to safeguard their technological advance with the support from the EU and national governments in terms of resources for research – like e.g. in shipbuilding-related technologies – which leads to high market shares also in the shipbuilding and supply sector.

- **Analysis and assessment of the impact of Disruptive Technologies on present value chain**

A competitive advantage for the European shipbuilding industry is certainly the still existing advance in high technology niches as e.g. in the cruise sector or related to emission abatement technologies.

As besides the issue of exploitation also the exploration of deep sea mining is a crucial issue for the future development, research still will have a strong role. Here, the market share in the research vessels segment gives an indication about the competitiveness of the European shipbuilding sector in this potential new market - also despite the fact that the first deep sea mining vessel has been built by a Chinese shipyard. As of July 2017, the EU and Norwegian shipbuilding sector had a share of 55% in the operating research vessel fleet and a share of about 44% in the two segments research vessels...
and offshore vessels. Additionally, European companies have a leading role in other technology-intensive segments like cruise shipbuilding and emission abatement technologies.

As the requirements from deep sea mining along the value chain are quite broad, i.e. comprising exploration, extraction, transportation and processing, actors in the shipbuilding value chain might find new opportunities for cooperation as a kind of overlappings in both value chains. The given characteristics of a deep sea mining vessel - i.e. serving as dispatching system, storage buffer, pre-processing facility like for dewatering and accommodation - extent the function of such a vessel and require additional input into the current the shipbuilding value chain.

Despite the strong position of the European shipbuilding sector in high-technology based niches, the uncertainties in the deep sea mining sector might provide threats which depend clearly on the future direction of this sector. Taking into account the three potential scenarios, threats may occur from different sides, e.g. from strong national industry policies either in favour or against the European shipbuilding industry or technological immaturity.

- **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

As explained with regard to a potential roadmap for the overall development of deep sea mining, a reliable forecast for a deep sea mining vessel market is not feasible.

Policy is an essential driver for deep sea mining and the required niche for adequate vessels – either in a classical sense in terms of industrial policy or in a more aggressive way in order to save national strategic interest.

China has clearly announced that it intends to become the leading country in the maritime sector as it considers this a prerequisite to become a world leading economy. In order to increase its leading role in the shipbuilding sector, the 'national shipbuilding action plan 2016-2020' stipulates that China has to enhance the scientific and technological innovation lead, to adjust and optimize the industrial structure of the shipbuilding industry, to develop advanced and efficient manufacturing, to integrate military and civilian developments, to promote international cooperations and to safeguard relevant measures, inter alia by financial support. This strategy relates also to the deep sea mining sector.

Assuming that this Chinese strategy might promote deep sea mining as an industry and related sectors like the shipbuilding industry, it will clearly provide negative impacts on the competitiveness of the European shipbuilding sector.

The EU has acknowledged already the importance of the Blue Growth markets in different programmes (e.g. FP7, Horizon2020) and strategic papers like WaterBorne Vision 2025+ and Leadership2020. This will support also the EU shipbuilding sector as part of the deep sea mining sector to enhance its technology advance. However, there must be severe concerns whether a EU industry policy for the support of the Blue Growth sector as it has turned out until today will be an equal driver for the European shipbuilding industry as the Chinese policy approach will be for its industry.

Technology – even it is certainly part of any industry policy – is an important driver as well as it has to ensure the economical viability of deep sea mining. Currently, a number of challenges do exist and

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62 ISL Fleet Database, Bremen, 2017
63 China’s Impact on European Shipbuilding, Shipyards’ and Maritime Equipment Association (SEA), Brüssel, 2017
which have to be solved by innovative and scalable technologies in order to turn deep sea mining into a commercial business.

Price development of raw materials and use of alternatives sources is also a driver that influences the feasibility of deep sea mining potentials. Given the current high costs for deep sea mining projects, future price developments is an essential key for decisions on future deep sea mining projects. Costs for the Solwara 1 has been currently estimated at around 750 mio $ but the actual plan to start exploiting the area in already 2019 seems to be unrealistic which leads to the assumption that costs will even increase. The technological advance of recycling influences also the price development as more efficient recycling processes will lower the demand for ‘new’ raw materials from terrestrial and deep sea mining.

Clear risks for the future development of deep sea mining vessels as a diverted demand from the deep sea mining industry derive from financial issues as explained before. The Solwara 1 project as a kind of success story or as a failure will here high likely have crucial impacts on the development of deep sea mining in the next 15-20 years.

Currently most essential obstacles for deep sea mining are the uncertainties about risks of deep sea mining for the marine environment. At present, most of the oceans which cover around ¾ of the earth are relatively unexplored. Hence, it is necessary to gather in-depth knowledge about impacts from deep sea mining on the marine ecosystems and ocean habitats. As research on this issue is going on, it remains unclear if and when negative consequences for the marine habitats can be overcome to develop a sustainable deep sea mining.

Also a potential obstacle is the further development of a legislative framework for deep sea mining. Although the ISA has been established to regulate the deep sea mining of international seabed, there is a risk that countries with strong political and economical power enforce national interests also in the deep sea mining sector at the expense of the ISA and its capacity to act. The current offensive Chinese strategy to become world leader in the maritime sector or the turning away of the U.S government from environmental commitments with its ‘America first’ strategy are references that there is a definitive threat for international organisations like the ISA to lose its primary task.

However, assuming a positive development of the deep sea mining sector, cross-sectoral are assumed to increase as the industry has a broad value chain comprising exploration, extraction, transportation, processing and distribution this offers the chance for the shipbuilding industry to establish new cross-sectoral collaboration. As described before, deep sea mining or production support vessels (PSV) have to fulfil different requirements like e.g. pre-processing facilities of raw materials which are not part of the competences of shipbuilding companies. With regard to the shipbuilding competences, European Companies are assumed to have a quite competitive position for high-technology-based markets like dredging, drilling, cutting, transport and remotely operated vehicles (ROV).

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5.3. Advanced emission abatement technology for shipping addressing the introduction of Emission Controlled Areas (ECAs) for NOx and SOx and of the global sulphur cap for ship fuel

**Sector/Mode of Transport:** Shipbuilding  
**SCORE:** 3 Europe has a competitive advantage in comparison

**Management summary**

A number of IMO regulations has been adopted in order to reduce SOx and NOx emissions from shipping. Different scrubber technologies have been used to comply with regulations on ‘SOx Emission Controlled Areas’ (SECAs) in recent years while other solutions – mainly based on SCR - offers NOx emissions reductions according to Tier III standards.

Experiences and evaluations of current scrubber technologies have shown a number of technical problems and environmental drawbacks that are to be solved by new innovative technology solutions in order to provide abatement technologies for ships operating in SECA and NECA regions.

The European shipbuilding industry has gained a leading role in the development of abatement technologies as scrubbers or SCR systems - however, as the demand for emission abatement technologies will increase, existing and new competitors from Asia are expected to operate on the market.

**Description of the main concept**

It is expected that typical diesel engines are still used for ship propulsion systems at least until 2030-2040.65 In order to tackle the challenge of reducing air emissions from shipping operations, the IMO adopted a number of international regulations. From 1 January 2016, vessels operating in ‘NOx Emission Control Areas’ (NECAs) in North American and the US Caribbean Sea have to comply with the IMO Tier III requirements which reduces nitrogen-oxide emissions (NOx) by approximately 76% compared to Tier II requirements. For European waters, the International Maritime Organization (IMO) designated the North Sea and the Baltic Sea as NOx Emission Control Area (NECA) from January 2021.

Additionally to the introduction of SOx Emission Controlled Areas (SECAs) in the North Sea and the Baltic Sea from January 2015, the IMO introduced a global sulphur cap regulation which limits the sulphur content in fuel oil used by ships to 0.5% and which will be compulsory from January 1, 2020. This global sulphur cap is considered as essential disruptive change having impact on the oil and shipping industry in the last 30 years as it is a substantial shift in fuel production turning away from ship fuel as residual.

Scrubber technologies have been used for vessels to comply with the current low-sulphur fuel requirements in SECA whereby the technology used in shipping differentiates between wet and hybrid scrubbers.

Wet scrubbers are a robust and effective technology for reducing sulphur emissions. Three different types of wet scrubbers exist currently which are applied in the shipping sector, i.e.

- ‘open loop’ systems
- ‘close loop’ systems
- ‘hybrid systems’

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65 BP Energy Outlook – 218 Edition
Open loop scrubber systems use seawater for scrubbing and neutralising the sulphur emissions without any additional agents. Along the process the sulphur exhaust coming from the engine lead into the scrubber where is washed with seawater. Within the washing process, around 98% of sulphur oxide are removed, even with fuel with 3.5% sulphur content. In order to work effectively, the seawater used for the cleaning process needs a high level of alkalinity which is why brackwater and fresh water are not relevant for open loop systems. According to MARPOL regulations it is mandatory to monitor the PH level of the wash water before disposing it to the sea.

Work processes in closed loop scrubber are quite similar to open loop systems – merely using fresh water with additional agents for scrubbing processes in lieu of sea water. During this process SOx is turned into innoxious sodium sulphate. Different to open loop systems, with close loop scrubbers the wash water is recirculated and only small portions of the wash water are disposed of by sea in order to avoid high content of sodium sulphate in the system. The required volume of water in a closed system is about half of the open loop system but requires storage tanks for used water and agents.

As third scrubber alternative, hybrid system has been developed combining open loop and closed loop technologies. Hence, the hybrid system operates the open loop scrubber in designated areas where required water and disposal requirements are fulfilled while the closed loop system is deployed under non-fitting operational conditions. Currently, an increasing share of hybrid scrubbers has been installed as this allows a broader flexibility of the vessel operation.

Common to all three scrubber technologies is that a treatment bypass is required for operation in none sulphur-limited waters in order to avoid any harms and additional maintenance processes.

The most relevant technology for reducing NOx emissions according to Tier III regulation is the Selective Catalytic Reduction (SCR). The SCR technology is based on a chemical reaction in order to neutralise NOx in the exhaust of a vessel engine and allows a reduction of NOx emissions of about 95% and above. This is achieved in a chemical process by converting NOx into nitrogen and water through a reducing agent that is added into the engine exhaust stream before the catalyst. Both, the exhaust gas and the agent are absorbed by a catalyst where the NOx into harmless substances nitrogen (N2) and water (H2O).

With the existing and the future introduction of the IMO Tier III regulation for NOx emissions, the SOx emission controlled areas in the U.S and in Europe and the upcoming global SOx cap from 2020, it is essential improve both technologies to optimize the scrubber and SCR systems for parallel operations onboard. With these upcoming NOx and SOx regulations, it is of particular importance for both technologies to offer a competitive solution as there are alternatives for complying with the IMO Tier III regulation and the global sulphur cap – particularly alternative fuels where LNG has a prevailing role.

Therefore, the need for combining scrubber technologies and SCR is a key challenge for the industry and hence known problems need to be improved.

Currently, in the shipping industry, the abatement of SOx and NOx emissions has been performed individually which is moreover also a cost-intensive measure. Therefore, research has been ongoing in order to analyse the potential to remove NOx and SOx in parallel with a focus on cost reductions.

66 HANSA International Maritime Journal, Hamburg, No. 5, 2017
67 Process evaluation of a SOx and NOx exhaust gas cleaning concept for maritime application, Chalmers University of Technology, Sweden, 2016, f
Currently, the combination NOx and SOx reductions by using wet scrubbers in shipping is not widely commercially available. In other industry sectors where fuel is used with high sulphur contents like in oil or coal running power plants, technologies for simultaneous abatements of SOx and NOx has been intensively researched – however, the transfer of results to the shipping sector has been not feasible yet.

Providing that technological challenges will be solved there is a high potential for a combined use of SCR and scrubber technologies – particularly due to the Tier III and the global sulphur cap regulation.

The potential for such a technological combination of SCR and scrubber systems is to be assumed as quite high. Roughly about 70,000 vessels are concerned by the current and upcoming NOx and SOx requirements. According to DNV-GL approximately a few thousands scrubber installations can be expected until 2020 with currently about 400 confirmed scrubber orders.68

With regard to SCR installations for complying with the Tier III requirements, currently about 500 vessels have been geared with these technologies.

A global market potential for SOx abatement technologies can be estimated at around 17 to 49 bn Euros until 2030 based on the current European SECAs and including the Mediterranean. Taking into account the global sulphur cap from January 2020, this market potential will even increase. With regard to NOx abatement technologies, a market potential of about 16 to 21 bn Euros is estimated covering the US NECAs and including the assumed NECAs in the North Sea and Baltic Sea.69

Given the fact that the sulphur cap is globally valid and the Tier III regulation currently in the North American and the US Caribbean Sea but with extensions to the North Sea and the Baltic Sea, the number of vessels requiring technologically-ready systems for combined SCR and scrubber systems is to be expected as high with consequently essential shares in the market potentials.

Analysis & Assessment of the impact on present industry structures

Scrubber and SCR technologies as emission abatement technologies to fulfill requirements with regard to NECAs and SECAs have been used either to tackle NOx or SOx emissions depending on the operational areas. The current challenge is the development of solutions for combining the NOx and SOx technologies for ships operating in SECA and NECA regions – and particularly with regard to the introduction of the global sulphur cap by the IMO from 2020 which refers also to operations on open sea.

SCR systems require high operating temperatures which means that currently the SCR has to be build locally before a wet scrubber in order to remove sulphur oxides before the cleaning process in order to avoid catalyst damages. In this case, SCR systems have to be further advanced to be proper for operational processes in exhaust emissions with still high contents of SOx. Alternatively, research is ongoing to put wet scrubbers before the SCR system. This requires that the exhaust emissions have to be reheated for providing the necessary temperature for the SCR. However, at present this technological approach would require additional energy, an increased fuel consumption and more carbon emissions and research is needed to solve this problem technologically.70

69 Green growth opportunities in the EU shipbuilding sector, Ecory a.o., Rotterdam, 2012
70 Your options for emissions compliance, Lloyd’s Register Marine, London, 2015
Consequently, optimised solutions have to be developed in order to determine whether a scrubber is to be built-in either before or after the SCR unit.

In the context of designing the combined abatement process, also the space need for installing both systems, i.e. SCR and scrubbers has to be solved. Furthermore, the individual operational requirements from ship operators have to be taken into account like operational speed and conditions in the areas where the vessel is planned to be deployed.

Currently, individual systems are on the market which are supposed to offer abatement technologies removing SO2, NOx and partly also CO2 in one process. However, no validation of market experiences is currently available. Reason for this is that ship owners hesitate with investing in new technologies due to uncertainties in the future development of international regulations, the ongoing financial burdens still due to the financing crisis and the uncertainty of the oil price development which is related to the possibility to use LNG as alternative fuel meeting the international SOx and NOx requirements.

The scrubber and SCR market is currently strongly driven by European suppliers like MAN, Wärtsilä, Rolls Royce, Yara, Saake, Wärtsilä, Clean Marine, Couple Systems, DuPont Marine Scrubbing Systems, Green Tech Marine, MES, Ecospec, Alpha Laval or Hamworthy Krystallo. While in 2006, only a few companies were working in the scrubber technology for shipping, there are today more than twenty companies involved in this technology business and more newcomers are expected – also from Asia - given the increasing demand for abatement technologies driven by stricter international environmental regulations.

- **Analysis and assessment of the impact of Disruptive Technologies on present value chain**

The impact of combining NOx and SOx abatement technologies are hard to assess as a number of issues are to be solved and alternatives do exist. However, ship owners require already today joint NOx and SOx technology solutions in order to provide them with the flexibility to deploy their vessels in SOx and in NOx controlled areas – either at the same time or consecutively. Therefore, the demand for individual NOx or/and SOx solutions concerning individual SECA or NECA requirements is becoming less likely. All the more, as the introduction of the global sulphur cap by the IMO extends also the global demand for SOx abatement installations leading to overlappings with NECAs.

Hence, as scrubber and SCR are both proven technologies they have a competitive advantage – at least currently as stand-alone solutions – which has to be continued now in well advanced combinations of both systems. Additionally, both technologies work as installations on new buildings and for retrofitting.

Provided a successful technological integration of SCR and scrubber systems on vessels, the demand for such a combined system will correspond directly to the requirements from shipowner’s side to invest in technologies addressing the current and upcoming legislative standards for NOx and SOx reductions. As estimated, about 70,000 vessels are concerned by these environmental related regulations. Based on a forecast from DNV-GL approximately a few thousands scrubber installations can be expected until 2020 with currently about 400 confirmed scrubber orders. In addition, about 500 vessels have been supplied with SCR technology in order to comply with Tier III.71

Looking at the total fleet and the current share of geared vessels with SCR and scrubber systems, the upcoming global sulphur cap and the Tier III regulation leads to the assumption that the number of

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71 Campaign for an environmental friendly cruise shipping sector, NABU - Nature And Biodiversity Conservation Union, Berlin, 2015
vessels which will have a demand for combined NOx and SOx abatement systems show high market potentials – despite alternative solutions (i.e. fuel alternatives).

Fuel alternatives like LNG, Methanol in this respect show still some uncertainties like the availability of bunker infrastructures, technological advance or price developments – particularly in relation to the price for HFO or MDO.

A potential threat to incumbents from new market players is comparable to the one on the cruise shipbuilding market. Currently, European suppliers play a leading role with high market shares in the development of technology-intensive scrubber and SCR systems – comparable to the high-tech cruise shipbuilding market. However, competitors from shipbuilding countries like South Korea, Japan and particularly China have been trying to enter technology-oriented niches in shipbuilding. Despite failures in attempts entering the cruise shipbuilding market like the case of Mitsubishi Heavy Industries, it is foreseeable that Asian shipbuilding companies and suppliers will enter the profitable high-tech markets – especially given the low revenues on the conventional bulker, tanker and container market segments.

In the cruise shipbuilding sector, a cooperation between China State Shipbuilding Corporation (CSSC) and the Italian shipbuilding company Fincantieri was agreed to for the construction of two Vista-class cruise ships for the U-S cruise operator Carnival, whereby Fincantieri will provide know-how and the technology platform. According to inside information, the Chinese government had put pressure on the cruise operator Carnival to build in China and to support the cooperation between Fincantieri and CSSC.72

Similar cooperations and policy-supported strategies aiming at know-how transfer from European to Chinese shipbuilding companies as in the cruise shipping sector will likely also take place also on the market segment for abatement technologies.

- **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

Environmental requirements from international organisations, i.e. the IMO and the EU are clearly the drivers for the development of emission abatement technologies in the shipping sector in order to make shipping ‘greener’. Societal awareness on the negative environmental impacts from shipping are partly forcing also ship owners to pro-actively improve the environmental performance of the shipping sector, particularly in the cruise sector – however, this is definitely not a decisive driver here.

With regard to legislative drivers, a potential threat might be the fact that SCR and scrubber technologies will allow the use of HFO further on and it is at present uncertain whether international regulation will occur in the future that foster clearly the use of alternative fuels instead of SCR and scrubber technologies.

Once the international regulation on Tier III and the global sulphur cap are effective, ship owners are obliged to react accordingly. With regard to the combined technology of SCR and scrubber for NOx and SOx reductions, barriers will be the market maturity and the availability of alternatives for emission abatements, like fuel alternatives. As scrubber and SCT technologies are already existing individually for NOx and SOx reductions, cross-sectoral collaboration is not required here but it might be beneficial as the SCR technology for the shipping sector based also on positive experiences from the road sector.

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Given the strong market position with regard to the current SCR and scrubber technology, it is assumed that the European shipbuilding sector will be also highly competitive with regard to combining NOx and SOx abatement technologies, although an increased competition is to be expected from the Asian and particularly Chinese shipbuilding sector.

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5.4. Smart ship

Technological solution: The innovative concept of the new generation of the ship using a range of technological solutions

Sector/Mode of Transport: Shipbuilding

SCORE: 3 Europe has a competitive advantage in comparison

Management Summary

The idea of building a smart ship should be treated as an innovative concept, not a new technology. Smart ship is a ship concept, where a number of new technologies will be implemented in the shipbuilding (propulsion & powering system) sector, for the needs of other sectors of the economy as well as trans-sector technologies (big data analytics, communication sensors, etc.). The idea of building a smart ship is related to the planned launch of autonomous vessels already demanded by ship-owners. The condition for the implementation of the above is to build a fully automated vessel, where all systems will be managed by a centralized IT system with an expanded decision segment (“artificial intelligence”) “communicating” in real time with land control centers, ship-owners and other business partners.

The idea of smart ship was created in cooperation between the European shipbuilding sector and ship-owners. Thus, European shipbuilding, with a sub-sector of Tier 1 suppliers, which is competitive on a global scale, becomes a beneficiary of new solutions leading to the creation of a smart ship generation vessel and, consequently, in the next few years of an autonomous ship. When assessing the issue, it should be clearly stated that we do not have a revolution in the construction of ships and the evolution from the level of automation of individual ship systems to the level of integrated management of all systems by intelligent decision systems that are (de facto the first smart ship generation ships are already in use) or they will be supervised by the ship's crew. Ultimately, intelligent decision systems will be able to independently control all ship's systems, which will be the basis for the operation of remotely controlled and autonomous vessels.

Description of the main concept

The concept of building a smart ship is related to the planned launch of autonomous vessels already requested by ship owners. The scenario of access to the construction and operation of autonomous ships, which began several decades ago, consists of several stages73:

- automation of functional processes of the ship - completed stages: propulsion & power system, electric power supply and distribution system,
- configuration of the integrated vessel control system that allows remote control of all functional systems of the ship and control them from the integrated control center, which is usually a bridge of the ship,
- application of Big-Data technology in centralized IT systems with an extensive decision system (“artificial intelligence”) as a part of the integrated vessel control system, thanks to which the ship as a system becomes a fully automated centrally controlled means of transport,
- use of a ship-to-owner ship-to-center communications system, using broadband connections (GSM, satellite communications) where the decision-making IT system continuously communicates in real time with land control centers, ship-owners and other business partners.

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73 Global Marine Technology Trends 2030, © 2015 Lloyd’s Register, QinetiQ and University of Southampton. First Printed: August 2015
As previously indicated, the idea of smart ship should be treated as a concept of a functional solution using a number of new technologies created for both shipbuilding and other sectors of the economy to build a ship whose operating costs will be as low as possible while maintaining the applicable standards of human safety and shipping (ship's crew limited to a minimum, minimized fuel consumption) and minimizing technologically possible emissions and heat (hybrid power supply, low-emission fuels, e.g. LNG or future replacement of combustion engines with fuel cells and new generation batteries with greater energy capacity).

The idea of smart ship is a concept developed jointly by ship owners and the shipbuilding sector (with a special role of Tier 1 suppliers, often integrators of ship systems) covering all elements of the ship, which will lead to the construction and operation of remotely controlled vessels and, ultimately, autonomous vessels. The concept of a smart ship uses technologies and technical solutions developed for the needs of the shipbuilding sector and particularly concerns:

- integrated propulsion & powering systems,
- ship automation systems,
- power supply systems

and technologies and technical solutions developed by other sectors and related research and development centers used by the shipbuilding industry in the process of shipbuilding and operation where we can distinguish:

- advance materials.
- big data analytics.
- robotics.
- sensors.
- communication

Figure 35 presents the scheme of the ship with an indication of its key systems, many of which are automated. These systems are monitored, controlled and managed by the integrated ship control system.
The use of automation on ships, followed by remote monitoring and control systems for individual ship systems and, finally, integrated ship control systems, was the process of evaluating a ship as a system that is manually and internally controlled from many points - a means of transport that is automatically controlled and managed from one of its internal center points. Such integration of control processes allowed for the next step in the evolution of the ship, which is the external monitoring of ship systems (implemented e.g. by the supplier of integrated ship control systems, the Kongsberg capital group - a global European supplier). And the next step is external control (tests are already carried out, as described in D3.2).

The construction of smart ship generation vessels by the European shipbuilding sector is a logical consequence of the strategy implemented by the sector in the last years. The strategy of building a competitive advantage on the world market for technologically advanced shipbuilding where the sector focused on the development of new technologies and implementations in the construction of ships, technologies that were created in other sectors of the European and global economy. Hence the natural process of developing the potential of the European shipbuilding sector, both in terms of production volume and technological level, to a level that allows the shipbuilding to use technologies and technical solutions expected by ship owners and allowing the construction of smart ship generation vessels.

The current level of technological advancement and technical potential as well as the production potential of the European shipbuilding sector allows to satisfy the demand from ship owners for smart ships. As indicated earlier in the part of the SCORE project "D2.1 Technical Analysis", the correlation of the development strategy of the European shipbuilding sector with the EU 2020 Strategy enabled the sector to reach a global level in technologies used in the production of ship systems as well as ships as a whole and the potential to meet the demand for modern highly advanced ships in selected sectors indicated in "D2.1 Technical Analysis".
Analysis & Assessment of the impact on present industry structures:

As already pointed out, the concept of smart ships is not a revolution in the structure and functions of a vessel, but an evolution aimed at building more and more technically advanced ships with the use of new technologies. An example is the evolution of the propulsion & powering system described in section 5.2, which has evolved over the decades thanks to the use of new technologies and new technical solutions. Currently, depending on the type of ship and the operating abilities expected by the shipowner, a variety of technical solutions are used, from the classic propulsion system with diesel engine and propeller on commercial vessels such as bulk carriers, tankers or container vessels to integrated electric propulsion systems (examples are azimuth thrusters with the possibility of rotating to any horizontal angle) increasing maneuverability of ferries, passenger ships or service ships of the offshore sector. This example illustrates the idea of smart ship, that is, constructing ships of next generations that meet the expectations of ship-owners and their customers dealing with passenger and cargo transport.

When analyzing the level of technical advancement of modern ships in the context of the construction and operation of autonomous vessels, it should be stated that the determinant of the currently understood smart ship generation are ships with integrated ship control system that monitors, controls and manages the individual automated key ship operating systems while enabling data exchange with stakeholders. Figure 36 presents a schematic configuration of the current smart ship systems.

![Figure 36 Configuration of the current smart ship systems](Source: own work)

Table 2 presents the level of technological advancement of key systems of the current generation of smart ships shown in Figure 36.
### Table 2: The level of technological advancement of key systems of the current generation of smart ships

<table>
<thead>
<tr>
<th>System</th>
<th>TRL</th>
<th>TRL reasons</th>
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</thead>
<tbody>
<tr>
<td><strong>Basic ship systems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propulsion &amp; powering Management</td>
<td>7 / 8 / 9</td>
<td>Technological level of system development as well as applied technical solutions are described in detail in section 5.2. TRL reasons are presented in Table 1</td>
</tr>
<tr>
<td>Management (including energy distribution and light system)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thruster Control</td>
<td>8</td>
<td>Technologies and technical solution proven and used in ship operation; technological development in these systems is related to the use of new devices that make up the system, new controllers using sensor technology and new control IT systems.</td>
</tr>
<tr>
<td>Ballast Management</td>
<td>8</td>
<td></td>
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<tr>
<td>Machinery Management</td>
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<td>Safety Management</td>
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<td>Alarm Management</td>
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<td>Maneuvering system</td>
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<tr>
<td>Navigation system</td>
<td>8</td>
<td>The system developed in a continuous manner, where both technologies typical of sea transport as well as those used in other sectors of the economy, including air transport, are often used; for security reasons, every new technical solution using new technologies is used in the ship operation after reaching the TRL 8 level.</td>
</tr>
<tr>
<td><strong>Auxiliary systems</strong></td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Communication system</td>
<td>8</td>
<td>The system developed in a continuous manner, where both technologies typical of sea transport as well as those used in other sectors of the economy are often used to transmit large amounts of data; for security reasons, every new technical solution using new technologies is used in the ship operation after reaching the TRL 8 level.</td>
</tr>
<tr>
<td><strong>Key elements of the integrated ship control system</strong></td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Integrated control system</td>
<td>9</td>
<td>The system developed in a continuous manner, where technical solutions typical of sea transport are used, including inter-sector information technologies; the system belongs to the group of integrated control systems of production and service processes developed for several decades. Technologies and technical solution proven and used in ship operation</td>
</tr>
<tr>
<td>Big data analysis system</td>
<td>9</td>
<td>The system developed in a continuous manner, where technical solutions typical of sea transport are used, including inter-sector information technologies; the system is an important element of integrated control systems of production and service processes, the task of which is to process large amounts of data in real time. Technologies and technical solution proven and used in ship operation</td>
</tr>
</tbody>
</table>
D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

LAN networks system

Technologies and technical solution proven and used in ship operation

Sources: own work

Ad 1. Applies to the situation when the ship is equipped with an integrated ship control system, which depends on the economic conditions on the shipowner's side

When analyzing the level of advancement of particular technical solutions and technologies used in the smart ship and anticipated for future use, it can be stated that they are part of the EU 2020 Strategy, especially meeting milestones included in EU programs concerning new technologies and environmental programs forcing new pro-ecological technologies and technical solutions such as:

- automation and robotization of technical processes in production and transport,
- intelligent control systems being the stage of creating “artificial intelligence” to manage processes, production, devices or means of transport,
- low-emission and resource-efficient propulsion systems,
- low-emission and resource-efficient electricity production and storage systems,
- electromobility.

As previously indicated, the idea of smart ship is the concept of continuous technical development of vessels using a range of new technologies and new technical solutions arising both inside the shipbuilding sector and in other sectors of the economy. The development path of the European shipbuilding sector is in line with the road map for the development of new technologies set out by the European Union. Technical configuration of the smart ship presented in Figure 36 and Table 2 is a ship which uses technologies that increase its economic efficiency in operation while lowering to an achievable level negative impact on the environment at the level of both individual automated systems and integrated control of all ship systems.

The main direction of the smart ship concept development is to bring the configuration of the integrated ship control system to a level that allows the vessel to be controlled from outside and ultimately to the autonomous ship. From a technological point of view, autonomous ships could be handed over to operation in the next 3-4 years. Whether it will be widely used will be decided by other conditions than technological ones.

The main suppliers of smart ship elements in the technical configuration shown in Figure 36 and Table 2 are generally enterprises that are Tier 1 suppliers in the ship value chain. For the most part, they are global players in the global market of system suppliers and their elements, where a significant part of these suppliers have their main headquarters in Europe. Below are the main players on the equipment.

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75 LeaderSHIP 2020 The Sea, New Opportunities for the Future Brussels, 20th of February 2013


77 WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, EUROPEAN COMMISSION Brussels, 28.3.2011

and systems supply market at the level of individual automated systems or at the level of integrated control of all ship systems (the country of the company’s headquarters is given in brackets)79:

- Fincantieri Group (Italy),
- Mitsubishi (Japan),
- ABB Marine (Finland, Norway),
- Caterpillar Marine Power System (Germany),
- GE Power Conversion (France),
- Inmarsat (UK),
- Kongsberg Maritime (Norway),
- MAN Diesek & Turbo Germany),
- Rolls-Royce Marine (United Kingdom),
- Schneider Electric (France),
- Siemens Marine Solutions (Germany)
- Wartsila (Finland),
- ZF Fridrichshafen AG Marine Propulsion System (Germany).

The above list clearly illustrates the competitive advantage of the European shipbuilding sector in the supplier sub-sector, where the majority are European enterprises that are the main companies in the global market of system suppliers described above. What is important are the regular players on the system market and their integration as part of the development of integrated ship control systems. These enterprises have generated a significant competitive advantage on the market and thanks to the development and implementation of new technologies in the production of ship equipment and systems, these companies are and will be in the next several years global leaders in the supply of next generation components as well as complete systems for next generation of smart ships.

- **Analysis and assessment of the impact of Disruptive Technologies on present value chain**

Figure 37 presents a diagram of the three main parts of the shipbuilding value chain. The configuration of the next generation of smart ship analyzed in this point is aimed at creating added value for both the ship-owner and the shipbuilding sector enterprises. As illustrated in the diagram, system elements are produced by Tier 2 suppliers (Part II) and the integration of the system as a whole is made by Tier 1 suppliers (Part II), who assemble the entire ship system in shipyards (Part III).

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The European shipbuilding industry has specialized in the building of the highly specialized ships of types below:

- passenger-car ferries gas-powered or electrical-powered,
- double sides ferries (double-ended ferries) and shuttle ferries,
- combined LNG, LPG and ethylene vessels,
- fishing vessels,
- tugs and cargo sea barges,
- seagoing luxury yachts,
- arctic ships with ice class,
- boats made using the technology of carbon fiber and fiberglass,
- the individual offshore to service offshore oil fields and gas and floating units of large,
- floating construction for maritime industries,
- the construction of wind farms at sea,
- warships.

The ships of the above types are high value added vessels where the ship-owners, in order to reduce their operating costs while increasing operational capabilities in various ship operation conditions, more and more often decide to order ships of the smart-ship generation than ship-owners of classic bulk carriers, container ships or tankers. The second ship-owners are interested in systems that reduce operating costs and are not necessarily interested in systems that enable remote control of the ship. Therefore, first of all, the European shipbuilding sector is the main beneficiary of the specialized smart ships ordered by ship owners - ships that precede remotely control vessels, which can be turned into autonomous ships.

The issue of design and construction of autonomous ships, in the context of improving the competitiveness of the European shipbuilding sector, is described in more detail in the report D3.2.,
Point 5.3 (Autonomous vessels), which describes issues related to the impact of building remotely controlled vessels and ultimately autonomous ships on the dynamics of the value chain created in the construction process and subsequent operation of the ship. In the analysis of changes in the value chain, it was pointed out that starting from the vessels described in this point, smart ships, through remotely controlled vessels up to autonomous ships changes the relationships between the shipowner, shipbuilding and Tier 1 suppliers. Shipbuilding in technological development order: smart ship of the current generation, remotely controlled and autonomous vessels and handing them over to operation will involve expanding the shipbuilding sector's offer to control and manage the technical side of ship operation by suppliers involved in systems integration, especially the configuration of integrated ship control systems.

The introduction of remotely controlled vessels and in the next step, autonomous ships will require the construction of land control centers and management of technical systems of ships (remotely serviced vessels, which already takes place and remote control of non-crew ships) and supervision of ship systems and, if necessary, taking over control over the autonomous vessel. This process of extending the offer by system integrators has already begun. An example is the Kongsberg Gruppen concern, which has already launched remote service centers for ship systems and technical support for ship crews. Handing over to operation of subsequent vessels with integrated ship control systems will require the construction of many such land ship control centers for the described smart ships, remotely controlled ships and autonomous vessels.

Enterprises from the European shipbuilding sector have been cooperating in the cluster system for many years creating jointly the added value in the value chain of construction and operation of the ship, which gives it a strong position in the global maritime economy. The authors of the paper The role of Maritime Clusters to enhance the strength and development of European maritime sectors explain the important advantages of a cluster enterprise system in production and service processes. They point to the fact that the European shipbuilding industry has achieved the highest global financial turnover over most of the last decade. This illustrates how important for European shipbuilding is to operate according to the “win-win” principle combined with the ability of shipbuilding to absorb new technologies emerging both inside and outside the shipbuilding sector in Europe and the global R&D&I sector.

- **Success factors for implementing new technologies, products and innovative concepts and strategies into present value chain**

The key factors facilitating the successive implementation of new technologies in the next generations of smart ship are:

- EU policy in building a pro-innovative European economy as a key to improving the competitive position of the European economy,
- environmental European policy related to minimizing the negative impact of transport on the environment,
- demand from shipowners focused on the continuous reduction of ship operational costs, costs both related to the operation of the ship's technical systems as well as direct and indirect costs related to the size of the ship's crews or fees for using the environment,
- wide use by Tier 1 and 2 suppliers as well as production shipyards of new technologies and new technical solutions developed both by the European, American and Asian R&D for various sectors of the economy where the shipbuilding sector absorbs new technologies and new technical solutions in the shipbuilding process.

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80 The role of Maritime Clusters to enhance the strength and development of European maritime sectors, Report on results, Commissioned by the European Commission (DG MARE), November 2008
In the above context, the idea of smart ship as an evolutionary technological advance in the construction and operation of ships is a process that has no barriers in the area of technology, technical solutions and EU development policy or restrictions on the part of shipowners. It is also important that a number of technical solutions used for the current generation of smart ship and planned for use in the case of remotely controlled and autonomous vessels are or will be also implemented in the production of other means of transport. There are two reasons. One is the universality of the series of technologies used in the construction of modern ships, thanks to which they are used in various sectors of the economy, and referring to the scope of research in the SCORE project, in the production of various means of transport. Examples are:

- hybrid propulsion and powering system currently used in the production and operation of cars,
- communication systems based on positioning technologies and data exchange over long distances, from GMDSS technology to satellite systems (INMARSAT and GPS),
- Big Data analysis system used in many areas of the economy allowing for the storage, processing and transfer of large amounts of data in real time,
- integrated process management systems in production and operation using, inter alia, IT technologies and sensor technologies.

Evolutionary technological progress in the construction and operation of ships is a process that has no barriers in the area of technology, technical solutions or EU environmental policy and the implementation of many systems presented in the diagram of key systems of the current generation of smart ships (Figure 36), including the integrated ship control system is the result of cross-sectoral cooperation and cross-sectoral technology flows.

Summing up, it should be noted that the current production and technological potential of European shipbuilding allows for the production of not only the current generation of smart ship but also for the construction of remotely controlled and autonomous vessels. D3.2 report, section 5.3 - Autonomous vessels, describes examples of actions in this area implemented by European shipbuilding in cooperation with ship-owners. The competitive advantage of European shipbuilding in the production of this type of vessels is also the result of the sector's use of other technologies in other sectors of the European and global economy, combined with high efficiency of the value chain created in the ship's production process (the issue is described in detail in report D2.1, point 5). This strengthens the position of European shipbuilding in the high value-added and technically advanced ship sector.

References

The role of Maritime Clusters to enhance the strength and development of European maritime sectors, Report on results, Commissioned by the European Commission (DG MARE), November 2008.


D3.1 Mapping of future perspectives and challenges for the value chain of European transport manufacturing industry

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