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TRANSPORT 2040

ANALYSIS OF TECHNOLOGICAL DEVELOPMENTS IN TRANSPORT

MARITIME, AIR, RAIL AND ROAD

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TRANSPORT 2040

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MARITIME, AIR, RAIL AND ROAD

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GLOSSARY

AI	Artificial Intelligence
AIS	Automatic Identification System (in maritime transport)
AL	Autonomy level
ATM	Air Traffic Management
Automatic	The system has automation functions that can complete certain operations without human control
Automatic bridge	Automatic (navigational) bridge, with crew always on the bridge (on a ship)
Automatic transport vehicle	Transport vehicle is supervised (e.g. by crew member or by control centre) and executes automatic functions
Automation	The processes, often computerized, that implement a specific and predefined method to execute certain operations without a human controlling it
Autonomous vehicle	Vehicle with some form of autonomy
Autonomy	The system has control functions that can use different options to solve selected classes of problems
Autonomy Assisted Bridge (AAB)	Continuously manned bridge with autonomous control functions
COLREGs	International Regulations for the Prevention of Collisions
Continuously Unmanned Ship (CUS)	Crew never on ship, except possibly during emergency recovery
HGV	Heavy Goods Vehicles
IoT	Internet-of-Things
IoV	Internet-of-Vehicles
IXL	Interlocking system (railway)
MaaS	Mobility-as-a-Service
MASS	Maritime Autonomous Surface Ships
NextGen	Next Generation Transport system (in the U.S.)
OCC	Operation Control Center (railway)
Remote control	Vehicle is remotely controlled, from another vehicle or from a Control Centre
RFID	Radio-Frequency Identification
SESAR	Single European Sky ATM Research
Shore Control Centre (SCC)	Owner's centre for monitoring and control (of ships)
TCS	Train Control System
unmanned	Without crew controlling the vehicle, but vehicle may not be autonomous, i.e. can be remotely controlled
UAS	Unmanned Aircraft System
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	a combination of V2I and V2V
VTs	Vessel Traffic Services

INTRODUCTION

INTRODUCTION

A number of technical and socio-technical factors are driving the development and adoption of automation. The report, *Transport 2040: Automation, Technology, Employment – The Future of Work*, provided an overview of the most important trends forecasted to affect the global transport sector by 2040. This current report provides additional details of that assessment. The research conducted is guided by a transport-technology analytical model that provides a structure for a systematic review across different modes of transport. This report reviews, in particular, the transportation technology through the lens of *transport vehicles* (e.g. ships, trucks, trains, aircraft) and the *technical infrastructure* that is needed for the operation of the vehicle (e.g. waterways and harbours, roads, railway tracks and freight terminals, as well as controlled airspace and airports).

With respect to both vehicles and infrastructures, technological advances are on the horizon that increasingly make it possible to perform key functions at higher levels of autonomy. The key functions analysed that are relevant to

the vehicles include the provision of energy and propulsion, navigation, communications and data transfer as well as cargo handling. The functions that are associated with the infrastructure include the provision of energy, the provision of a suitable path, communications and data transfer as well as terminal facilities. In addition to the technical feasibility of those technologies supporting these functions, the transport operations are constrained by such factors in the business environment as regulations and governance, economic benefits, social acceptance, knowledge and skills of operating personnel and labour market dynamics. All of these will impact the likelihood of developing, deploying and adopting the automation.

In the subsequent chapters, for each transport mode, the most relevant technological advances are identified and analysed in relation to this business environment. These analyses are summarized in a qualitative assessment, and start-up-curves are produced for selected technologies.

MARITIME TRANSPORT

1

1 MARITIME TRANSPORT

1.1 INTRODUCTION

The introduction of novel technologies is a continuous process that has been happening in different phases and to different extents. Initially, individual electronic components were *connected* (e.g. steer by wire control). With the advent of computers, analogue components were replaced by *digital*

components that provide a wider functionality (e.g. decision support, using data provided off-board). An even higher level of decision support was introduced with the advent of *autonomous* systems, which can take decisions on their own, but under the supervision of human operators.

FIGURE 1-1 Illustration of decision support in LR autonomy levels

1.1.1 “Levels of autonomy” and further terminology

In the maritime industry, the seven-point scale of autonomous levels introduced by Lloyd’s Register (LR) (Table 1-1) has broad acceptance. This scale does not physically locate the human in/on the loop; the human in control could be outside the vehicle or the infrastructure. Across different transport industries, a range of scales of autonomy have been applied. For example, mappings of the LR scale to broadly used scales in other transport-related industries are provided in Annex 1.

The interrelation of connected, digitalized and autonomous systems with the level of decision support in the context of the LR autonomy scale is illustrated in Figure 1-1.

Novel technology makes it possible to automate and remotely monitor tasks in engine, deck and nautical departments of the ship¹. Hence, it is technically conceivable that individual departments, or even the entire vessel, can be operated

unmanned for different periods of time. For instance, in the past decades, periodically unattended machinery spaces were installed², resulting in a reduction of crew and a change of work patterns. From a technical perspective, similar developments are also conceivable for nautical operations, although at present there is no legal foundation for unattended bridge operations during a voyage. In the deck department, developing technical solutions to predominantly manual tasks is a challenge, in particular with respect to maintenance tasks during a voyage and to mooring operations.

The levels of autonomy that are applied on board may vary in each phase of the voyage, as the phases of the voyage have different levels of complexity. For instance, during a sea passage in unrestricted waters usually a good amount of time is available for nautical decision-making, since the environmental influences, such as waterways, other traffic and weather conditions, are predictable. During this phase of the voyage, a highly autonomous operation is technically less

TABLE 1-2 Terminology related to automatic steering, remote operation, remote monitoring and autonomy for ships

MANUAL NAVIGATION OF MERCHANT SHIPS	The navigating officer gives the command for the wanted course and speed, either to a helmsman or as an autopilot setting and for bridge navigation of the ship’s main engine. The navigating officer has electronic charts with his vessel’s own position and course. A radar system shows the course and speed of other ships.
AUTOMATIC COURSE STEERING	Course steering takes place between encoded positions, while the ship’s autopilot ensures that the ship goes from position A to B.
DECISION-SUPPORT	Decision-support consists in planning a route and speed profile in order to reach a port at a given time with a prediction of the sea and wind conditions underway. More extensive decision-support could include guidance for the navigating officer about the performance of an evasive action in narrow waters.
REMOTELY OPERATED NAVIGATION	Control is performed from a remote location, either on-board (e.g. partially unattended machinery spaces), from a control terminal on board another ship, or from a land-based control center. Ship-board systems, both propulsion machinery and navigation systems, may operate in automatic mode for periods of times. But the strategic planning and control is still performed by a human operator.
REMOTE MONITORING	Measured values from sensors in machinery spaces, for example on course and speed are shown in real time in an operation centre ashore, or on board another vessel. Full monitoring includes transmission of TV monitoring and radar pictures so that the operation centre has sufficient information about the ship and its surroundings to be able to perform remotely operated navigation.
PARTIAL AUTONOMY	The ship has systems for assessing the situation and the consequences and for advising the navigating officer on how to react. The navigating officer is not necessarily present in person on the ship’s bridge.
FULL AUTONOMY	The situation is perceived and assessed, and a decision on which action to take is made without any intervention by human beings.

Adapted from: Blanke, Henriques and Bang, 2017, p. 3

¹ Good terminological definitions related to automatic steering, remote operation and remote monitoring for ships are provided, e.g. by Blanke, Henriques and Bang, 2017, p. 3. See Table 1-2 for a selection of terms.

² For details on general requirements on unattended machinery spaces, see SOLAS Chapter II-1, Regulations 45-53.

demanding than in phases where the environment is more dynamic, e.g. when leaving berth; or even highly dynamic, e.g. during port departure and during an emergency handling. In these latter phases, more interaction may be required between the systems and human operators. These operators could be located either on board or in a remote control centre on land or on another vessel. The typical options for control modes during the phases of a voyage are listed in Figure 1-2.

1.1.2 Strands of development in maritime transport

Research and developments on novel technologies and automation in the maritime industry approach the target of an unmanned autonomous vessel from two directions (Bruhn, 2018). The first development path aims at relocating the operator to a remote control station, e.g. a shore-based control centre, from where the ship can be remotely operated via a high-bandwidth connection. Development progresses gradually, moving from manual to autonomous control. On the second development path, the operator on board is gradually relieved by AI-based assistance, and eventually the operator may become obsolete. These two development paths ultimately will result in a stage where operating unmanned autonomous vessels becomes technically feasible, as is illustrated in Figure 1-3.

However, while there is general agreement that these two development strands are currently being pursued, some argue that the time frames mentioned in Figure 1-3 can be considered ambitious³. For instance, DNV GL states that “it may be optimistically assumed that international regulations for autonomous ships could be in place by 2035” (DNV GL, 2018, p. 63). This time frame is also reflected in the work schedule of the IMO Correspondence group on Maritime Autonomous Surface Ships (MASS), established at Maritime Safety Committee, 99th session (MSC 99)⁴. Nevertheless, in national waters and according to national regulations, autonomous ships for specialized operations may be sailing during the next decade (Blanke et al., 2017; MSC 98/INF.13).⁵

Examples of such specialized operations include: YARA BIRKELAND, a 120 TEU open top container vessel in Norway; in passenger transport, the RoBoat platform in Amsterdam and an Autoferry in Trondheim; and offshore autonomous utility vessel HRÖNN, operating in the Trondheim fjord. (See section 1.2.1.2 for details.)

The subsequent sections provide an overview of technologies and qualitative trends, a transport technology analysis and requirements pertaining to the workforce.

FIGURE 1-2 Control modes during phases of an autonomous voyage

Control modes:

OCT On-board Control team

AUT Automatic Bridge or Automatic Ship

ECT Emergency Control team

RC Remote Control (Direct)

DIR Direct Control

CA Constrained Autonomous

Adapted from Rødseth and Nordahl (2017)

³ Personal communications with experts during the autonomous ships workshop of the German Institute of Navigation (DGON) working group on autonomous maritime systems on 11 April 2018 and the SINTEF Ocean “Future Developments in Autonomous Shipping” event, held during SIMM, on 5 Sept 2018.

⁴ See MSC 99/WRP1/Add.1, 25 May 2018.

⁵ A collection of resources on international developments on autonomous shipping is maintained by the Norwegian Forum for Autonomous Ships (NFAS) at: <http://nfas.autonomous-ship.org/resources-en.html>

FIGURE 1-3 Race between remote control and autonomy - maritime transport

Sources: Fraunhofer CML, WMU analysis

1.2 OVERVIEW OF TECHNOLOGIES AND QUALITATIVE TRENDS

1.2.1 Core automation functionalities

1.2.1.1 Automation of maritime traffic management

The present situation in international maritime transport can be summarized as follows: Traffic has to adhere to International Maritime Organization's (IMO) International Regulations for the Prevention of Collisions, 1972 as amended (COLREGs). In areas with high traffic densities or challenging waterways the degrees of freedom in which traffic can move are restricted, for instance, by traffic separation schemes in coastal waters, harbours and canals. In other areas, traffic is monitored by vessel traffic services (VTS), which assist in organizing traffic, providing navigational assistance and up-to-date regional information that is relevant with regard to navigation (e.g. weather, waterway conditions, obstacles) to the ship crews. Despite all these provisions, the responsibility ultimately lies with the officer on watch (OOV) or the captain).

The task of managing surface vessel traffic requires nautical skills and reliable information on the position and key data of each vessel (e.g. size, weight, route, velocity, propulsion and steering performance), and reliable environmental data (e.g. waterways, weather conditions, temporary hazards).

With an increasing number of autonomously operating ships, these autonomous vessels will be able to negotiate paths among themselves. However, for the foreseeable future a service that provides environmental information and that assists in parallel with the operations of autonomous and non-autonomous vessels will still be needed. Such a service is likely to be located in land-based control centres. The expectation is that during a transition period these control centres will be manned with personnel that possesses practical experience with operations aboard ships. At a later stage, operations will be increasingly performed by personnel that has not served aboard ships⁶.

⁶ This evolution bears similarities to developments in the aviation sector, whereby in many countries air traffic controllers are not required to have an air pilot license.

1.2.1.2 Automation of driver or operator tasks

Over the past decades, automation has gradually been introduced in the engine department, making it possible, for instance, to have periodically unattended machinery spaces. With respect to the nautical department, applications include the navigational autopilot and include assistive vehicle functions (e.g. track keeping, speed control and fuel saving) to autonomous vehicle operation, with or without human supervision, such as dynamic positioning. The design philosophy of many of these systems is to assist the human operator in performing tasks; and to alert the human operator in situations when human intervention is required. In order to be able to react adequately and timely when such situations occur, the human operator requires good “situational awareness”, regardless of the operator being located aboard the vessel or if control is applied from a remote location. Situational awareness can be achieved by providing user interfaces that present the information that is relevant for decision-making in a particular situation, in a comprehensible manner. Minimum requirements on the design of the human machine interface are specified in:

- ISO 8468:2007 Ships and marine technology - Ship's bridge layout and associated equipment - Requirements and guidelines;
- ISO 2412:1982 Shipbuilding - Colours of indicator lights;
- IMO A.1021(26) Code on alerts and indicators; and
- ISO 9241-210:2010 Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems.

When control is applied from a remote location, the operator needs to be made aware of additional latencies in the control loop, which is *“due to the communications that cause a delay between his/her action and the actual ship reaction. The latency should be continuously displayed during the operations (e.g. manoeuvring) and a warning should be issued when the latency is over predefined limits”* (Bureau Veritas, 2017, p. 7). In this context, a remote location could be a place aboard the ship, other than the bridge or the engine control room; but it could also be a control centre on land. This technological evolution bears similarities to existing applications in the military sector, e.g. globally operating airborne and waterborne drones, which are controlled over long distances from remote control centres.

Traditionally, the maritime industry has been rather conservative with respect to the introduction of novel technologies. Given the agenda of Maritime Autonomous Surface Ships at IMO, one can expect international regulations for autonomous ships to be in place before 2035 (DNV GL, 2018, p. 63). But for specific operations in national waters (inland or near-coastal), autonomous ships sailing by 2028⁷ may be possible. At the time of writing, planning of test areas for autonomous shipping is in progress in Denmark, the Netherlands, Norway and the United Kingdom.

Some examples of current developments of autonomous ships for special applications and trades include the following:

- A fully electric 120 TEU open top container ship *YARA Birkeland* is under development. The vessel, which in August 2018 was commissioned to be built by Vard Brevik shipyard (Kongsberg, 2018), is intended to operate fully autonomously. The plan is for loading and discharging to be done automatically using electric cranes and equipment; the ship will be equipped with an automatic mooring system, with berthing and unberthing to be done without human intervention, while with respect to dock-side no special implementation process will be required. The vessel is expected to be manned in the first years of operation, and then to transit to fully unmanned operations.
<https://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/4B8113B707A50A4FC125811D00407045>
- In the ReVolt concept developed by DNV GL and by Transnova, Norway, an unmanned short sea vessel, which is 60 metres long and is fully battery powered, will operate autonomously at a speed of 6 knots, with a range of 100 nautical miles and a cargo capacity of 100 twenty-foot containers.
<https://www.dnvgl.com/technology-innovation/revolt/>
- A remotely operated Fireboat for Ports is currently being developed by Robert Alan Ltd. and Kongsberg.
<https://www.km.kongsberg.com/ks/web/nokbg0238.nsf/AllWeb/0999B2CFDB694B71C125822C00343E88?OpenDocument>
- In the city of Amsterdam, the Amsterdam Institute for Advanced Metropolitan Solutions (AMS institute) and MIT are jointly developing roboat, “a new kind of on-demand infrastructure: autonomous platforms will combine together to form floating bridges and stages, collect waste, deliver goods and transport people, while also collecting data about the city”.
roboat.org
- In Trondheim, the Norwegian University of Science and Technology (NTNU) is developing a 32 foot driverless passenger ferry which, supported by land-based sensors, is intended to operate autonomously on a waterway.
<https://www.maritime-executive.com/article/autonomous-mini-ferry-moves-forward-in-trondheim#gs.sQTrc4Q>
- The RAmora (<http://ral.ca/series/ramora/>) concept of an autonomous tug has been developed since 2015; simulated tests were successfully performed in 2017.
<https://www.rina.org.uk/towbot.html>
- In April 2018, the Maritime Port Authority of Singapore signed a Memorandum of Understanding with Keppel Offshore & Marine Ltd. and the Technology Centre for Offshore and Marine, Singapore (TCOMS) to jointly develop autonomous harbour ships. “The vessels would be used for a variety of applications, including harbor

⁷ In different regions target dates vary. For instance, a study published on 7 November 2018 by the Chamber of Commerce in the Ruhr Valley suggests that in Germany autonomous ships may be operating on inland waterways by 2033.

operations such as channeling, berthing, mooring and towing operations”.

<https://worldmaritimenews.com/archives/251143/singapore-to-develop-autonomous-vessels/>

Projects that focus on offshore operations include the following:

- The *Hrønn* autonomous offshore utility vessel is currently under development by the Safe Implementation of Autonomous and Remote Operation of Ships (SIMAROS) project, a collaboration of Automated Ships Ltd., Kongsberg Maritime AS, DNV GL, Fjellstrand, Inmarsat and the Norwegian Maritime Authority.
<https://www.km.kongsberg.com/ks/web/nokbg0238.nsf/AllWeb/65865972888D25FAC125805E00281D50?OpenDocument>
- In June 2017, a consortium of Japanese companies, including the shipping firms, Mitsui OSK Lines and Nippon Yusen, and the shipyard, Japan Marine United, announced plans to build a fleet of 250 self-navigating cargo ships ‘by 2025’
<https://www.theguardian.com/world/2017/jun/08/japanese-self-driving-cargo-ships-within-decade>
- In the military domain, in January 2018, the U.S. Navy experimental self-driving ship *Sea Hunter*, which can operate autonomously for up to two months, successfully completed a two-year test programme.
<https://www.darpa.mil/news-events/2018-01-30a>

1.2.2 Automation of maintenance

Maintenance procedures in maritime transport differ quite significantly from maintenance procedures in other transport modes. In the rail, aviation and road transport modes, vehicles typically are taken out of service for planned maintenance periods regularly. In contrast, in maritime transport, in general maintenance tasks are performed during the journey.

Advances in the development of sensor technology and reliable networks make it possible to closely monitor the condition of equipment aboard vehicles and in the transport infrastructure. As a result, it becomes possible to schedule maintenance work more flexibly and on demand. We will also see predictive maintenance increasingly using an array of data, not only from vehicle and assets, but also from other sources e.g. weather data. This will greatly increase the reliability of transport operations.

The high tech content of machinery aboard ships are increasing, as are the skills-level requirements of the personnel that perform maintenance tasks on this machinery. Nowadays, on modern ships the status quo is moving towards propulsion systems that are under continuous monitoring by the manufacturer. Increasingly, maintenance

tasks (e.g. software updates) are either performed directly and remotely by the manufacturer, by the ship crew who are guided remotely by the operator, or by service teams of the manufacturer that board the ship for short periods of time. In this situation, first operators consider scenarios where the number of officers in the engineering department aboard is further reduced, and maintenance work is contracted to service providers of the equipment manufacturers⁸.

For such scenarios to happen, a high level of reliability of systems under seagoing conditions needs to be achieved and systems are needed that require less maintenance. In case of a defect, the affected system must be able to enter fail-safe mode, ideally providing residual functionality until an external repair crew reaches the vessel. This repair crew must be able to reach and board the ship, and be highly skilled to perform repairs on the specific type of system. It is envisaged that such crews will be located in service centres around the globe. By employing “digital twins”, it will become possible to plan and test maintenance procedures on a digital model of the system, before intervening in the actual operations of the ship^{9,10}. Digital twins will also make it possible to plan more flexible inspection intervals with classification societies, known as “condition-based class models”¹¹.

Technologies that enable remote controlled maintenance operations include virtual reality and high-bandwidth global communications networks with a high level of reliability and security. Airborne and underwater drones will provide maintenance crew remote access to parts of the ship that are hard or dangerous to reach. Scenarios in the more distant future envisage repair robots aboard vessels that can perform repairs which will be remotely controlled by a maintenance crew.

1.2.3 Automation for customer interface

Customer interface in the maritime domain are particularly important for freight transport and logistics, as well as for consumers. Freight transport and logistics users are now accustomed to capacity-sharing platforms¹², which provide information on available connections and are gradually enhanced by booking and payment functionalities. In the future, there will be services that cover multimodal transport solutions that select the optimal transport modes for legs of the transport chain (see Figure 1-4).

Technological prerequisites for making use of interfaces between transport modes include standardized data formats, methods for assuring data integrity, e.g. blockchain technology and methods for data analysis (“big data”). Together with the Internet of Things, these are the top three issues, as perceived by the maritime industry, “both in its impact on seaborne trade and in the likelihood of its occurring over the next ten years” (Global Maritime Forum, 2018).

⁸ Personal communications with Dr. Max Johns, Managing Director of the German Ship Owners’ Association, 16 April 2018.

⁹ <https://www.dnvgl.com/services/data-smart-asset-solutions-digital-twin-65556>

¹⁰ <https://group.bureauveritas.com/insight/veristar-aim3d>

¹¹ <https://www2.eagle.org/en/news/press-room/abs-makes-the-case-for-condition-based-class-model-ons.html>

¹² For instance, web-based information services such as the HAPAG LLOYD service finder (<https://www.hapag-lloyd.com/en/service-finder/bydeparture.html>), or MAERSK schedules (<https://www.maersk.com/schedules>).

FIGURE 1-4 Illustration of planning of multimodal transport chains

For consumers, web interfaces and mobile apps will make it possible to access a new range of services (see section 1.2.4). Technologies, such as chatbots and natural language processing, will improve the convenience and the quality of the interaction between customers and automated systems. However, this development is likely to have a negative impact on the number of service centre employees.

1.2.4 Automation for planning and new services

An increasing degree of interconnectivity of transport modes makes it possible for current stakeholders and new players to create novel types of services that address demands of customers and transport service providers. We are now witnessing the emergence of new and innovative services and platforms with the potential to further enhance mobility planning and provision, for instance, Mobility as a Service (MaaS) applications for customers and availability-oriented business models for transport providers. With such systems in place, end consumers will be able to book logistics services directly from transport providers, which is likely to result in a reduction of back-office staff. A study conducted by the Global Maritime Forum points out that the “increasing influence of non-maritime disruption” and “artificial intelligence” are the two issues the maritime industry feels least prepared for right now (Global Maritime Forum, 2018).

A large application area for private customers is the planning and booking of leisure trips on passenger ferries and cruise vessels. In the leisure travels sector, operators offer a range of products, satisfying diverse customer interests; but the consultancy on matching cruises to customer interests and on cruise-planning are currently largely still in the hands of specialized travel agencies. In the future, sophisticated customer support systems, which make use of big data analysis and can be accessed either via web-based applications

or through mobile apps, are expected to increasingly put pressure on travel agents who are specialized on brokering cruises.

Advances in the area of additive manufacturing (“3D printing”) are expected to influence maritime transport in two ways. First, 3D printing will achieve a level of maturity that makes the production of industrial quality spare parts possible (Geissbauer, Wunderlin and Lehr, 2017). Hence, a range of spare parts will not need to be kept aboard the vessel or shipped long distance, but can be produced on demand in specialized printing shops located in the vicinity of harbours around the globe. Secondly, by means of 3D printing a range of the transported goods can also be produced locally or regionally. This will omit the need for transporting these goods — and the packing that is currently required to protect goods during the journey — over long distances. Instead, the raw material for 3D printing of the goods will be transported, i.e. plastics, nylon, metal, ceramics and organic materials. This development will have a significant impact on transport volumes and transport routes.

Finally, timely access to operational on-board data via data networks will make it possible to create availability-oriented business models. As is already becoming standard practice, the manufacturers of modern ship machinery are able to monitor the condition of the machinery remotely. In case this monitoring indicates that adjustments to operations or maintenance become necessary, the ship crew can be advised or a repair crew can be dispatched in time to board the ship at the next harbour. In a further step of this development, instead of a purchasing a piece of equipment, an operator will purchase or lease the availability of the function that is provided by a piece of equipment from an external service provider. Hence, the responsibility for planning of all maintenance is moved from ship to shore¹³.

¹³ Such developments are already taking place in other transport domains. For instance, in the tyre industry, Michelin tyres offers “*Michelin fleet solutions*” (<https://www.michelintruck.com/services-and-programs/michelin-fleet-solutions/>). A trucking company no longer purchases physical tyres, but makes leasing contracts with the service provider for supplying tyres and maintenance services that guarantee to the customer “the capability of moving safely for a certain distance”.

1.3 TRANSPORT TECHNOLOGY ANALYSIS

In this analysis, the most relevant trends in each transport mode were reviewed with respect to economic benefit, regulation and governance, technical feasibility, social acceptance, knowledge and skills and labour market dynamics.

- *Economic benefit* encompasses all the benefits that businesses and society can gain from technology minus its opportunity cost. The opportunity cost concerns not just the financial cost, but also what is lost by not choosing other alternatives.
- *Regulation and governance* covers the local and international regulations necessary to the technology being operated in non-confined environments. For such regulations to emerge, policies endorsing such technologies have to be pursued. Generally, social acceptance is a prerequisite for both.
- *Technology readiness* describes the level of maturity in terms of technology and certification¹⁴. Novel technologies that are required to implement trends in each cluster are listed in Annex 2.
- *Social acceptance* describes to what degree society approves the novel technology.
- *Knowledge and skills* covers the skills that are required by the future workforce that interacts with novel technologies.
- *Labour market dynamics* addresses the immediate effects of the technology on the labour market.

Judgment of these factors makes it possible to estimate the “start-up curves” for each trend. The following tables provide a summary of the findings for each of the six factors by cluster.

1.3.1 Core automation functionalities

1.3.1.1 Automation of traffic management

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	<p>Today, vessel traffic services (VTS) are currently in operation in the vicinity of major ports and in highly frequented rivers and sea areas.</p> <p>Automation of traffic management would primarily affect officers and ratings. Concentrating ship operations in operation centres is likely to lead to an overall reduction of nautical crews. However, in the current environment, crew costs are not a major factor, so currently the economic benefit is considered low.</p>
II. REGULATION AND GOVERNANCE	<p>Preliminary results of the ongoing scoping exercise at IMO exhibit two main challenges with respect to remote and autonomous operations. First, a person needs to be in charge. Secondly, all maritime regulations assume that the person in charge resides aboard the vehicle. Both challenges require a substantial evolution of maritime regulations. However, concerns have been raised if the regulations will be available in 2030 as anticipated by MSC 99 (May 2018).</p>
III. TECHNICAL FEASIBILITY	<p>In its current stage of development, vessel traffic management (VTS) has a recommendatory role. Situations are observed and advice is provided to ship crews, but the final decision lies with the captain. It is technically feasible to assign control centres a more active role (e.g. as the Carnival Fleet Operations Centre in Hamburg illustrates). The main challenge is a secure, robust and reliable worldwide data connection with sufficient bandwidth (an issue that is expected to be resolved to a certain extent by 2030) and IT security.</p>
IV. SOCIAL ACCEPTANCE	<p>There is unlikely to be any social concerns over changes to the operation of traffic management centres, with the exception of potential concerns over enforcement through the private sector and maritime safety if it includes managing movements of automated vehicles.</p>
V. KNOWLEDGE AND SKILLS	<p>Staff in control centres will be faced with the challenge of performing operations remotely, considering not only different types of vessels/machinery, but also the different performance envelopes of the vehicle/equipment under control. One challenge will be to consider the environmental impacts on the equipment under control.</p>
VI. LABOUR MARKET DYNAMICS	<p>Traffic management operators may initially be recruited from nautical officers who gained operational experience on ships, but who will increasingly be educated on land only.</p>

¹⁴ For instance, at the time of writing, systems are undergoing test operations that are technically capable of operating autonomously, but it seems fair to conclude that the safety assurance of autonomous systems is not a mature discipline (McDermid and Daffey 2018).

1.3.1.2 Automation of driver or operator tasks

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	<p>The most dominant cost factor in maritime transport currently is fuel, not labour costs. Hence, driving factors that could promote automation are fuel saving and environmental restrictions. Nevertheless, operators are investigating possibilities of further reducing crew numbers, particularly officers, although they will keep a “residual crew”.</p>
II. REGULATION AND GOVERNANCE	<p>On the international level, at MSC 99 (in May 2018), a working group was tasked to review the international regulations with respect to the adaptations that are necessary for autonomous ships. (See MSC 99/WP.1/Add.1)</p> <p>Previous work contracted by Denmark (MSC 98/INF.13 and MSC 99/INF.3) pointed to recommendations, including the following ones:</p> <ul style="list-style-type: none"> - Autonomous ships are, to the greatest possible extent, regulated internationally by the IMO to ensure that new autonomous ship types can operate in as large a geographical area as possible and to avoid jurisdictional issues. - National test areas are regulated through permits/exemptions on individually adapted terms rather than through general rules. - The regulation of autonomous ships should be drawn up so that the role of the classification societies in relation to autonomous ships is shifted from the component/equipment level to the systemic and operational level. - The national and international regulation of autonomous ships should be a goal-based framework regulation. <p>Options for implementing new legislation are:</p> <ol style="list-style-type: none"> (1) To create a new code on autonomous ships; or (2) To include the topic of autonomously operated ships in various passages of existing legislation. <p>Currently, the majority of stakeholders consulted appear to prefer option 2. Moreover, the European Union (EU) should not itself regulate any issues related to autonomous ships that are regulated at the IMO level. At the IMO level current provisions are being assessed in the MASS Working Group to determine the preferred option.</p> <p>Expected time frame:</p> <ul style="list-style-type: none"> - “regulatory scoping exercise”: completion by 2022 - rule development: typically 8-12 years - rules into force: earliest 2035 <p>On a national/regional level, initiatives are on the way, most notably in Denmark, Japan, the Netherlands, Norway and the United Kingdom.</p> <p>If business cases for specialized trades in certain regions of the globe emerge, there is a possibility that “regional legislation” will be created by bilateral contracts.</p> <p>However, the majority of administrations and policy-makers prefer to develop international regulations first.</p>
III. TECHNICAL FEASIBILITY	<p>Technology enabling the implementation of higher levels of automation is currently being developed across all transport modes. While few stakeholders actually see unmanned ships entering service in the foreseeable future, the majority of ship operators expect future ships to be operated by a smaller number of officers who in the future will be assisted by both higher automation levels on board and by shore-based service providers. To make reliable remote support of operations possible, reliable and secure communications need to be implemented.</p> <p>First, ports, e.g. Singapore, are currently starting to develop autonomous and remotely operated support ships and infrastructure for support of autonomous merchant vessels. Here, the aim is to create an operative advantage over regional competitors.</p>
IV. SOCIAL ACCEPTANCE	<p>From a societal perspective, autonomous ships present the following potential:</p> <ul style="list-style-type: none"> • An environmental advantage due to fuel savings and new means of propulsion • Enhanced safety both in open waters and in ports • Significantly increased cost-efficiency and productivity • Optimization of the logistics chain via IT solutions • Improved infrastructure for, inter alia, transport to and from islands and for densely trafficked routes.

1.3.1.2 Automation of driver or operator tasks (Contd.)

KEY ISSUES	SUMMARY OF FINDINGS
V. KNOWLEDGE AND SKILLS	Assuming that navigation will be replaced by automation, the remaining jobs will require a different skill set, with more sophisticated service industry sector and back-office tasks being carried out in addition to vehicle supervision. Further challenges will emerge when a controller operates more than one vessel simultaneously.
VI. LABOUR MARKET DYNAMICS	The precise labour market effects depend on the use cases for ship automation, the speed of implementation and the disruption potential of the technology, which tends to be slow in the maritime industry compared with road transport, for example. Nautical officers will be most affected. They will face a transition of work from controlling operations aboard the ship to remote controlling of the vessel from a control centre. The resulting new work patterns and working hours may contribute to making the job of the seafarer more attractive, and make it easier to secure skilled crews (Deloitte's Global Shipping and Ports group, 2011).

1.3.1.3 Automation in harbours

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	Beyond mere efficiency improvements, the focus of efforts in harbour automation is part of a long-term strategy and plan to provide novel services in order to remain competitive. Ports are a special node in the transport chain where different transport modes are merged. From a technical perspective, this position offers possibilities for newly integrated services, such as route optimization.
II. REGULATION AND GOVERNANCE	With respect to automatic vehicle operations, few legal challenges exist as long as automated vehicles operate on private grounds. There are open issues on how to regulate automated harbour vehicles that need to cross public roads when moving between different areas of the harbours (e.g. as is the case in the Port of Hamburg HHLA Container Terminal Altenwerder (CTA). Some challenges need addressing concerning the possibility of novel integrated services, e.g. regarding the preservation of intellectual property rights when merging data from customers of different transport branches.
III. TECHNICAL FEASIBILITY	Mature technology that allows for automatic port operations is already available and in operation. However, it should be noted that all existing fully autonomous ports are newly built, and are not the result of renovations or extensions of previously existing ports. Existing seaports invest in digitalization of specific services, such as specialized autonomous ground vehicles (AGVs, cranes, diggers), and they are involved in research projects on autonomous support vessels (e.g. tugs). There are also a number of programmes on integrating different entities of the transport chain in networks, in order to optimize cross-modal transport flows. Future challenges go beyond mere efficiency improvements and focus on a holistic, long-term strategy. (Examples: in Europe: smartPORT (Hamburg), Smart Port Rotterdam, Smart Port Antwerp; in Asia: Singapore's PIER 71 Smart Port Challenge)
IV. SOCIAL ACCEPTANCE	A frequently cited fear of port automation is a loss of the workforce at least for the "evolutionary" digitalization developments in existing ports. Examples such as Container Terminal Altenwerder (Hamburg) have shown that the reduction of labour can be limited, but requiring a set of competencies that is different from conventional terminals. Others, such as Port of Los Angeles have proven to have limited social acceptance.
V. KNOWLEDGE AND SKILLS	There is a transfer of low-skilled jobs to new types of medium and highly skilled jobs. There are also examples of physically demanding jobs that, through supporting automation, now become accessible to a wider range of personnel. For example, cranes can be operated remotely from control centres, omitting the requirement of being able to climb ladders to the crane cabin. The training needs for the new upcoming and changing jobs resulting from increasing automation and technology are currently being discussed in various fora.
VI. LABOUR MARKET DYNAMICS	The strongest impact will be on low-skilled job profiles. There will be an increased demand for the medium- and high-skilled workforce. In these areas, ports will have to compete against other industries for a skilled workforce. In Europe, ports are currently able to cover the demand of skilled personnel by offering competitive salaries.

1.3.2 Automation of vehicle maintenance

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	Maintenance regimes that allow for a more flexible scheduling of maintenance tasks and optimal alignment of maintenance and journey planning offer an economic benefit. Locating highly-specialized maintenance staff in control centres, from where they can maintain a fleet of vessels on demand, may come at a lower cost than placing highly-skilled maintenance staff aboard each ship.
II. REGULATION AND GOVERNANCE	Regulations need to be adapted. Most classification societies are already engaged in projects on including predictive maintenance in their rule sets. Issues under discussion include ownership of the data that is generated by the large amount of sensors aboard and that can be commercially sensitive, as the data is collected from machines and systems that are provided by different manufacturers.
III. TECHNICAL FEASIBILITY	<p>Predictive maintenance of vehicles and machinery has been a field of research in various transport and manufacturing industries for decades, including the shipping industry. Products have reached a level of maturity that makes it possible to deploy and operate sensors and recording units that are capable of operating reliably in harsh environments aboard ships.</p> <p>With an increasing number of systems and components that collect data, the processing of this data has become a challenge. If this data is transferred to land, reliable global communications solutions need to be provided that offer data security and high bandwidth. The industry expects to be able to deliver such solutions on a wide scale within the next decade¹⁵.</p>
IV. SOCIAL ACCEPTANCE	The introduction of predictive maintenance will have an effect within the industry, but this is not a development that will attract much public notice or scrutiny. Maintenance personnel that operates from control centres on land will have more socially acceptable jobs than crew that travels aboard ships for extended periods of time.
V. KNOWLEDGE AND SKILLS	As systems aboard ships become more sophisticated and interconnected, the maintenance staff needs to be trained to keep up with the required skills. Just as the evolution from mechanics and electricians to mechatronics took place, e.g. in the car industry, new skills need to be acquired by maintenance crews in shipping, including IT skills (algorithms and communications) and electronics (e.g. sensors).
VI. LABOUR MARKET DYNAMICS	Performing maintenance tasks remotely can reduce the number of highly qualified personnel that needs to work aboard each ship. Future maintenance crews could consist of a smaller number of crew members on board, who are qualified to perform more general tasks, and who, on demand, can be instructed in remote collaboration with highly-qualified experts in centralized service centres. Such service centres might not be run by the ship operators but by third party service providers. The possibility of working in such service centres instead of aboard ships for extended periods of time might attract new personnel.

1.3.3 Automation for customer interface

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	Maritime transport operators and transport alliances already started to offer transport planning and booking platforms to registered customers. These platforms can provide economic benefits to both customers (e.g. through direct and fast search of adequate services) and operators (e.g. through direct booking and improved use of the available transport capacity).
II. REGULATION AND GOVERNANCE	No regulatory or governance conflicts are foreseen. All data must be processed and transferred securely.
III. TECHNICAL FEASIBILITY	The necessary core technologies (databases, secure communications, web-based and app-based interfaces) have already been developed in other industries and can be/currently are being introduced in the maritime industry. Front-end technologies, such as natural language processing and chatbots with AI, are expected to experience significant improvements within the next decades.

¹⁵ Personal communications with various satellite company representatives at the SMM 2018 international maritime trade fair.

1.3.3 Automation for customer interface (Contd.)

KEY ISSUES	SUMMARY OF FINDINGS
IV. SOCIAL ACCEPTANCE	Being able to book services directly from the transport service provider might be attractive to customers. As we have seen in other domains, the issue of data security will need to be addressed here as well. But solutions are being developed that can be applied across industries.
V. KNOWLEDGE AND SKILLS	Most knowledge on online search and booking mechanisms that are acquired in other domains in everyday life can be transferred to the search and booking of shipping services. This trend affects service personnel and end consumers in the same manner.
VI. LABOUR MARKET DYNAMICS	The introduction of automation in information provision and bookings continues. This is likely to have a negative effect on the number of employees in the service sector.

1.3.4 Automation for planning and new services

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	Automation for planning can result in transport services that are more flexible with respect to customer demands. The implementation of such planning services requires integration of cross-modal transport resources. This might be a business case for new service providers. Similarly, in industrial 3D printing, e.g. of spare parts and goods, we may see a new group of manufacturers that are able to provide goods on demand, both in time and in place.
II. REGULATION AND GOVERNANCE	Service providers offering cross-modal transportation solutions face challenges with respect to customs. In the context of 3D printing, the topic of intellectual property rights of the printed product needs to be resolved.
III. TECHNICAL FEASIBILITY	With respect to cross-modal transport solutions, the main technical challenges are big data processing, data analytics and data science. These are all the subject of intensive research and development across industries, which have yielded existing solutions and expected improvements. In the field of 3D printing, the technical challenges are larger. In particular, finding a wider range of printing materials and new ways of printing a combination of materials are major challenges.
IV. SOCIAL ACCEPTANCE	Main concerns are with respect to general data privacy and intellectual property rights.
V. KNOWLEDGE AND SKILLS	Only secondary effects are present in the tech sectors developing these solutions.
VI. LABOUR MARKET DYNAMICS	While new platforms and transport services may well prove to be highly disruptive, particularly once vehicle automations become part of the business and service model, their effects on transport workers in service planning roles are likely to be only minimal.

1.4 ESTIMATION OF QUANTITATIVE IMPACTS

The qualitative findings summarized are expanded to include a quantitative assessment of the impact of the six factors on labour. The assessment begins with explaining the correlations between the development of the six factors and the demand for labour. The impact of the six factors for each technology

category are judged from a labour demand perspective. A factor is deemed “negative” when its development impacts negatively on labour demand; “neutral” when its impact is expected to be nil or only marginal; and “positive” when the factor is favourable to labour in the foreseeable future.

KEY TECHNOLOGY CATEGORIES	JUSTIFICATION					
	Economic benefits	Regulation and governance	Technical feasibility	Social acceptance	Knowledge and skills	Labour market dynamics
Core automation functionalities Traffic management	●	●	●	●	●	●
Core automation functionalities Driver or operator	●	●	●	●	●	●
Automation of vehicle maintenance	●	●	●	●	●	●
Customer interface	●	●	●	●	●	●
Planning and new services	●	●	●	●	/	●

● Negative effects ● Neutral effects ● Positive effects / Not applicable

1.5 DEVELOPMENT OF START-UP CURVES

The previous findings are compiled into quantitative judgments in the form of start-up curves (s-curves). The start-up curves sought to capture the process through which technology historically develops. These curves are widely used to model technology development as most technologies follow this pattern. The six factors identified before are an internal part of the curves, as a change in those factors is likely to affect how the curves are shaped. The curve in Figure 1-5 refers to the adoption of highly automated ships (SOLAS manned ships

that are more high tech thereby leading to a crew reduction) as a percentage of the world fleet. This curve shows that for maritime transport the adoption of novel technologies traditionally happens in incremental steps (see Figure 1-5). The adoption of highly automated ships under human supervision is expected to reach between 11 per cent to 17 per cent by 2040, and these ships are expected to operate short to medium distances and in specialized trades.

FIGURE 1-5 Adoption curve for highly automated ships (SOLAS ships, with reduced crew onboard)

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AIR TRANSPORT

2

2 AIR TRANSPORT

2.1 INTRODUCTION

In the past decades, new technologies such as autonomous vehicles, big data and artificial intelligence have been developed at impressive speeds, which promised to bring the world's economy into a new age of automation. The McKinsey Global Institute (2017a) predicted that although only 5 per cent of all occupations can be automated entirely, 60 per cent of all occupations can automate at least 30 per cent of associated job activities. Studies have found that technological progress usually creates new jobs in addition to removing repetitive activities. Thus the total number of employment may not decline significantly economy wide (McKinsey Global Institute 2017b). Nevertheless, the impacts to specific industries can be substantial and imbalanced. It is therefore important for stakeholders to understand imminent changes and develop the right strategy in advance.

This section focuses on the employment effects of technological progress and automation in the aviation sector, and attempts to explore possible scenarios of technology adoption and productivity growth. Some notable observations follow hereunder:

- In many cases, new technologies and automation solutions have been developed to improve system performance in terms of safety, speed and service quality. With the trend of airport privatization and increased airline competition, many organizations are putting high priority on efficiency-improving automation and technologies.
- Coordination and cooperation between multiple stakeholders are often needed for new automation

systems to be introduced in the aviation sector. Changes in business process and government regulation may also be necessary, especially for safety-related operations.

- Disruptive technologies may emerge in selected sectors, notably airport passenger operations, customer and sales services and cargo logistics. In other cases, smart technologies allow full automation to be implemented at flexible scales, allowing even small airports to adopt full automation. These innovations are likely to have more significant impacts on low-skilled labour. Countries and airports that face shortage of low-skilled labour, such as Japan and Hong Kong, are eager to expedite the automation process. Companies facing strong labour unions may also have additional incentives for automation.
- We expect selected new technologies to be progressively introduced in areas such as airport passenger processing, autonomous vehicles, cargo/luggage processing and supporting infrastructures. New technologies and automation solutions will be progressively adopted in selected markets by 2025, followed by system-wide implementation in the following decades.

The following section reviews prominent technologies and automation solutions, followed by a review of labour productivity growth in the aviation industry. The last subsection proposes possible scenarios of technology adoption, and changes in labour demands.

2.2 PROMINENT TECHNOLOGIES AND ENABLING FACTORS

With new technologies being introduced at unprecedented rates, it is impossible to review and evaluate all innovations and automations that may be adopted in the decades to come. Therefore, we classify prominent technologies into four categories so that exemplary automation solutions within each category can be reviewed. Such an approach allows us to identify industry trends based on the analysis of a limited number of sample technologies. Specifically, the following four categories have been used for classification purpose. These are: automation of core functionalities; technology and automation related to maintenance; new technology on customer interface; and new technology-enabled services. They are reviewed in detail in the following subsections.

2.2.1 Automation of core functionalities

There are significant network effects in the aviation industry. For example, a flight delay is likely to cause delays of the subsequent flights performed by the same aircraft. A sharp performance and/or capacity decline at one hub airport, such as those caused by bad weather and major incidents, may spread to other parts of the network. That is, network effect incidents at one airport may lead to system-wide problems. To address such "propagation effects", the air transport industry puts high priority on improving coordination and cooperation among different stakeholders such as airlines, airports, air traffic control and regulatory agencies. The adoption of major technologies and automation schemes often requires a

system-wide cooperation and readiness check. One notable example is the so called next-generation air transport systems, which comprise many different modules and systems. These systems typically involve multiple technology/service providers and regulators, sometimes across country borders.

Next Generation Air Transport Systems

To enhance safety and operational efficiency, leading economies are developing the so-called next generation air transport systems. Notable examples include the Next Generation Transportation System (NextGen) in the United States and the Single European Sky ATM Research (SESAR) project.

NextGen is a large system-wide modernization plan led by the Federal Aviation Administration (FAA) in the United States, with the aim to improve the safety, efficiency and predictability of air transport systems. In addition to new technologies, related operational procedures also need to be revised and re-organized, notably in the areas of Multiple Runway Operations (MRO), Performance Based Navigation (PBN), Surface Operations and Data Sharing and Data Communications. There are several key elements included in the NextGen. For example, the Automatic dependent surveillance-broadcast (ADS-B) system utilizes satellite signals to provide accurate location-related information to air traffic control systems and pilots. This ensures that aircraft are safely separated in the sky and on the ground.

The Next Generation Data Communications system replaces voice communication with data exchange. This allows information update to be automatic, so that automated systems can identify safety risks and alerts prior to human intervention. The Next Generation Network Enabled Weather (NNEW) system integrates global weather and sensor reports into one system. This enables better operation decisions to be made based on weather and operational conditions on the ground and in the air. The System Wide Information Management (SWIM) system integrates different information and data into one platform, ensuring consistent and comprehensive data supplied and shared by all stakeholders.

NextGen is a long term project involving multiple modules, and is expected to be continuously improved beyond 2030. As of today, major improvements have been implemented in selected airports and corridors in the United States leading to improved performance and increased capacity.

NextGen is an ongoing system innovation that involves timely information updates and exchanges, operations automation and performance monitoring. Although automation replaces some human activities (e.g. replacing voice communication with automatic data exchange¹⁶), the main benefits are increased system capacity, efficiency and safety. With sustained growth in traffic volume, network size (e.g., number of airports served) and information available at real time, more automation functions need to be incorporated to reduce the complexity and workload of key personnel, such as air traffic controllers.

The SESAR is another ongoing project under the Single European Sky (SES) initiative, with an aim to improve air traffic management (ATM) performance and construct an intelligent air transport system in Europe. Currently, the SESAR 2020 programme has been allocated a budget of €1.6 billion till 2024 to focus on four key areas -- airport operations, network operations, air traffic services and technology enablers. A large number of systems and applications have been tested/adopted in selected airports, such as collaborative decision-making (CDM), advanced dynamic capacity-balancing (DCB), integrated network operations plan (NOP), airport operations plans (AOPs), often with the assistance of system-wide information management (SWIM) and communications, navigation and surveillance (CNS) systems.

With extensive information exchange and the use of IT systems, SEARS enhances the system automation level, reduces operational costs and fuel consumption, and increases airspace and airport capacity, system predictability and efficiency. These benefits are more important than labour input savings. Because these systems involve multiple functions and systems, stakeholders must work jointly on issues such as data exchange and process standardization, performance monitoring and safety checks.

Airport Automation Technologies

Productivity and efficiency growth is of increasing importance to airports. Many airports have been commercialized, corporatized and/or privatized. Managers now face more pressure from shareholders and investors to continuously improve efficiency. In addition, airport investments are sporadic and expensive. Adding capacity is a complex and lengthy process. With sustained traffic growth, airports are forced to increase the productivity and utilization rate of existing terminals, runways and supporting facilities. As a result, many new technologies have been/are being introduced at airports, such as Machine Readable Travel Documents (MRTDs) and Advance Passenger Information System (APIS); radio-frequency identification (RFID) for luggage and cargo handling; Air Cargo Automation; Baggage Handling Automation and Self-Service Kiosks; Converged Integrated Airport Solutions (CIAS); Flight Information Displays Systems (FIDS); Building Integration System (BIS); and Luggage 3D-scanning, among others. The functions and benefits of selected systems are briefly summarized below:

- MRTD and APIS systems allow machines to read and validate various passenger IDs, such as passports and visas, crew member certificates, biometric IDs, and to recognize a large number of faces in near-real-time. Combined with artificial intelligence, these systems automate and expedite security check and immigration clearance of passengers and airport employees. The use of face recognition software is being used beyond security check points to increase security operations throughout the airport area.
- Air Cargo Automation and Baggage handling automation systems have already been implemented in the airport industry for some time. Combined with Automated Storage and Retrieval Systems (ASRS) and modular

¹⁶ See, for example, systems such as the Terminal Flight Data Manager (TFDM) and En Route Automation Modernization (ERAM)

designs, they are becoming more efficient, expandable and capable of handling more types of freights (e.g. express/general air cargo, passenger baggage and aircraft equipment). Baggage handling automation facilitates luggage screening, conveyance, storage and retrieval and loading and unloading functions. In some airports, the use of RFID further enhances automation by removing the need for manual bar code scan. Self-Service Kiosks, which allow passengers to check in with minimum staff support, reduces customer queuing time and airport labour needs.

- Robot loading/unloading. This includes loading/unloading of cargo and bags, including operations such as Unit Loading Device (ULD) staking and cargo build-up; transport to/from aircraft stands and cargo terminals; and loading/unloading to/from aircraft. Although most of these functions are still performed manually, automated systems are being developed and introduced.
- Converged Integrated Airport Solutions (CIAS) integrates different systems to common platforms using open standards and protocols. For example, a Flight Information Displays Systems (FIDS) and Flight Information Management Systems (FIMS) can collect, store and exchange various data related to flight information within and beyond airports. This allows different stakeholders such as passengers, airlines, airports, public transport operators, ground handling and professional services to improve their planning. With better planning and coordination, operational efficiency and service quality can be improved. In other cases, a Building Integration System (BIS) link different subsystems together, such as fire alarm and control, access control, CCTV and monitoring, lighting control and people movers. Such common platforms open doors for better coordination and planning at the airport level.
- Driverless vehicles. Various driverless cars and autonomous vehicles are being tested and introduced in airports. For example, self-driving aircraft-towing vehicles facilitate airport ground operations and handling. Existing cargo vehicles and shuttle buses may also be replaced with autonomous vehicles. With better coordination and management, the number of moving vehicles at airports can be reduced. This reduces incidents and accidents,¹⁷ as well as the demand for human drivers. Driverless wagons and tug vehicles are being used in baggage transport and airport ground transportations too (see, for example, Remote Controlled Tug Vehicle (ROTV) and Automated Aircraft Towing Vehicle Systems).

Whereas many of these technologies have already been introduced and used in selected markets, they are still evolving quickly with new features and concepts incorporated. Baggage handling system can be used as an example. Many airports have made substantial investments for sophisticated baggage handling systems that include improved automated baggage conveyers, storage, transfers and various levels of x-ray scanning. The complexity of such large integrated systems often requires in-house maintenance teams and

large capital investments. Companies like Vanderlande are introducing new modular systems.¹⁸

Instead of using fixed and integrated luggage conveyors, automated guided vehicles (AGVs) are used to convey bags to destinations (e.g. X-ray scanners, loading/unloading stations) that can be dynamically assigned. Compared with existing systems, such solutions offer more flexibility and reliability: with increased demand, capacity can be progressively expanded with more AGVs. Locations of X-ray scanners and loading stations can be conveniently chosen and changed.

The failure of a few AGVs and loading stations does not prevent the rest of the system from operating. As a result, the new generation system brings more flexibility, scalability and resilience, thereby allowing full automation to be feasible and affordable even for small airports. These types of innovations, while not offering radically new functions, could bring significant changes to the aviation industry by lowering the technical and monetary barriers of full automation. These types of innovations are expected to reduce the need for low-skilled labour, such as cargo loading/unloading, baggage handling, cargo build-up, security check, among others, while moderately increasing on-site technical support employment.

2.2.2 Automation of maintenance

Many vehicles and equipment are used at airports (e.g. aircraft tugs, baggage vehicles and cargo loaders, de-icing vehicles, airfield starter units, catering trucks, tank trucks, transfer buses, ambulances, ground power units, lavatory service vehicles and lift trucks). The automated maintenance of vehicles being developed in the car manufacturing industry will be progressively introduced to the airport sector. Because related analysis is available in other sections of this report, they are not discussed further in this section.

On the aircraft side, a jet aircraft comprises several millions of components, and can be used for more than 20 years. This implies that significant costs will be incurred related to maintenance, repair and overhaul services. Well-defined maintenance procedures have to be strictly followed. In addition to scheduled maintenance and checks (e.g. A, C, D checks), line maintenance and running repairs may be triggered by data collected from thousands of sensors installed in an aircraft.

The maintenance procedures and associated data collection/reporting have been defined and monitored by multiple stakeholders including the aircraft manufacturers (e.g. Boeing and Airbus), regulators (e.g. Maintenance Review Board Report (MRBR) and FAA), and inter-governmental/industry associations (e.g. the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA)). These strict requirements and regulations focus on performance check and quality control, allowing for procedural innovations by different identities. Maintenance robots and procedures developed for military aircraft can be adopted for commercial aircraft after industry endorsement. For example, Sandia National Laboratories has developed

¹⁷ Autonomous vehicles are expected to be safer than human drivers in the long term since drivers tend to be distracted.

¹⁸ For more details, see <https://www.vanderlande.com/>

robot for aircraft surface finishing, and software for aircraft maintenance planning.¹⁹ With many sensors installed in an aircraft, engineers can scan aircraft systems easily, identifying components in need of replacement or repair.

This also allows suppliers to identify parts nearing the end of their life. Prescriptive maintenance further enables engineers to not only predict what will happen, but offer what-if scenarios to show how each possible event may impact operations. For example, instead of simply replacing some parts every three months, it may be better to pinpoint when a part will actually reach its lifespan, and then determine if a repair or replacement is the best option.

With vast amounts of data being collected through sensors and Internet-of-Things (IoT), prescriptive maintenance will be further advanced in aircraft maintenance operations. Micro-robots are being developed for inspection and maintenance of hard-to-reach parts, such as aircraft engines.²⁰ Automated carbon fiber placement machines are being developed to replace manual work and increase operational efficiency. Many automation technologies are being developed in the aviation industry.

Government agencies have encouraged and/or contributed directly to automation technologies. For example, the FAA sponsored the Carnegie Mellon Research Institute to study automated inspection of aircraft.²¹ The project developed robots, sensors and software that can automate the inspection. Applications are also being developed to use drones to inspect aircraft.²² To enhance Europe's global competitiveness, the European Commission supports the Horizon 2020 programme, which secured close to €80 billion in support for the period 2014-2020. Automation in aircraft repair and maintenance has been listed as an important area under the RepAIR project within Horizon 2020. In another project, the Additive Manufacturing Optimization and Simulation (AMOS) Platform, efforts are made to develop automatic methods and models to quantify damage and to repair and remanufacture components.

Technologies being developed in other sectors, such as blockchains and 3D printing, are also being introduced into the aviation sector. Airbus conducted a study of blockchain in 2016 which identified multiple market potentials.²³ One possible application is to distribute sensitive design and manufacturing data via blockchain securely to 3D printing facilities located in different countries. Aircraft can thus always receive maintenance and repair services in a timely manner. Blockchain technology also helps to create a secure way of sharing and managing information related to the procurement of aircraft parts and to maintenance history among different service providers. These innovations' impacts on employment should be quite moderate, as they mainly focus on service quality enhancements.

2.2.3 Automation for customer interface

Labour has always been a major cost component of airlines. Labour unions have been quite strong in the aviation industry. As a result, companies in the aviation industry have put high priorities on labour-saving solutions, and the sector has been a pioneer in adopting automated customer service solutions. Online ticketing, payments and other sales support (e.g. miles redemption, seat selection, change or upgrade tickets, extra luggage and the order of meals) are now standard functions. Companies like Ryanair and Heathrow airport are turning their websites into portals that also offer advertisements of services, such as hotel reservations, car hire and holiday packages.

In addition to these functions, new services are being developed in the areas of customer interface, often powered by AI and Big data technologies. For example, AI powered Chatbots are being developed to help sell products or answer customer inquiries. In other cases, computers offer suggestive solutions to assist human agents to make the final decision. For example, the Dutch airline KLM developed systems to assist customer service. The system first processes questions and answers used by operators previously. When a customer agent receives phone calls, suggestive responses will be retrieved from a database and displayed in front of the agent's computer for consideration. For standard and repetitive questions, automated and prepared answers are offered without the intervention of humans. Such virtual assistant service thus shortens the response time and increases employee productivity, instead of completely replacing human activities.

The airline resorts to such an approach as "a personal approach is extremely important to KLM as this is what defines our social media service. Applying AI, KLM can handle a greater volume of questions while still maintaining its personal approach and speed."²⁴ Apparently, such systems may be further improved by integrating with existing knowledge management systems. In other cases, AI-backed customer interfaces also allow airlines to collect more data in a systematic way, so that airlines can both solve specific problems and better understand customers' behaviour, decision-making and preferences.

Robots have also been used in customer services. Japan Airlines, Glasgow Airport and EVA Air have all presented their robot customer service agents. For example, the robot used by JAL can speak multiple languages, and provide information related to flight status and weather conditions.

Although some customizations are inevitable, we expect the airline industry to adopt many customer interface applications that are based on common platforms. As a result, the impact on labour employment will be similar to other transport modes and industries.

¹⁹ See, for example, "Automation Tools for Flexible Aircraft Maintenance" SANDIA report (SAND2003-3501) Unlimited Release. Available at <http://prod.sandia.gov/techlib/access-control.cgi/2003/033501.pdf>

²⁰ See, for example, the report at <https://www.economist.com/science-and-technology/2017/09/30/tiny-robots-will-inspect-and-fix-jet-engines-from-the-inside>

²¹ "Automated Inspection of Aircraft", Office of Aviation Research, DOT/FAA/AR-97/69. U.S. Department of Transportation and Federal Aviation Administration.

²² See, for example <http://www.flightsafetyaustralia.com/2015/11/robots-in-the-hangar/>

²³ See related report at <http://www.airbus.com/newsroom/news/en/2017/03/Blockchain.html>

²⁴ See reports at <https://www.siliconrepublic.com/machines/klm-machine-learning-digitalgenius>, <https://www.travelweekly.com/Travel-News/Airline-News/Artificial-intelligence-driving-KLM-social-media-strategy> and <http://www.aviation24.be/airlines/air-france-klm-group/klm-royal-dutch-airlines/klms-next-step-using-artificial-intelligence-social-media/>

2.2.4 New services

Many new services are expected in the years to come. Based on market outcomes in the past, such services are likely to enhance passenger experiences and increase service quality instead of replacing human jobs altogether. An illustrative example is the “track-and-trace” service, which was an important innovation in the logistics sector when first introduced. Such automated services add value to customers without reducing employment. In fact, more capital and labour inputs have been secured as they become standard services.

The indoor positioning system is a promising new service. Gatwick airport in the United Kingdom installed more than 2,000 Beacons²⁵ in order to provide passengers with an indoor navigation service that can direct them to locations, such as check-in terminals, departure gates and baggage claim. Miami airport installed similar systems to provide personalized proximity marketing to passengers (e.g. notifications of special events, discounts and new products and services and a “Near me” feature that advertises nearby dining and shopping facilities).

Indoor GPS signals are typically not strong and less accurate. With precise indoor positioning systems, a digital map provides a more precise and accurate path suggestion to travellers, sometimes through augmented reality way finding functions. Airports can also use beacons to proactively notify passengers with information, such as the map and layout of terminals, boarding time, announcements, or other flight details. Because indoor position systems collect passengers’ movements continuously, sometimes in real time, rich data will be made available to airlines, airports and shops.

For example, airports will be able to identify the queuing time at check-in counters and security check lines. Airlines will be able to identify the use of lounges, queue length and availability of seats near different boarding gates. Shops will be able to analyse the time passengers spent at different product counters, shopping patterns throughout the day and crowding conditions at restaurant and food catering areas. With analysis tools such as Big data, the information may be used by companies to develop novel new services.

An unmanned aircraft system (UAS), or drone, is a type of aircraft with no human pilot onboard. Companies such as Amazon and Uber have been developing services that utilize UAS to deliver products or provide ultra-short-haul commercial flights. UAS can also be useful for the first- and last-mile delivery of small packages, or emergency response to humanitarian crises and natural disasters. Sophisticated UAS systems have already been deployed for military purposes.

Subject to regulation and safety requirements, new applications may be developed for commercial aviation. The IATA believes that although currently uncontrolled UAS operations can present operational risks to civil aviation, in the long term they may be used to provide valuable services, such as safety checks of aircraft and runways, airport perimeter monitoring, bird and wildlife control and warehouse

operations. UAS may also be used for the transport of parcels and cargo in rural and remote locations.

The concept of autopilot is not new. Aviation automation can help pilots on various flight control tasks, or replace certain manual operations; help analyse, summarize and present the most important information to pilots to reduce information overload; and to help pilots in the management of flight missions with information related to flight progress. With the support of other infrastructures, such as the instrument landing system, existing automation systems can already significantly reduce the workload of pilots. However, the generally accepted view in the literature relating to the role of the human factor in aviation that critical /ultimate flight decisions need to be made by pilots, and pilots need to be informed about the intention and decisions of autopilot systems.

Airlines and regulators also need to come up with solutions against possible cyber attacks on computer systems. Because most commercial aircraft need only one or two pilots, it is unclear whether the number of pilots for passenger aircraft can be further reduced. On the cargo side, pilotless aircraft have been developing rapidly, especially for services to/from small airports, which are complementary to existing air cargo operations. Therefore, the effects on pilot employment remain highly uncertain. While we expect new autopilot functions and services will be continuously developed in the years to come, they are unlikely to significantly reduce pilot numbers in the short to medium terms. In the long term, negative impacts on pilot demand may eventually emerge.

Virtual reality (VR) and augmented reality (AR) applications are being developed and used in the aviation industry, especially for educational and training purposes. VR uses computer technology to build a simulated environment. Powerful VR flight simulators have been extensively utilized in pilot training, which are very expensive to purchase and operate. Companies are developing more affordable options, such as virtual reality headsets, goggles, side stick controllers and motion sensors. These options, if developed well, can ease space and mobility constraints on pilot training, and significantly reduce the costs of training and system reconfiguration. AR uses computer technology to superimpose virtual elements in the real world. It can be used to train aircraft maintenance engineers in different locations, and to help passengers and airport drivers navigate through different locations.

With the development of promising technologies, we expect many new services to be introduced in the aviation sector. Although it is difficult to precisely measure the implications of these services for employment, past experiences suggest that the main changes brought about are new functions and higher service quality. In other cases, automated systems may allow airlines to exploit new business opportunities (e.g. to do more dynamic pricing and thus extract more surplus and revenue from travellers). These automation and new solutions are unlikely to reduce employment significantly as current labour and jobs were deployed for existing services that are not directly affected.

²⁵ Beacons are small devices that use Bluetooth low-energy (BLE) wireless technology to pinpoint the location of customers in places, such as airports and stores, which may also deliver messages to customers’ mobile devices, including smart phones and tablets.

2.3 THE AVIATION INDUSTRY –IMPLICATIONS FOR THE LABOUR FORCE

For a better understanding of future automation solutions, it is useful to examine the aviation industry's historical productivity growth and employment patterns. Although individual technology's effect may differ from each other substantially, variability is likely to be reduced at the aggregated system level. However, few studies have examined the aviation industry's global pattern of labour productivity growth. This is partly due to the significant differences in market structures, network configuration, service quality and input prices across countries and regions, which makes it difficult to benchmark airlines' performances. For example, the employee to aircraft ratio has been frequently used in the aviation industry as a measure of labour productivity.

A lower ratio is usually interpreted as signifying higher labour productivity. Wang et al. (2014) compared this ratio across

different airlines as reported in Table 2-1. However, the authors cautioned relying on one partial indicator only. For example, a higher ratio may be caused by either excessive labour input or a higher service level, or both. Low cost carriers (LCCs) tend to use fewer flight attendants per aircraft, as they offer simple, no-frill services. Besides, a larger aircraft (e.g. an Airbus A380) usually requires more flight attendants to operate and many more engineers to maintain the aircraft compared to a smaller aircraft (e.g. a Boeing 737). Therefore, without accounting for factors such as service quality and fleet mix, partial factor productivity indicators, such as those frequently used to measure labour productivity, may provide misleading results (Windle and Dresner 1992).

TABLE 2-1 Employee to Aircraft Ratio for Selected Airlines, 2001-2010

YEAR	China Eastern	China Southern	Air China	China A/VG	Thai Airways	Singapore	Cathay	American	Delta	United	Continental	Air Canada	North America A/VG	Lufthansa	Air France	KLM
2001	192.9	147.5	224.4	191.9	320.5	304.7	206.4	90.7	93.7	154.7	82.2	93.7	111.5	255.0		244.7
2002	168.8	139.6	227.4	185.5	315.0	286.6	200.8	99.2	90.4	127.0	79.2	98.9	101.6	273.6	181.6	237.6
2003	169.4	133.1	208.4	175.2	315.2	263.9	181.0	92.6	84.8	118.4	65.1	103.3	94.1	248.2	187.7	252.2
2004	202.1	119.1	194.2	173.7	311.9	266.5	177.3	90.9	81.8	122.7	64.4	90.9	91.6	246.0	192.6	175.3
2005	162.8	131.9	175.8	156.2	297.4	248.4	172.0	88.3	85.8	123.9	63.6	87.9	91.2	210.2	179.7	179.7
2006	187.3	152.9	159.6	165.5	304.5	242.0	185.3	86.3	85.5	119.6	64.4	82.8	88.8	217.5	178.1	178.1
2007	181.5	137.8	162.7	159.1	303.2	240.7	137.3	89.9	95.2	119.6	67.5	75.4	81.5	196.5	174.1	174.1
2008	184.0	141.7	135.4	151.3	305.5	229.7	144.6	94.3	91.9	116.7	64.0	77.9	78.6	202.5	168.3	168.3
2009	178.7	139.3	153.8	155.0	296.7	243.0	140.6	88.7	82.5	68.2	66.0	74.0	76.7	155.6	166.8	166.8
2010	160.8	160.3	139.0	152.9	287.6	244.3	141.5	85.6	97.8	74.3	74.3	72.7	81.2	164.9	167.6	167.6

Source: Wang et al. (2014)

Russell (2017) noted that even government agencies in the same country may come up with quite different productivity measures of the airline industry. For example, in the United States the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS) had calculated very different productivity growth rates for the U.S. airlines, partly because there were differences in output allocation among different production accounts. In addition, BLS used revenue passenger miles and revenue ton-miles to calculate output quantity, whereas the BEA used deflated revenue streams to compute real output.

Despite the limitations and sometimes inconsistent findings, empirical studies of the aviation industry have identified significant improvements in total factor productivity (multi-factor productivity) and labour productivity. Alamdari (1998) studied labour productivity and costs among U.S. and European airlines' during 1978-1994. She noted that during 1978-1981 there were no significant gains in labour productivity, a trend probably due to aviation services offering new destinations and service competition following deregulation. However, labour productivity increased at an annual rate of 6 per cent from 1981 to 1984, levelling out in

the following years until it rebounded to about 3.5 per cent after 1990.

Duke and Torres (2005) concluded that on average the aviation industry's overall multifactor productivity and labour productivity increased by 2 per cent and 2.4 per cent a year respectively during 1972–2001. In comparison, the corresponding growth rates of the private business sector were 0.7 per cent and 1.7 per cent respectively. The growth rates fluctuated over the period. Multifactor productivity of the aviation industry grew at 5.1 per cent per year during 1973–79, slowed down to 0.8 per cent during 1979 to 1990 before rebounding to 2.1 per cent in the early 1990s. Labour productivity followed a similar pattern, albeit registering slightly higher growth rates.

Using industry-wide data, Apostolides (2017) concluded that the average annual labour productivity of the U.S. airline industry grew at 2.4 per cent, followed by a sharp decline in 2001 due to the 9/11 terrorist attack. He noted that improvements in maintenance were one driving force of labour productivity. For example, compared to visual inspection, ultrasonic scanning introduced in the mid 1990s can reduce the time needed to check the wing fuel tank from

800 man-hours to 48 hours. The utilization of computer-based maintenance programmes had in some cases reduced the number of maintenance schedules by 25 per cent. However, Apostolides (2017) concluded that the annual growth rate of labour productivity was 4.2 per cent during 1990–1995, which subsequently declined to 0.6 per cent in the following years. Such a sharp decline in the growth rate seems to suggest that technology is only one of the many factors determining labour productivity growth.

Russell (2017) studied productivity changes in the U.S. market during 1990 and 2014. His analysis suggested that the average growth rate of labour productivity was 3.9 per cent during this period, significantly higher than the U.S. business sector's growth rate of 2.1 per cent. Labour productivity in the aviation sector experienced the most significant growth from 2002 to 2007, mainly due to the fast output expansion by lower cost carriers and aggressive labour cuts by legacy carriers. In terms of multifactor productivity, the aviation industry's average growth rate was 3.3 per cent, much higher than the 1 per cent growth rate of the private nonfarm business sector during the same period. The related comparisons are reported in Figure 2-1 and Figure 2-2, respectively.

FIGURE 2-1 Labour productivity in air transportation and the U.S. business sector

Source: Russell (2017)

FIGURE 2-2 Multifactor productivity in air transportation and private nonfarm business

Source: Russell (2017)

Instead of using industry-wide data, a number of studies investigated the productivity of selected airlines. Although the obtained growth patterns may not be representative of the whole aviation sector, they are not rendered complicated or biased by the inclusion of different types of airlines. Compared to full service airlines, LCCs provide simpler, no-frill services with fewer inputs (Windle and Dresner 1999, Fu et al. 2011). Therefore, including more LCCs in a sample is likely to lead to higher calculated productivity. An estimation bias will be introduced if the quality of airline service is not properly accounted for in efficiency benchmarking.

Oum et al. (2005) measured the total factor productivity of 10 major North American airlines, which grew by 12 per cent between 1990 and 2001. The moderate growth was partly due to the excessive capacity acquired by these airlines in the late 1990s, followed by sharp demand declines caused by the 9/11 terrorist attack. Wang et al. (2014) and Yan et al. (2018) investigated major airlines' productivity change during 2001–2010. Their sample included major network carriers in Asia, Europe and North America. The annual productivity growth rates of North American carriers mostly ranged between 3-4 per cent, whereas Chinese airlines achieved slighter higher growth, a trend driven mostly by substantial output increases and major market consolidations during 2002-2004.

To summarize, empirical studies of selected markets suggest that the aviation industry has been able to achieve higher growth in total factor productivity and labour productivity than the overall non-farm economy, mostly within the range of 2-4 per cent. Among other factors, such as LCC growth, market

structure change (i.e. mergers and acquisitions), technology improvement and automation, market/demand growth have all contributed to productivity growth. Productivity growth rates, however, have been fairly volatile from year to year, especially in the presence of external shocks, such as the 9/11 terrorist attack, the surge in fuel prices and the global financial crisis.

Few studies have investigated the aviation industry's employment pattern on the global scale, probably due to the challenges in compiling consistent data across countries. Bearing such challenges and limitations in mind, this study attempts to conduct a preliminary analysis based on data compiled from the following sources: (a) The IATA report series of "Economic Performance of the Airline Industry"; (2) The Geneva-based Air Transport Action Group (ATAG) report series, "Aviation Benefits Beyond Borders"; and (3) the A4A Airlines for America website.²⁶

Where possible, data are reconciled with other available statistics, including those provided by the World Bank. Overall, data variances across different sources are mostly in the range of 5 per cent.²⁷ Table 2-2 and Table 2-3 report global labour productivity using alternative indicators including revenue passenger kilometre (RPK) per employee and available seat kilometre (ASK) per employee. During 2012-2016, although labour productivity growth was about 2.5 per cent a year, airline employment actually increased by slightly more than 3 per cent a year. This is probably due to the combined effects of economic recovery and low fuel prices during the sample period.

TABLE 2-2 Airline labour productivity (RPK per employee) during 2012-2016

YEAR	airline employee (million)	yearly change% (airline employee)	RPK (million)	yearly change % (RPK)	RPK/airline employee	change % (RPK/airline employee)
2012	2.27	1.6%	5,520,842	6.0%	2,432,089	4.3%
2013	2.35	3.5%	5,824,084	5.5%	2,478,334	1.9%
2014	2.41	2.6%	6,172,191	6.0%	2,561,075	3.3%
2015	2.55	5.8%	6,635,006	7.5%	2,601,963	1.6%
2016	2.65	3.9%	7,124,350	7.4%	2,688,434	3.3%

Source: WMU analysis

TABLE 2-3 Airline labour productivity (ASK per employee) during 2012-2016

YEAR	airline employee (million)	yearly change% (airline employee)	ASK (million)	yearly change% (ASK)	ASK/airline employee	change % (ASK/airline employee)
2012	2.27	1.6%	7,000,614	5.5%	3,083,971	3.9%
2013	2.35	3.5%	7,327,547	4.7%	3,118,105	1.1%
2014	2.41	2.6%	7,742,481	5.7%	3,212,648	3.0%
2015	2.55	5.8%	8,256,906	6.6%	3,238,002	0.8%
2016	2.65	3.9%	8,870,293	7.4%	3,347,280	3.4%

Source: WMU analysis

²⁶ See for example data available at <http://airlines.org/dataset/world-airlines-traffic-and-capacity/>

²⁷ However, significant variances were noted in air cargo data from different sources. Therefore, caution has been exercised in making inferences using freight statistics. In addition, countries may have different classifications of aviation employment. Even agencies within the same country (e.g. the U.S. BLS, BEA, DOT and A4A) may have slightly different data definitions. Therefore, it is more useful to identify industry trends instead of particular statistics.

Although a number of studies have investigated airport efficiency and costs, few have provided detailed statistics of labour productivity. The Air Transport Research Society (ATRS) Airport Benchmarking Report²⁸ is probably the best source for such analysis, which provides data for more than 200 airports and airport groups around the world. Due to license restrictions, this study could not directly use and present the related data. However, based on data analysed in previous studies, we found that labour productivity of airports in the ATRS sample changed significantly from year to year during 2002-2014. Average growth rates mostly ranged between minus 4 per cent and plus 4 per cent, depending on indicators (i.e. Passenger/ cargo/aircraft movement per employee) and regions (i.e. Asia / Europe / North America) used.

Although in-depth analysis is needed to disentangle the causes of such significant changes, the following factors

have played important roles: (a) significant changes in traffic/output due to external shocks during this period (e.g. global financial crisis and jet fuel price volatility); and (b) many airports outsourced labour-intensive operations. Although outsourcing decisions by airports may not significantly change their total factor productivity, such decisions may dramatically change partial factor productivity indicators (i.e. an increase in labour productivity at the expense of the productivity of contract services/other expenses²⁹).

Such a nominal increase in airport labour productivity does not necessarily imply job loss. In many cases, it simply relocates jobs from airports' payrolls to other companies. These possible data issues prevented the identification of reliable growth patterns of airport labour productivity. Anecdotal evidence suggests that it is comparable to that of the airline sector, with privatized airports achieving higher efficiency than their public counterparts.

2.4 PROJECTIONS UNDER ALTERNATIVE SCENARIOS

With rapid technological progress and significant market dynamics in the aviation sector, it is quite challenging to obtain reliable job market forecasts for the aviation industry. For planning and policy considerations, it is nevertheless valuable to use certain reference estimates. Based on historical development, available information related to promising technologies and expert views that was collected through consultations, this study came up with the following estimates for selected sectors of the aviation industry. Due to the challenge in obtaining precise long-term forecasts, as already noted, it is important to evaluate the trends predicted and the particular growth rates estimated.

Airport Operations and Automation Adoption Rates:

The percentages included in Table 2-4 are the estimated adoption rates for selected airport functions. For example, by 2025 about 15 per cent of the vehicles on airport grounds are expected to be driverless. The adoption ratio will increase to 45 per cent and 85 per cent in 2035 and 2045 respectively.

TABLE 2-4 Technology adoption rates for selected airport operations

AIRPORT OPERATIONS		2025	2035	2045
Airport autonomous vehicles	15%	45%	85%
Passenger processing automation	25%	50%	85%
Cargo/luggage operations	30%	60%	90%

Source: WMU analysis

Table 2-5 summarizes the estimated efficiency gains in labour productivity growth for the low skilled and high skilled labour segment. In general, automation will displace low-skilled employees doing repeated operations. However, with the introduction of more advanced technology, such as artificial intelligence, even high-skilled labour may be affected. For

example, an airport security officer needs to go through extensive training and tests before he/she is qualified to read scanner images. As more advanced scanning machines (e.g. 3D scans) and software are introduced to the industry, these security officers will only be needed for complex and irregular cases.

²⁸ For more information about this report, see <http://www.atrsworld.org/airportawards.html>

²⁹ For a discussion of partial productivity measures frequently used for airports, see for example Oum et al. (2003) and Windle and Dresner (1992).

TABLE 2-5 Efficiency gains for labour inputs in different categories

YEAR	Efficiency gain (%)	
	Low Skilled	High Skilled
2025	10	5
2030	20	8
2045	50	20

Source: WMU analysis

Supporting infrastructure:

Automation in supporting infrastructures, such as air traffic control, airport ground operations, will be a long and

steady process. Because this involves the coordination and cooperation of many subsystems, predicting adoption rates for a specific module/function can be difficult. Aggregated estimates for labour demand is therefore provided.

TABLE 2-6 Efficiency gains for labour inputs in support infrastructure

YEAR	Efficiency gain (%)	
	Low Skilled	High Skilled
2025	10	5
2035	20	8
2045	40	10

Source: WMU analysis

Note the forecasts only capture labour productivity growth driven by new technology and automation. The effects of a market structure change (e.g. growth of LCCs, mergers and an alliance formation) are not included. Therefore, forecasts are lower than the historical labour productivity growth discussed in section 3. Needless to say, the actual/net labour demand is jointly determined by demand growth. As the aviation industry is expected to grow about 4-6 per cent a year,³⁰ the total employment in the aviation industry is likely to grow rather than decrease. However, demand for certain jobs, especially those employing low-skilled labour, may decline significantly.

Policy-makers and training institutes should plan for the affected employees. It should also be noted that countries

and airports may choose their own best strategy. For example, the Japanese Government encourages airports to expedite the automation process, as there is a shortage of low-skilled labour due to the country's ageing population. Hong Kong International Airport has also been troubled by the supply shortage of ground-handling labour, and thus is actively exploring automation options.

It is hoped that this analysis will contribute to a better understanding of the effects of technological progress and automation on the labour force in the aviation industry so that decision-making policies can be designed to promote innovation and social welfare.

³⁰ For a review of the long-term demand forecasts by major organizations such as Boeing, Airbus and ICAO, see Oum et al. (2009).

2.5 TRANSPORT TECHNOLOGY ANALYSIS

The following tables provide a summary of the findings along the six factors considered.

2.5.1 Core automation

2.5.1.1 Next Generation Air Transport Systems (with a focus on advanced air traffic management systems)

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	With an ongoing system innovation in place, a timely information update and exchange, operation automation and performance monitoring will occur. It will bring clear benefits in terms of increased system capacity, efficiency and safety. Such performance improvements will bring economic benefits through increased output and revenue and reduced costs.
II. REGULATION AND GOVERNANCE	Major government agencies are leading and supporting these initiatives. However, certain challenges related to safety-related regulations are in place. Cooperation and coordination among different governments/organizations in different countries are needed.
III. TECHNICAL FEASIBILITY	This is an ongoing system-wide innovation with automation modules to be progressively added when the associated technologies have been fully developed and tested.
IV. SOCIAL ACCEPTANCE	Because the next generation aviation systems and air traffic control systems are mostly internal/ supporting applications, social acceptance will be neutral.
V. KNOWLEDGE AND SKILLS	To keep up with the fast growing traffic volumes and operational complexities, new technologies and skills need to be constantly developed and applied.
VI. LABOUR MARKET DYNAMICS	Although automation and next generation air transport systems will reduce the demand (growth) of air traffic controllers, it will generate many supporting jobs in the supporting sectors of IT, system design, sensor, aeronautics and astronautics.

2.5.1.2 Airport Automation

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	Airport automation and various “smart airport” applications will involve substantial initial investments. But they will bring clear economic benefits through increased service quality, efficiency and a reduction in costs for low-skilled labour.
II. REGULATION AND GOVERNANCE	Because substantial personal data will be collected at airports by airlines, airports and government agencies (immigration, security check, customs), tight regulations on privacy and data security will be in place.
III. TECHNICAL FEASIBILITY	Rapid technological progress are being achieved in the areas of artificial intelligence, air cargo automation systems and handling robots. However, major challenges remain in developing reliable security solutions, such as 3D scanning and automated scan image reading.
IV. SOCIAL ACCEPTANCE	Because airport system providers are usually large companies that provide very specialized solutions, there will not be much social disruption or resistance. However, there may be security concerns when foreign technologies are used in security or personal data-related systems.

2.5.1.2 Airport Automation (Contd.)

KEY ISSUES		SUMMARY OF FINDINGS
V.	KNOWLEDGE AND SKILLS	There will be higher knowledge/skill demands for employees specialized in system developments. Operators and front-line airport employees will be required to receive additional training for using the new systems, which will not be very challenging.
VI.	LABOUR MARKET DYNAMICS	Many high-value added jobs like consultants, IT and engineering will be created in the introduction of these new systems and solutions. Some low-skilled jobs like loading/unloading, luggage check in, cleaning will be eliminated.

2.5.2 Automation of maintenance

KEY ISSUES		SUMMARY OF FINDINGS
I.	ECONOMIC BENEFITS	Clear economic benefits are associated with maintenance automation. Even moderate improvements in aircraft reliability and working conditions will lead to significant savings for airlines and the aircraft supply chain.
II.	REGULATION AND GOVERNANCE	There will be some technical regulations and endorsements from government and international organizations, such as the FAA and ICAO.
III.	TECHNICAL FEASIBILITY	Modern aircraft are very sophisticated products with numerous components and sensors installed. New materials and technologies are constantly being developed and tested. However, only mature technologies can be used for aircraft maintenance to ensure the integrity and safety of aircraft.
IV.	SOCIAL ACCEPTANCE	Aircraft maintenance involves very specialized technologies and skills. While maintenance automation will reduce jobs in selected sectors, the social impact will be relatively low. Therefore, social acceptance should not be a major concern.
V.	KNOWLEDGE AND SKILLS	There will be higher knowledge/skill demands for employees specialized in system developments. Maintenance technicians and engineers will need additional training. This will be a progressive rather than a disruptive process since there will be significant continuity in aircraft technologies.
VI.	LABOUR MARKET DYNAMICS	Aircraft maintenance involves mostly high-skilled jobs. Maintenance automation will reduce the job growth rate for technicians, but could lead to increased salary/compensation because employee productivity will be improved.

2.5.3 Automation for customer interface

KEY ISSUES		SUMMARY OF FINDINGS
I.	ECONOMIC BENEFITS	Automated customer interfaces have brought about significant savings. Online ticketing, payments and other sales supports are becoming standard functions. New online/virtual assistance services will bring additional savings in operation costs and improved service availability.
II.	REGULATION AND GOVERNANCE	Bigdata technology and machine learning often require the collection of much personal data. There will be strict regulations on the collection, storage, sharing and analysis of such data.
III.	TECHNICAL FEASIBILITY	New technologies in the fields of big data, artificial intelligence, and voice recognition will need to be further developed to meet customers' expectations.

2.5.3 Automation for customer interface (Contd.)

KEY ISSUES	SUMMARY OF FINDINGS
IV. SOCIAL ACCEPTANCE	Low-skilled jobs, such as sales and customer service, will be negatively affected. Significant concerns will be voiced over personal data, privacy and proactive marketing. As a result, social resistance toward certain applications will emerge.
V. KNOWLEDGE AND SKILLS	Customer service agents will need extra training and skill developments to use the new applications and systems. In addition, they will increasingly handle complex situations that cannot be processed by automated systems. Therefore, increased demands for new skills and training will emerge.
VI. LABOUR MARKET DYNAMICS	Certain low-skilled jobs will be negatively affected, but not totally replaced as passengers still demand/ prefer personalized services.

2.5.4 Automation for planning and new services

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	New services, such as indoor positioning and drone delivery, will lead to new revenue sources and new functionalities. They will bring additional economic benefits, although some time will elapse before these new services have a significant impact on the aviation industry.
II. REGULATION AND GOVERNANCE	There will be tight scrutiny and policy reviews as some technologies (e.g. drone/UAS) may impose security threats in the short term.
III. TECHNICAL FEASIBILITY	New solutions are being developed and introduced. However, more technological breakthroughs will be needed to make these new services commercially viable.
IV. SOCIAL ACCEPTANCE	Most of these new services are not designed to replace existing functions. Therefore, social acceptance will mainly pertain to the safety and data use/privacy aspects.
V. KNOWLEDGE AND SKILLS	New jobs will be generated that call for enhancements in employee knowledge and skills.
VI. LABOUR MARKET DYNAMICS	The focus on new services and new jobs means the impacts on existing jobs and employees will be limited.

2.6 ESTIMATION OF QUANTITATIVE IMPACTS

As before the correlation between the six factors and their impact on the labour demand are summarised in the table below. A factor is considered “negative” when its development has a negative effect on the labour demand;

“neutral” when its impact is expected to be nil or only marginal; and “positive” when the factor is favourable to labour in the foreseeable future.

KEY TECHNOLOGY CATEGORIES	JUSTIFICATION					
	Economic benefits	Regulation and governance	Technical feasibility	Social acceptance	Knowledge and skills	Labour market dynamics
Core automation functionalities Next Generation Air Transport Systems	●	●	●	●	●	●
Core automation functionalities Airport Automation	●	●	●	●	●	●
Automation of maintenance	●	●	●	●	●	●
Customer interface	●	●	●	●	●	●
Planning and new services	●	●	●	●	●	●

● Negative effects ● Neutral effects ● Positive effects / Not applicable

2.7 DEVELOPMENT OF START-UP CURVES

The previous findings were compiled into start-up curves (s-curves). In civil aviation, a high level of automation has already been implemented. As for the other transport modes, the start-up curve estimates reflect the areas with the most potential for automation, as developed in the previous section. The curves consider ground vehicles in airports and air traffic control (ATC) for the different regions of the world. Curve estimates are based on expert judgment which takes into account the above-mentioned factors (economic benefits, regulation and governance, technical feasibility,

social acceptance, knowledge and skills and labour market dynamics). The results show that the introduction of further technologies and enhanced automation is not expected to have a significant effect on flight crews in the short- and medium- term. In Asia, Europe and North America more than half of the ground vehicles (i.e. 50 per cent to 70 per cent) are likely to be replaced by 2040. The adoption of automated systems in ATC will also be high North America (65-85 per cent), followed by Europe (60-80 per cent) and Asia (50-70 per cent) - see Figure 2-3.

FIGURE 2-3 Start-up-curves for airport ground vehicles and airport ATC in different regions

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RAIL TRANSPORT

3

3 RAIL TRANSPORT

This chapter provides an overview of the technology developments taking place in rail transport. Because of the specificities of the infrastructure, a global assessment of rail transport is only possible by providing more details that

are inherent to the local context. The next sections describe the conditions that most affect automation in rail transport, including the contextual factors that create the basis for the technology to be implemented.

3.1 OVERVIEW OF TECHNOLOGIES AND QUALITATIVE TRENDS

3.1.1 Core automation functionalities

Railways are typically very constrained in their movement vectors, defined by the rails, and in regard to time, defined by the schedule. Thus, the planning and operation of automation in railways has been underway for many years. Beyond the basic principles of wheel/rail and the schedule, the railway system covers very different applications, which have basic principles in common, but which are very different in their use and operational rules. Basically, five different clusters should be taken into account here:

- 1) Metros in larger cities and agglomerations. Those systems have fully automatic operations for many years already. For example, the first VAL³¹-System between Lille and Villeneuve-d'Ascq came into regular operation in 1983. In Germany the subway in Nuremberg operates on two lines that are fully automatic since 2008. Fully automatic metros or subways are in operation in many cities such as Frankfurt, Jacksonville, London, Lyon, Paris, Taipei and many others. Around 50 systems are in operation and several more are under construction, which is a clear indication of the success of the economic concept.
- 2) Freight on mainlines. Fully automatic freight rail systems are in use for several years in closed and fenced networks of industrial areas like mines. In Australia, the first fully automatic long-distance freight trains were certified for regular operation in 2018. In closed industrial areas in different countries fully automatic freight trains are already in operation.
- 3) Automatic shunting. Whereas remote controlled locos have been common for more than 50 years, there are currently first operations for full autonomous shunting e.g. at the DB workshop yard in Paderborn.
- 4) High-Speed, Long-Distance and Mainline railways. Different levels of automation are in use, but no full automation is in place. Full automation is the subject of research and development. Even today, signalling and control systems allow remote controlled vehicles and distance control, with only exact positioning at stations

and object recognition lacking.

- 5) Regional rail on secondary lines. This is the most complex case due to very different operational and topological conditions and very limited economic capacities, and often these systems are missing a capable train control and signalling system. Different levels of automation up to full automation are also the subject of research and development.

Depending on whether the technical and operational constraints and the objectives of automation differ widely, the ideal conditions for automation are as follows:

- Local, closed or fenced networks (e.g. metros, industrial railways)
- Networks with low topological and operational complexity
- Operational constraints
- An up-to-date control, command and signalling system (e.g. ETCS)
- Homogeneous, medium speed range
- Uniform vehicles as much as possible, or at least a small variety of vehicles

To summarize, enclosed areas such as metros or industrial railways offer better conditions for the introduction of automated driving than classic "open" railway areas. A very heterogeneous landscape exists in regard to the technological base. High-speed lines, for example, are already pointing to a high degree of automation. Today the new standardized European Train Control System (ETCS) is available, which can form the foundation for further automation. Currently, the Automatic Train Operation (ATO) module for ETCS is under development and standardization (S2R (2015)). In other scenarios, it may make more sense to build a completely new solution, for example, with more intelligence capabilities in the vehicle and less intelligence the infrastructure.

³¹ Today the acronym is understood as "Véhicule automatique léger" but it was initially defined as "Villeneuve-d'Ascq à Lille"

Typical approaches for the migration are increasing in the level of automation. The new concept presented here shows two approaches: First, full automation in the sense of UTO in specific segments of the railway network, which is optimally suitable. Secondly, remote control by a train driver in the operations control centre.

As automatic railway operations, including unattended train operations, are of high relevance for some of the railways in Europe, in addition to the technical and functional issues, the operational and legal aspects also need to be clarified. Approaches for migration need to take into account the fact that each intermediate step to fully automatic trains and to unattended train operations in the future needs to be safe, secure and accepted by customers.

3.1.1.1 Automation of traffic management

Automatic traffic management has a long history in railways as centralized control existed since the outset. Therefore, the automation of traffic management has been undergoing development and implementation for a long time. The first electrical interlocking was developed with a focus on automation. One very specific aspect of railways is the parallel operation of the more than 100 years old interlocking systems in cooperation with up-to-date fully comprised operations control centres (OCC). Most countries still have a huge number of legacy interlocking and control centres, e.g. Germany has still roughly 3,000 interlocking and control centres, and some are more than 100 years old. One state of the art computerized OCC can manage several thousand kilometres of rail lines from one control centre. For example, Switzerland has four control centres for its whole network and Germany manages seven centres covering the complete long-distance network and major parts of the regional network.

The constant development towards highly centralized operations control centres (OCC) for many years has already reached a high level of automation for signallers and dispatchers. The staff largely adopted the daily workload cycle involving only a few operators at night and full staff at peak times. One can expect that for functions like conflict detection and conflict resolution systems will emerge that provide an even higher level of automation.

3.1.1.2 Automation of train driving tasks

While the rail traffic automation is state of the art and more or less invisible for the traveller or the freight customer, the main issue is the automation of the train driving itself. Four different grades of operation (GoA) are standardized in the IEC 62267 (IEC (2009)). Initially, they were meant to be used for urban systems, but today the definition is applied to all rail systems. The first grade called “non-automated train operation - NTO” uses only automatic route setting and train separation – typically realized by interlocking and train control systems. The GoA2 “semi-automated train operation - STO” uses safe speed, braking and acceleration control. Both are already in use in the current technology.

The next GoA3 “Driverless train operation - DTO” has automatic obstacle detection, in addition to continuous speed supervision. The driver is still on board for the handling

of technical problems and emergencies and to supervise passenger transfers. In the highest level GoA4 “unattended train operation - UTO” no driver is on board any more. The main issue here – besides the obstacle detection – is the handling of technical problems and emergencies which can be done automatically or remotely from the OCC (Brandenburger, 2018).

Innovative approaches like the Next Generation Train (NGT) from the German Aerospace Centre (DLR), involves developing a new railway system based on the UTO-concept. It includes specific train designs for high speed cargo trains, automatic single freight wagons and automatic rail busses, specific operational concepts and specifically adopted infrastructures (Winter, 2018).

A fully automatic train operation brings new technical, operational and legal challenges. Most of the technical and functional issues can be solved by using existing technologies. The two most important issues are the safe and dependable on-board localization and obstacle detection. With respect to the operational issues, the pertinent question is, how far do automatic trains have to behave like trains with drivers. The most complex question is the certification of automatic systems with respect to the comparable human-controlled system. Suitable migration strategies are to be used to win experience and confidence with automatic solutions.

The current issue, in some parts of the world, is that today train drivers are scarce in the labour market. So, besides the operational issues, automation needs to be implemented to reserve the available train driver for those services where they cannot be replaced in the next decade. One approach under discussion today is to reduce the skill level of the train driver’s education from medium to low, while implementing more sophisticated assistance systems. Several systems for driver assistance are already in operation or under development.

3.1.2 Automation of condition-monitoring and maintenance

Globally, this field involves two areas: First, condition-based maintenance, made possible with all the new sensors in the rolling stock and infrastructure, which has resulted in lower maintenance costs through better planning and less spare parts needed; and, secondly, predictive maintenance, which occurs at an earlier stage, with possible resulting savings above 20 per cent, even without automation of shop floor work.

3.1.2.1 Automation of rail vehicle maintenance

The automation of vehicle maintenance can be divided into supervision and diagnosis in the initial step, and in the execution of the maintenance and repair work in the second step.

Today up-to-date rail traction units operating as locos and passenger trains, which are typically multiple units, are already equipped with a multitude of sensors and prepared for condition-based maintenance (CBM). Most of the suppliers are offering 24/7 support and remote supervision and diagnosis. The future target is predictive health monitoring (PHM), which extends the maintenance cycles, on the one

hand, and avoids unplanned maintenance and repair work as far as possible, on the other. Here automation, together with smart data approaches, is an ongoing trend, which does not necessarily have a significant impact on the workforce.

Another relevant trend is the automation of the vehicles where a slow but steady automation process has been ongoing for many years. The focus here is mainly on reducing the “d”-tasks³². Full automation is not expected in the near future. This trend will lead to an evolutionary and rather slow reduction of the workforce, combined with an improvement in working conditions.

3.1.2.2 Automation of rail infrastructure maintenance

The maintenance of the rail infrastructure involves supervision, diagnosis and the execution of the maintenance and repair tasks.

Today up-to-date rail traction units operating as locos and passenger trains, which are typically multiple units, are already equipped with a multitude of sensors and prepared for condition-based maintenance (CBM). Most of the suppliers are offering 24/7 support and remote supervision and diagnosis. The future target is predictive health monitoring (PHM) which extends the maintenance cycles, on the one hand, and avoids unplanned maintenance and repair as far as possible, on the other. Automation and smart data approaches are an ongoing trend, which do not necessarily have a significant impact on the workforce.

Another relevant trend is the automation of vehicles which has been slowly but steadily proceeding for many years. Here the focus is mainly on reducing the “d”-tasks.

3.1.3 Automation for customer interface

The customer interface in public transport covers the ticketing and the pre-trip and on-trip information part. With respect to the ticketing, a significant automation has been deployed for many years. First, almost all ticket counters have been reduced over the past 40 years and will become completely obsolete in the future, being replaced by vending machines. As a second step, the ticket vending machines will also be reduced and replaced by customer-owned mobile devices, for example, smartphones. Hence, a multimodal information, booking and ticketing system, fully based on mobile devices with few human interaction points, might be the next trend.

The pure information systems have a long history of automation starting from mechanical solutions on the platforms up to dynamic cross-linked displays in many types and sizes. Individual computer-based information systems were one of the next levels of development up to Personal Travel Assistants (PTA), which have become more and more sophisticated. Today they include booking and ticketing functionalities and many added-value functions, for example, information about parking places, location of elevators or shops and connections to other modes of transport. Many different PTA-apps for smartphones are available today.

The development of data exchange of schedule and real-time data was underdeveloped for many years, but today robust standards are in operation. The current availability of information on the Internet has led to a new quality of pre-trip and on-trip information.

Step-by-step automation has had a negative effect on the number of available personnel for service and information at the stations. An increasing number of railway stations are operated remotely, without local personnel at the site.

3.1.4 Automation for planning and new services

A broad bandwidth of planning tasks in railways and other modes of public transport have been automated for a long time. In fact, scheduling of railway services was one of the earliest tasks for computerization in railways. Today more or less all planning tasks are done by computerized or automatic systems. Some few examples are the definition of schedules, including stability assessments and incident effect simulations, planning and engineering of tracks, stations and interlocking, dispatching, control, command and signalling, among others.

Hence modern technologies like big data frameworks are used to analyse the use and recovery after technical problems, to predict future demand and to create more and better tailored services.

Radically new services, especially those with a high degree flexibility and demand-orientation called Mobility-as-a-Service (MaaS), require new technologies, e.g. a possible concept of on-demand fully automatic rail buses like the Siemens Automatic Nano Transport System (ANTS). Those concepts are only feasible without a driver on-board. As soon as such a fully automatic platform is available, many new services become available including mobile post offices, banks, stores and shops, autonomous parcel delivery, among others.

³² Either known as 3D: Dirty, Dangerous and Difficult or 4D (especially for robotics): Dull, Dirty, Dangerous and Dear.

3.2 TRANSPORT TECHNOLOGY ANALYSIS

3.2.1 Core automation functionalities

3.2.1.1 Automation of rail traffic management

KEY ISSUES		SUMMARY OF FINDINGS
I.	ECONOMIC BENEFITS	The business case behind traffic management automation is the adoption of a number of operators in an OCC to the traffic situation, as described above, in view of reducing personnel costs and improving the general financial efficiency of operations.
II.	REGULATION AND GOVERNANCE	Technology is being rolled out in many countries. No regulatory issues are known.
III.	TECHNICAL FEASIBILITY	The technology is proven in use and in roll-out in many countries.
IV.	SOCIAL ACCEPTANCE	The real, or even supposed, increase in safety has led to a high social acceptance.
V.	KNOWLEDGE AND SKILLS	The main effect of the introduction of automation is that the number of available operators can be better adapted to the traffic situation.
VI.	LABOUR MARKET DYNAMICS	The labour market dynamic will be minimal as the overall workforce of signallers and dispatchers is on the small side, and this workforce is typically educated by the railway infrastructure manager.

3.2.1.2 Automation of train driving

KEY ISSUES		SUMMARY OF FINDINGS
I.	ECONOMIC BENEFITS	The economic benefits of fully automatic trains (GoA4) are not fully clear outside of Metro Systems. In mainline trains personnel will still be on board e.g. for service. In some areas like freight or regional rail transport, the trend involves a trend to better quality service.
II.	REGULATION AND GOVERNANCE	Many major regulatory hurdles still remain for use of highly automated trains (GoA4) on public networks or in passenger transport.
III.	TECHNICAL FEASIBILITY	The technological development still necessary to enable full automation under all operational conditions (GoA4) is currently ongoing, both in regard to sensor technology (i.e. different weather conditions) and to control algorithms using artificial intelligence.
IV.	SOCIAL ACCEPTANCE	Social acceptance of highly automated trains depends on their safety and reliability performance. How the media and decision-makers frame the discussion about the first unavoidable accident will impact public approval or disapproval.
V.	KNOWLEDGE AND SKILLS	Assuming that the core railway operation will be similar, and the driving will be assisted by a higher level of automation (GoA3), the train driver jobs will not require a different skill set. When full automation (GoA4) occurs, no driver will be required on board.
VI.	LABOUR MARKET DYNAMICS	Already today there is a significant lack of skilled train drivers, and the development of fully automatic trains (GoA4) will require time. Therefore, no major impact on the labour market is expected.

3.2.2 Automation of supervision and maintenance

3.2.2.1 Automation of vehicle supervision and maintenance

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	There are clear economic benefits in the use of predictive maintenance, particularly for Locos and Passenger Trains, as it allows for clear cost reductions through identification of the optimum time window to carry out maintenance tasks.
II. REGULATION AND GOVERNANCE	This technology is in use or in roll-out for many different Locos and Passenger Trains. No regulatory issues are known. It is not in use for freight wagons due to the lack of power on board.
III. TECHNICAL FEASIBILITY	This technology is in use or in roll-out.
IV. SOCIAL ACCEPTANCE	As reliable public transport is expected, social acceptance is good.
V. KNOWLEDGE AND SKILLS	Today, typically, locos and passenger trains are equipped with automatic on-board diagnostics (sometimes combined with 24/7 remote support from the supplier) so that the knowledge and skills of the train drivers are not increasing. The knowledge and skills of the maintenance and repair crews are focused on software and computers.
VI. LABOUR MARKET DYNAMICS	No major effects on the labour market are to be expected as maintenance and repair are to be done as usual.

3.2.2.2 Automation of infrastructure supervision and maintenance

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	Automation of infrastructure maintenance through use of embedded sensors and big data analytics provides a clear economic benefit, allowing clear cost reductions through identification of the optimum time window to carry out infrastructure maintenance tasks.
II. REGULATION AND GOVERNANCE	Only small regulatory issues to be expected in the case of maintenance cycle extension for safety critical assets and IT security.
III. TECHNICAL FEASIBILITY	Continuous improvement of sensor technology and data science capabilities for analysing unstructured big data formats.
IV. SOCIAL ACCEPTANCE	No issues with social acceptance are to be expected.
V. KNOWLEDGE AND SKILLS	Only secondary effects in the technology sectors developing these solutions.
VI. LABOUR MARKET DYNAMICS	Minimal labour market effects are to be expected, as this will mainly result in better scheduling of the maintenance activities and less unexpected repair.

3.2.3 Automation for customer interface

KEY ISSUES		SUMMARY OF FINDINGS
I.	ECONOMIC BENEFITS	Due to clear economic benefits much of the information, booking and ticketing functionalities are already highly automated today. Intermodal and international web-based platforms are in use.
II.	REGULATION AND GOVERNANCE	No regulatory or governance conflicts expected.
III.	TECHNICAL FEASIBILITY	Beyond continuous improvement, the main development of more personalized solutions are expected.
IV.	SOCIAL ACCEPTANCE	Beyond general data privacy and IT security concerns, no issues are to be expected.
V.	KNOWLEDGE AND SKILLS	Only secondary effects in the technology sectors developing these solutions.
VI.	LABOUR MARKET DYNAMICS	Much of the information, booking and ticketing functionalities are already highly automated, therefore further work in this domain, while improving the customer experience and efficiency, are unlikely to have any wider and direct labour market effects.

3.2.4 Automation for planning and new services

KEY ISSUES		SUMMARY OF FINDINGS
I.	ECONOMIC BENEFITS	Automation in planning can deliver much more demand-responsive transport services, allowing the railways to use budgets more efficiently.
II.	REGULATION AND GOVERNANCE	No regulatory or governance conflicts expected.
III.	TECHNICAL FEASIBILITY	Beyond service improvement and some work relating to big data, data analytics and data science, no further developments are expected.
IV.	SOCIAL ACCEPTANCE	As service improves and mobility as a service becomes highly accepted, no issues are expected to emerge.
V.	KNOWLEDGE AND SKILLS	Only secondary effects are expected in the technology sectors that are developing these solutions.
VI.	LABOUR MARKET DYNAMICS	Much of the information, booking and ticketing functionalities are already highly automated, therefore further work in this domain, while improving demand orientation and efficiency, is unlikely to have any wider or direct labour market ramifications.

3.3 ESTIMATION OF QUANTITATIVE IMPACTS

Following the same methodology as before, the impacts were summarised in the form of correlations between the labour demand and the six factors identified as key for technology adoption. A factor is “negative” when affects negatively the

labour demand; “neutral” when its impact is expected to be nil or only marginal; and “positive” if a favourable effect on the labour demand is foreseen.

KEY TECHNOLOGY CATEGORIES	Economic benefits	Regulation and governance	Technical feasibility	Social acceptance	Knowledge and skills	Labour market dynamics	JUSTIFICATION
Core automation functionalities Rail Traffic management	●	●	●	●	●	●	<ul style="list-style-type: none"> No relevant effect on signallers and dispatchers (staff reduction was already carried out in the past) Minor effects on train drivers (mainly covered by normal retirement)
Core automation functionalities Train Driving	●	●	●	●	●	●	
Automation of maintenance Vehicle maintenance	●	●	●	●	●	●	<ul style="list-style-type: none"> No major impact on train and loco maintenance staff. Better planning of maintenance service
Automation of maintenance Infrastructure maintenance	●	●	●	●	●	●	<ul style="list-style-type: none"> No major impact on infrastructure maintenance staff. Better planning of maintenance service
Customer interface	●	/	/	●	/	●	<ul style="list-style-type: none"> New and improved services for customers, including mobility as a service

KEY TECHNOLOGY CATEGORIES	Economic benefits	Regulation and governance	Technical feasibility	Social acceptance	Knowledge and skills	Labour market dynamics	QUANTIFICATION
Planning and new services	●	●	/	●	/	●	<ul style="list-style-type: none"> New and improved services for customers, including mobility as a service

● Negative effects ● Neutral effects ● Positive effects / Not applicable

3.4 DEVELOPMENT OF START-UP CURVES

The previous findings are expanded into a quantitative assessment using start-up curves. These show a probable pattern to be followed technology, having in mind the development six factors as considered previously. In rail transport, the adoption rates differ considerably, depending on the type of application, which is reflected in multitude of start-up curves estimated. The curves provide an overview of areas in which automation is most likely to increase and that can most impact labour. The results reveal that the

introduction of fully automated unattended metro vehicles, which predominantly are taken into service on newly built lines, range from 4 per cent in Africa to 21 per cent in Europe by the year 2040 (see Figure 4-1, e). The largest adoption of fully automated freight trains is expected to take place in the Latin America and Caribbean region (see Figure 4-1, g). The adoption of fully automated freight operations is already at 30 per cent, and by 2040 will increase to 70-90 per cent in Asia, Europe and North America.

FIGURE 3-1 Start-up curves for different types of trains

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ROAD TRANSPORT

4

4 ROAD TRANSPORT

This chapter provides an overview of technology in road transport. A focus to technology that can affect the labour force

is given. At the end, start-up curves for Heavy Goods Vehicles (HGV) and buses and taxis in different regions are provided.

4.1 OVERVIEW OF TECHNOLOGIES AND QUALITATIVE TRENDS

4.1.1 Core automation functionalities

4.1.1.1 Automation of traffic management

Traffic management of road-based transport has traditionally been carried out by traffic managements centres covering urban areas, public transport fleets, or special infrastructure, such as bridges and tunnels (Papageorgiou, 2003). Recent trends have seen these setups being simplified through image recognition systems, drastically reducing the need for staff in these traffic management centres to monitor the multitude of screens in early implementations of this technology. Even more recent developments have brought further efficiency improvements, where no more physical local centres are required, through outsourcing of the whole traffic management task to third parties, which manage remote centres, creating a “traffic management as a service” approach (Joshi, 2015).

When attempting to predict the future implications of automation on traffic management vis-à-vis its potential effects on the labour market effects, two areas need to be discussed. First, the issue of automation of the actual traffic management tasks that will likely lead to further reductions in operator positions, with more and more tasks being carried out by algorithms. Secondly, how automated vehicles will affect current traffic management approaches, and what future developments will be required to ensure safe and efficient operation of mixed traffic fleets of automated and manually operated vehicles. Here one might well witness an increase in the demand for human labour involving more sophisticated roles for highly trained individuals.

Further developments relating to sensor capabilities, the magnitude of sensor deployment in vehicles and infrastructure, the quantity and usefulness of less structured big data sets, algorithms, artificial intelligence, particularly coupled with deep learning capabilities of systems, will in all likelihood drastically reduce the need for human involvement in the traditional traffic management tasks, as they now exist. Today algorithms are able to spot incidents in the network which require intervention with increasing sophistication, and they are also able to initiate the appropriate responses directly. But, more importantly, the impacts of particularly highly automated vehicles on these traditional traffic management techniques need to be seen, both in terms of needs and potentials (Calvert, 2018).

Automated vehicles, whether privately owned “cars,” existing ones, or new types of vehicles fleets enabled by new services and platforms, will to some degree by definition not behave like a human driver. They will also, unlike humans, not require constant nudges or prompts to influence rather than control driving tasks, but all driving functions, involving lateral and longitudinal control, can be directly influenced. This will provide a great potential for eco-driving and the most efficient speeds and routes through the network. While first ideas and concepts are emerging in this space, the implications for traffic management are not yet clear, with a possibility of approaches, ranging from vehicles acting autonomously, a number of individually managed vehicles with central oversight, or one integrated system (Pourmehraba, 2017).

4.1.1.2 Automation of driver or operator tasks

While the hype over road vehicle automation is constantly increasing, its transformation into actual products and services in the market does not yet allow for predicting precise implementation scenarios. This pertains in particular to whether vehicle automation will be one further step, or perhaps an end-point, in the process of adding ever more assistance functionalities to vehicles (van Arem, 2017). But the extent to which automation has a limited effect on current fleet composition, fleet size and private and public fleets ownership is still unclear.

At the other end of the scale, we might witness a mobility revolution, disrupting conventional public transport, but also potentially affecting freight transport, and leading to a drastic reduction of private car ownership levels, particularly in dense urban areas, with a modal shift to new fleet-based shared-mobility platforms and systems (Sperling, 2018). Obviously, the latter scenario will have much larger labour market effects and will need government intervention.

But even without a large disruptive effect on the industry, many current driving jobs are likely to be impacted by vehicle automation (Groshen, 2018). This includes Heavy Goods Vehicles (HGV) and urban delivery vehicle drivers for freight transport and coach, bus, and taxi drivers (including private for-hire vehicles) for public transport. With the promise of efficiency gains, personnel cost reduction and improved road safety, one might see an uptake of vehicle automation in this area. But the potential role of a driver, operator or service agent following this technology uptake requires further scrutiny.

The argument on personnel cost saving through automation would suggest a fully driverless (humanless) vehicle operation. While on specific controlled corridors with possibly direct and dedicated access to production facilities and/or distribution centres, this might theoretically be possible, the reality for the majority of user cases is likely to involve parts of the road network that the vehicle will be unable to negotiate without human intervention. Or, particularly with the increasing use of demand matching platforms, without more frequent stops for loading and unloading.

Therefore, while the case for a negative scenario with a large unemployment of now unneeded drivers can be made, the reality will likely be a more nuanced situation. We will potentially see the traditional role of the driver be transformed into a very different one, and one could argue into a more highly skilled position. The “vehicle and service agent” will increasingly be removed from driving, or even vehicle monitoring tasks, as we move up the SAE level to full automation. In this case, only extremely rare and unusual situations will require driving tasks, otherwise there will be a move towards more back-office and service-industry related tasks, with IT processing and client interaction.

But assuming a move towards a more disruptive scenario involving new innovative transport services and platforms, there will be labour market effects not directly through existing jobs being affected by vehicle automation, but through existing industries being challenged via new business models, partly enabled by vehicle automation. One can imagine the current effects of ride-hailing systems and apps, such as Uber, Lyft, Didi, or Grab, in terms of modal shifts, regulatory conflicts, protests and disruptions of highly protected and regulated industries, but on an even larger scale (Reck, 2018). The effects on the labour market can be large, with a move towards a gig-economy.

4.1.2 Automation of maintenance

4.1.2.1 Automation of vehicle maintenance

A current key technology trend, independent of the use of vehicle automation, is the large increase of various types of sensors fitted into modern road vehicles, and thus the amount of data collected and generated. With the proliferation of data connectivity, both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), or the combination thereof (V2X), a highly data-rich environment will be created with a wealth of vehicle-related data. These sensors include video cameras (side, forward, and/or rear-facing), radar and lidar, in addition to those monitoring vehicle movements, such as speed, acceleration, deceleration, and jerk; plus sensors relating to airbag deployment or Advanced Driver Assistance Systems (ADAS) functionalities.

This flood of data, when coupled with the right data analytics approaches can, and partly already does, enable predictive vehicle maintenance. This step change in maintenance regimes allows identifying the optimized time windows for maintenance, with large efficiency gains. With a potential move towards more fleet-based systems there will be even more of a business case for using these systems. A key issue here is access to and ownership of these data sets, with Original Equipment Manufacturers (OEM) currently fighting

for their rights to control these data sets, but also recognizing the role of the vehicle owners in this context (European Commission (EC), 2017). A move to a centralized maintenance system away from smaller independent operators is likely, with the associated impact on the labour market.

4.1.2.2 Automation of infrastructure maintenance

In an analogous development to in-vehicle sensors, currently a vast number of sensors are embedded into the physical road transport infrastructure, including road surfaces, bridges and tunnels -- albeit this is being done at a much slower implementation rate given the planning, construction and turnover of infrastructure vs. road vehicles. This will also enable a predictive maintenance regime, where infrastructure repair work can be scheduled in an optimal time frame, enabling the public sector, which typically owns and/or manages the transport infrastructure, to use public budgets more efficiently. Here, the effects on the labour market are likely to be minimal, mainly impacting public sector staff and budgets. But it could involve an element of outsourcing data-related work and possibly maintenance work to the private sector.

In addition, much more unstructured big data sets, including information derived from social media and crowdsourcing data, have the potential to further improve evidence-based vs. scheduled maintenance (Farah, 2018). One example, often quoted in this context, is that motion data from standard smartphones, when scaled-up to the right magnitude of data points, can, just by being inside a vehicle, build up a picture on road damage (e.g. potholes) occurring and worsening over time. Again, at a relatively low cost in this case, this can allow the optimizing of essential maintenance work. Having already discussed data access and ownership, other data-related key issues to be addressed in this context are privacy protection and cyber-security, both on a technical and on a procedural level; and cross-sectoral approaches, for example in banking or telecommunications, can be considered.

4.1.3 Automation for customer interface

Automation relating to the customer interface in road-based transport relates mainly to public passenger transport, but with the rise of demand-matching and capacity-sharing platforms it increasingly also relates to freight transport and logistics. In addition, future developments might bring about increased co-modality, inter-modality and the emergence of new types of vehicles and services, with mixed use of passenger and freight, either shared or at different times. Key customer interface in this context includes facilities for booking, payment and information provision, typically through Apps and/or online access. Here, the necessary standards back-office procedures may be subject to increasing automation, including the use of chat-bots for direct customer interaction (Ferreira, 2017).

In the multimodal, including road transport sector, travel planners and information systems have been developed for more than 15 years. While initially comprising purely information systems, these increasingly also have booking and payment functionalities, including also parking and use of smart-cards. Here, a common standard or format is usually missing, coverage is both restricted geographically and often

does not cover all modes or operators due to conflicting commercial interests. In more recent times international IT platforms have shown a keen interest in providing similar functionalities on a global level, with Google for information provision and Uber for transport services for example, as well as booking and payment functionalities.

4.1.4 Automation for planning and new services

Automation can also have an impact on the planning of transport services generally, including the necessary back-office processes. There is a large potential here for a breakthrough in efficiency and customer convenience and experience (Shen, 2017). Such an approach can enable a move from the current rigid time-tabled operation of road transport modes, both in terms of time and routes, to a much more flexible on-demand service tailored to passenger's needs in terms of vehicle and trip characteristics. Such approaches are possible even without vehicle automation,

but in this application automation is likely to contribute to commercially attractive business cases; a trend we can already see now with tests and trials being carried out by tech sector companies, such as Waymo (formerly Google Car), or Uber.

Moreover, we are now witnessing the emergence of new and innovative services and platforms with the potential to further enhance mobility planning and provision. These include the aforementioned platforms, but also concepts such as Mobility-as-a-Service (MaaS). MaaS builds on the concept of multimodal travel planners with booking and payment functionalities, but it takes things a step further by providing a subscription-based model for transport. This is based on the bundle approach already mainstreamed by the telecommunications sector, for example (Basu, 2018). Another related concept in this context is the development of a potentially open source Operating System (OS) specifically for automated vehicles, including interfaces to information, bookings and payments and platform services.

4.2 TRANSPORT TECHNOLOGY ANALYSIS

The following tables summarise how the six factors contribute to the technological development. These findings supporting evidence on the qualitative and quantitative assessment that follows.

4.2.1 Core automation functionalities

4.2.1.1 Automation of traffic management

KEY ISSUES		SUMMARY OF FINDINGS
I.	ECONOMIC BENEFITS	There is a clear business case for both increasing automation of control and decision-making tasks and the outsourcing of traffic management to the private sector with a view to reducing personnel costs and improving the general financial efficiency of operations.
II.	REGULATION AND GOVERNANCE	No major regulatory and governance hurdles are foreseen here, other than those related to the outsourcing of public sector responsibilities to the private sector, enforcement functions and the risk of vendor lock-in.
III.	TECHNICAL FEASIBILITY	Both operating traffic management with minimum numbers of staff, and remote operation, with the option of outsourcing, are already an established practice. Using AI for more sophisticated decision-making will require further development.
IV.	SOCIAL ACCEPTANCE	Social concerns over changes to the operation of traffic management centres are unlikely to emerge, with the exception of potential worries over enforcement through the private sector and over road safety if it involves managing movements of automated vehicles.
V.	KNOWLEDGE AND SKILLS	Assuming a decrease of staff numbers in traffic management through the automation of tasks, it is likely that the position will require more knowledge and skills, particularly in the IT field, including programming, statistics and data science/ analytics.
VI.	LABOUR MARKET DYNAMICS	Any changes through automation in traffic management will mainly affect public sector staff, with net gains for the private sector and with remaining roles gaining in sophistication. Unless vehicle automation becomes disruptive, the impact on the labour market dynamic will be minimal.

4.2.1.2 Automation of driver or operator tasks

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	There are very clear economic benefits to be expected from vehicle automation, with large financial savings from cutting driver staff in public (taxi, bus) and freight transport (HGV, local delivery). In some cases personnel will still be required but they will handle different tasks.
II. REGULATION AND GOVERNANCE	Many major regulatory hurdles still remain before the use of highly automated vehicles (SAE levels 4-5) in public areas takes place, both in terms of the type approval for road safety (United Nations Economic Commission for Europe (UNECE)), and the various governance schemes for public transport provision, freight/ delivery.
III. TECHNICAL FEASIBILITY	More technological development is necessary to enable full automation in all geographical areas (SAE level 5) relating to both sensor technology (i.e. different weather conditions), and control algorithms using AI, potentially benefitting from deep learning.
IV. SOCIAL ACCEPTANCE	Social acceptance of highly automated vehicles hinges on the safety performance of these vehicles, with the media and decision-makers having broad influence by dint of how it will frame the discussion about the first unavoidable accident, and the potential concern over data privacy.
V. KNOWLEDGE AND SKILLS	Assuming that core vehicle operation, i.e. lateral and longitudinal control, will be replaced by automation, then the remaining jobs will require a different skill set, with more sophisticated service industry sector and back-office tasks being carried out, in addition to vehicle supervision.
VI. LABOUR MARKET DYNAMICS	The precise labour market effects depend on the specific applications for vehicle automation, the speed of implementation and the disruption potential of the technology. In public transport fewer jobs are likely to be replaced by different tasks as in freight transport, rather they will be abolished.

4.2.2 Automation of maintenance

4.2.2.1 Automation of vehicle maintenance

KEY ISSUES	SUMMARY OF FINDINGS
I. ECONOMIC BENEFITS	There are clear economic benefits for a wider use of predictive maintenance, particularly for public transport or freight transport fleets, which allows clear cost reductions through identification of the optimum time window to carry out vehicle maintenance tasks.
II. REGULATION AND GOVERNANCE	Regulatory and governance frameworks are barely impacted, apart from the potentially necessary interventions to safeguard commercial data and ensuring fairness of access to and ownership of data generated through on-board sensors.
III. TECHNICAL FEASIBILITY	The area of predictive vehicle maintenance is a fast developing sector reaching maturity, with only minor additional further technological developments foreseen. A large scaling-up of this technology might require further data storage, analytics and communication solutions.
IV. SOCIAL ACCEPTANCE	Large scale deployment of predictive vehicle maintenance, both for private cars and for vehicle fleets will likely have a negative impact on small garages and repair shops which will be at a disadvantage to large chain operators, a fact that society might perceive negatively.

4.2.2.1 Automation of vehicle maintenance (Contd.)

KEY ISSUES		SUMMARY OF FINDINGS
V.	KNOWLEDGE AND SKILLS	With the increasing technical sophistication of road vehicles, the role of car mechanics has already evolved to include a multitude of IT skills. This trend will further intensify both with the use of predictive maintenance and with automated vehicles (sensors and algorithms).
VI.	LABOUR MARKET DYNAMICS	Key labour market effects of automation for vehicle maintenance will involve a likely move away from smaller independent garages and car repair shops to larger international chains, with a minor potential of personnel reductions due to the higher efficiency levels involved.

4.2.2.2 Automation of infrastructure maintenance

KEY ISSUES		SUMMARY OF FINDINGS
I.	ECONOMIC BENEFITS	Automation of infrastructure maintenance through the use of embedded sensors and big data analytics provides a clear economic benefit allowing clear cost reductions through identification of the optimum time window to carry out infrastructure maintenance tasks.
II.	REGULATION AND GOVERNANCE	No regulatory or governance conflicts foreseen.
III.	TECHNICAL FEASIBILITY	Continuous improvement of sensor technology and data science capabilities for analysing unstructured big data formats.
IV.	SOCIAL ACCEPTANCE	No issues with social acceptance are foreseen.
V.	KNOWLEDGE AND SKILLS	Only secondary effects in the tech sectors developing these solutions.
VI.	LABOUR MARKET DYNAMICS	Minimal labour market effects are foreseen, as this will result mainly in less personnel and budget pressure on the public sector.

4.2.3 Automation for customer interface

KEY ISSUES		SUMMARY OF FINDINGS
I.	ECONOMIC BENEFITS	In the past multimodal trip planners have typically been developed and implemented with research funding or subsidies from the public sector as no clear business case existed. This was aimed at making a modal shift to public transport.
II.	REGULATION AND GOVERNANCE	No regulatory or governance conflicts foreseen.
III.	TECHNICAL FEASIBILITY	Beyond continuous improvement, no further development foreseen.
IV.	SOCIAL ACCEPTANCE	Beyond general data privacy concerns, no issues are foreseen.

4.2.3 Automation for customer interface (Contd.)

KEY ISSUES		SUMMARY OF FINDINGS
V.	KNOWLEDGE AND SKILLS	Only secondary effects in the tech sectors developing these solutions.
VI.	LABOUR MARKET DYNAMICS	Much of the information, booking and ticketing functionalities are already highly automated, therefore further work in this domain, while improving the customer experience and efficiency is unlikely to have any wider and direct labour market effects.

4.2.4 Automation for planning and new services

KEY ISSUES		SUMMARY OF FINDINGS
I.	ECONOMIC BENEFITS	Automation in planning can deliver much more demand-responsive transport services, allowing the public sector to use budgets more efficiently. New platforms, such as ride-hailing, have already experienced phenomenal economic success and are likely to further develop.
II.	REGULATION AND GOVERNANCE	Transportation Network Companies (e.g. Uber) have already experienced enormous regulatory conflict in regard to ride-hailing apps in many markets and regions. More widespread use and more sophisticated services using vehicle automation are likely to further intensify this trend.
III.	TECHNICAL FEASIBILITY	Beyond service improvement and some work relating to big data, data analytics and data science, no further developments are foreseen.
IV.	SOCIAL ACCEPTANCE	Beyond general data privacy concerns, no issues are foreseen.
V.	KNOWLEDGE AND SKILLS	Only secondary effects in the tech sectors developing these solutions.
VI.	LABOUR MARKET DYNAMICS	While new platforms and transport services may well prove to be highly disruptive, particularly once vehicle automations becomes part of the business and service model, their effects on transport workers in service planning roles are likely to be only minimal.

4.3 ESTIMATION OF QUANTITATIVE IMPACTS

The below table summarised the correlations between the six factors and the labour demand for selected technologies. As before, a factor is deemed “negative” when its development contributes impacts negatively the labour demand; “neutral”

when its impact is expected to be nil or only marginal; and “positive” when the factor is favourable to labour in the foreseeable future.

KEY TECHNOLOGY CATEGORIES	Economic benefits	Regulation and governance	Technical feasibility	Social acceptance	Knowledge and skills	Labour market dynamics	JUSTIFICATION
Core automation functionalities Traffic management	●	●	●	●	●	●	<ul style="list-style-type: none"> No direct relevance to transport industry from an economic standpoint. Technology can be implemented without any disruptive risk, or the need for new governance approaches. Highly mature technology using mainly off-the-shelf components with a cloud-based system. Approach has low visibility for the wider society, but no effect on transport workers. Upgrade of knowledge and skills necessary, particularly IT skills, but no effect on transport workers. Key driver here is automation; hence a reduction of personnel for running traffic management centres, but no effect on transport workers.
Core automation functionalities Driver or operator	●	●	●	●	●	●	<ul style="list-style-type: none"> Economic benefits for the trucking and haulage industry, but negative effects for transport workers, due to likely job losses from automation. Requires large regulatory efforts, which might slow down implementation, which in turn will also slow down the negative effects on transport workers. Technical feasibility differs widely from use case to use case vis-à-vis technology readiness and regulatory impact, and on balance has a neutral impact on transport workers. Overall jobs are likely to improve with more skilled and less dangerous and repetitive tasks to be performed. The key motivation for investment in more expensive automated vehicles is the savings in personnel costs. However, this has a negative impact on transport workers.
Automation of maintenance Vehicle maintenance	●	●	●	●	●	●	<ul style="list-style-type: none"> Requires less interaction by mechanics as maintenance moves from a scheduled event to an on-demand activity. Technology can be implemented without any disruptive risk, or the need for new governance approaches. Uses off-the-shelf technology, but some further technology development is required. Challenges might arise from the necessary upscaling. Approach has low visibility for the wider society. This technology affects the frequency of interventions, but is neutral in terms of the tasks to be performed by transport workers The lower frequency of interventions ultimately will lead to a decrease in workers
Automation of maintenance Infrastructure maintenance	●	/	●	/	/	●	<ul style="list-style-type: none"> Requires less interaction by workers as maintenance moves from a scheduled event to an on-demand activity. Not relevant in this context. Highly mature technology using mainly off-the-shelf components. The lower frequency of interventions ultimately will lead to a decrease of workers.
Customer interface	●	/	/	/	/	●	<ul style="list-style-type: none"> Neutral economic benefits, as it mainly replaces current publicly funded efforts, such as trip planners. An automation of the customer interface is ultimately aimed at reducing the number of transport workers required for ticket sales and information, for example.

● Negative effects ● Neutral effects ● Positive effects / Not applicable

KEY TECHNOLOGY CATEGORIES	JUSTIFICATION					
	Economic benefits	Regulation and governance	Technical feasibility	Social acceptance	Knowledge and skills	Labour market dynamics
Planning and new services	●	●	/	/	/	●
<ul style="list-style-type: none"> Some services make for a very clear business case resulting in often very aggressive market domination, which can lead to very rapid negative impacts on transport workers. Depending on the type of service, the disruptive impact could be high, requiring broad regulatory change, which will slow down implementation, and thus the effects on transport workers, Nevertheless, impacts on transport workers employed in the area of service planning are likely to be only minimal with this technology. 						

● Negative effects ● Neutral effects ● Positive effects / Not applicable

4.4 DEVELOPMENT OF START-UP CURVES

The previous assessments are condensed in the form of quantitative judgements modelled as start-up curves. The curves follow the predicted behaviour of selected technologies while internalising the six factors depicted before. In road transport, by 2040 buses and taxis are expected to be strongly affected by automation (Asia 90-98

per cent, Europe 89-97 per cent, North America 76-84 per cent, Latin America and the Caribbean 48-50 per cent (see Figure 4-1). Heavy Goods Vehicles (HGVs) will mostly be affected in North America (42-58 per cent), Europe (17-33 per cent) and Asia (12-16 per cent).

FIGURE 4-1 Adoption curve for road transport applications (HGV and Bus/Taxi) in different regions.

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ANNEXES

ANNEX 1: SCALES OF AUTONOMOUS OPERATION

SHIPPING (LR) (LLOYD'S REGISTER, 2017)		AUTOMATION LEVEL	ROLES OF THE HUMAN / OPERATOR	ROLES OF THE SYSTEM (TYPICALLY IT SYSTEM)
AL 0		No automation	Manual operation. Performs all actions and decision- making; Operator is on board but may control the vessel remotely, e.g. via radio link	Passive role, presents information and executes operator commands <i>Example(s):</i> navigation controls, engine telegraph
AL 1		On-board Decision Support	All actions taken by human operator	Decision support tool presents options and may influence the actions chosen. Data is provided by systems onboard <i>Example(s):</i> RADAR, route planning
AL 2		On- and Off-board Decision Support	All actions taken by human operator	Decision support tool presents options and may influence the actions chosen. Data is provided by systems on or off- board <i>Example(s):</i> dynamic positioning capability plots, weather routing
AL 3		'Active' Human in the loop	Decisions and actions are performed with human supervision	System prepares recommendations; Actions are performed by the system; Data is provided by systems on- or off- board <i>Example(s):</i> "NAV autopilot", Periodically unattended machinery spaces
AL 4		Human on the loop, Operator/ Supervisory	Supervises systems; Has opportunity to intervene and override, in case of high-impact decisions	Decisions and actions are prepared by the system and performed autonomously, once approved by the human operator
AL 5		Fully autonomous	Rarely supervises system	Decisions and actions are entirely made and actioned by the system. Alerts operator in case of uncertainty.
AL 6		Fully autonomous	No supervision by human; Monitoring from a remote control centre	Decisions and actions are entirely made and actioned by the system during the mission

	CORRESPONDENCE TO SELECTED SCALES IN TRANSPORT INDUSTRIES					
	AVIATION (NBAA, 2000)	AVIATION (FAA, 2016)	RAIL (UITP) (IEC 62267, 2009)	AUTOMOTIVE (BAST, 2012)	AUTOMOTIVE (VDA, 2015)	AUTOMOTIVE (SAE J3016) (SAE, 2016)
	1	Full Manual	GoA 0; GoA 1	Driver only	Driver only	No driving automation
	2	Manual	GoA 1	Driver only	Driver only	No driving automation
	2	Manual	GoA 1	Driver only	Driver only	No driving automation
	3	Tactical Auto-Flight	GoA 2	Assisted	Assisted	Driver Assistance; Partial driving Automation
	4	Full Auto-flight	GoA 3	Partially automated	Partly automated	Conditional driving automation
	--	Full Auto-flight	GoA 3	Highly automated; Fully automated	Highly automated; Fully automated	High driving automation
	--	--	GoA 4	--	Driverless	Full driving automation

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ANNEX 2: ENABLING TECHNOLOGIES

CLUSTERS OF TRENDS

TECHNOLOGY	Core automation	Maintenance	Customer interface	New services	
Automatic twistlock systems	X				
Exo-skeletons	X	X			
Additive manufacturing ("3D printing")		X		X	
Gantry cranes	X				Automated vehicles
Agvs	X				
Straddle carriers	X				
Automatic mooring and docking systems	X	X			
Battery electric locomotives	X				
Electric and hybrid propulsion	X			X	
Automated collision avoidance	X			X	Physical robots
Physical handling	X	X			
Underwater inspection		X			
Land inspection & repair		X			
Inspection drones (airborne, underwater)		X			
Short range (ie 802.11P, wifi, bluetooth)	X	X	X	X	Reliable wireless communication networks
Medium range (cellular 3G/4G/5G)	X	X		X	
Long range (broadband satellite)	X	X		X	
Rfid platforms	X	X			
Electronic product code (epc)	X	X	X	X	
Internet of things	X	X			
"V2x connectivity"	X			X	
Sensor networks	X	X			
Standardization	X	X	X		
Inter-modal communications networks	X				
Data collection	X	X	X		Data collection and processing
Cloud computing	X				
Cross-corporate data sharing	X		X		
Data processing / databots	X			X	
Data mining / big data analysis	X			X	
Neural networks / "deep learning"	X	X		X	
Digital back-end it solutions / restful interfaces	X	X	X	X	
"Digital twin"	X	X		X	
Artificial intelligence	X	X	X	X	
Reliability and robustness of systems	X	X	X	X	
Blockchain		X	X	X	
Cyber security	X	X	X	X	
Cargo security: fast x-ray	X				Human-computer interaction
Augmented reality	X	X	X	X	
Suitable user interfaces	X	X	X	X	
Natural language processing			X		
Pervasive computing	X		X	X	

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