A taxonomy of skills and knowledge for efficient autonomous vehicle operation

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Abstract. The autonomous vehicles are expected to bring unprecedented changes in the labor sector and the workforce. Traditional jobs will be alleviated, new will be created while people involved in the autonomous vehicle operation should be qualified with additional skills and knowledge in order to be able to deal with the new technology and the various systems. Furthermore, the impact on the role of the 'driver' is anticipated to be significant in all transportation modes. The purpose of the present research is to identify the skills and knowledge required for an efficient and proper operation of any autonomous vehicle. Both professional and private operators and all transportation sectors (road, rail, maritime, aviation) and autonomous levels will be considered as each one has different requirements.

Keywords: autonomous vehicles, taxonomy, skills, knowledge.

1 Introduction

Autonomous or driverless vehicles are equipped with various systems and sensors for assisting driver during the driving task or fully substituting him in higher levels of automation. Automation is expected to increase road capacity, minimize or alleviate accident occurrence and congested phenomena, reduce traffic violations and improve safety levels as they react faster and more appropriate than human drivers [1]. The advent of autonomous vehicles will also bring major changes to the labor sector and the workforce as many jobs will be alleviated, new jobs will be created while workers may need to be reskilled and upskilled. People involved in the autonomous vehicle operation should be qualified with additional skills and knowledge in order to be able to deal with the new technology and its various functions. Additionally, the impact on the role of the 'driver' is anticipated to be significant in all transportation modes as the driver (professional or private) will have the opportunity to abstain from the driving process and be focused on secondary tasks or even remotely control and operate the vehicle.

The scope of the present research is to identify skills and knowledge required for an efficient operation of any autonomous vehicle considering all transportation sectors and automaton levels. Both professional and private drivers, various categories of the labor sector and professions involved in the autonomous vehicle construction and operation will be analyzed in order to reveal the new needs arisen from the advent of automation.

Project deliverables, reports, studies, articles, scientific papers, websites were reviewed and experts were contacted for identifying the requirements for all workers and drivers. The taxonomy of skills and knowledge formulated can be related to HMI development in order to meet anticipated skills of the operator and his new training needs.

2 Road Sector

Each level of automation requires different systems and sensors inside the vehicle and therefore additional driver skills and knowledge as automation level increases. In levels 2 and 3 the driver continuously cooperates with the vehicle on the driving task [2] and he should monitor the systems in terms of supervising their status, performance and appropriate operation. The intense of monitoring decreases in level 4 and 5 and requires driver concentration maintenance [2]. The driver should be familiar with all sensors and systems in each automation level and be aware of their location, how they work, the principles governing them, their capabilities and limitations, understand their decisions and actions and recognize errors [3,4]. It is necessary, for the driver of levels 1-4 to be able to take over the vehicle control when necessary either due to system limitations or failure. The control take over must be achieved within a short period and therefore driver keeps high levels of situational awareness and concentration [5]. The road sector is considered to be very complex and the safe interaction and communication between all different (vulnerable) road users is of major importance. People with programming skills in machine learning and artificial intelligent are needed for the algorithms and software development so that the autonomous vehicles can understand the surroundings, detect any (physical) object around and (re)act safely. Since big amount of data will be recorded continuously from the AV's various sensors, backend software engineers are necessary for data storage services, design of APIs for proper communication and data transmission. Along with the software engineers, robotics and electrical engineers will be involved in the design of hardware, electrical and communication systems, while the automotive engineering skills will be upgraded to meet future cars characteristics. Existence of communication models and wireless networks should enable the information and data transmission and exchange between the vehicle, the infrastructure as well as the traffic management centre (TMC). In automation levels 3 and 4 the vehicle communicates with the infrastructure and its various units (e.g. lane marking, traffic lights) and as a result all infrastructure characteristics should be appropriately designed (e.g. road surface quality) [6]. People working in the TMC should know how to recognize the data received and the skills to process and analyse it.

Concerning public transport (PT), the driver should be trained for operating an autonomous vehicle and skilled for monitoring its operation remotely ensuring safety for the passengers and the other interacting road users. The passengers of an autonomous bus should be familiar with its operation principles, recognize its actions and know who they should contact or how to evacuate the bus in case of emergency [7]. Programming and engineering skills are required for developing the systems necessary for the automated bus operation Due to the absence of driver, there will be need for high quality in-vehicle means of communication [8]. Logistic operators should also be skilled and

have knowledge in remotely controlling the process and managing the delivered cargo if driverless vehicles are used in terms of dispatching, scheduling and routing and monitor the process [9] while intervention is possible via an operation center using wireless transmission. The very critical issue of cyberattack risk requires experts with continuous education on these issues for ensuring cybersecurity and encryption protection. Law specialists are required for formulating and establishing suitable regulations and framework for the operation of autonomous vehicles as well as solve liability issues in case of failure or incident occurrence.

Table 1. Skills and Knowledge for AV operation in the road sector.

Skills	Description
Social Skills	Communication, Team working, organization, problem-solving
Programming and Computer Skills	Artificial Intelligence, Algorithms, software development, backend/frontend skills, machine learning, higher-order skills in big data analysis, Cybersecurity and encryption protection, security systems for protecting external communication for AVs, data protection
Engineering/ Technical Skills	Sensors and systems development, hardware development, Robotics, electrical engineering, automotive engineering, digital road map database access, firmware, Smart Traffic Light controller system, smart signs, advisory road marking, Testing and Simulation Skills
Driver Skills and Knowledge	Cooperation-collaboration with the vehicle, Efficiently monitoring and supervising the system, Concentration maintenance, Familiarity with all electronic devices and sensors, Knowledge of their limitations and capabilities, Understand the information and warnings from the systems based on the surroundings, Knowledge of differences among different levels of automation, Situational awareness and transition of control skills, Capability of recognizing errors -malfunctions and act properly
Remote operation (PT)	Skills and knowledge for efficient remote monitoring and operation of the PT vehicle
Communication skills	V2I and V2V communication model, Wireless communication, ad hoc network, DSRC Multi-Channel Test Tool
Traffic management center	Collection and processing skills from the data transmitted from the infrastructure and the vehicles
Law skills	Legal framework and standards for the autonomous vehicle operation Liability issues in case of incident occurrence, Data generated by V2X infrastructures to be compliant with national or international law

3 Rail Sector

The automatic train protection is already installed in GoA1 (Grade of Automation) for ensuring the automatic activation of the brakes in case of speeding or other risky situations while the automated train operation is introduced from GoA2 for safe movement and control. Continuous monitoring, track supervision, communication, operational knowledge, selective attention, high levels of situational awareness, skills of critical diagnosis and other social, perceptual and cognitive skills are considered important for the train driver of GoA1 and 2 also in case of intervention [10].

Table 2. Skills and Knowledge for AV operation in the rail sector.

Skills	Description
Social Skills	Communication, Team working, organization, skills in timetable management, problem-solving, slit-second decision making, Knowledge in human factors for passengers and workers safety
Programming and Computer Skills	Same as in the road sector (Table 1)
Engineering/ Technical Skills and Knowledge	Same as in the road sector (Table 1) Systems for driverless and unattended train operation, automatic train protection and automatic train operation, diagnostics, Signaling technologies, new signaling and position technologies, Knowledge of the European Train Control System (ETCS) and wireless delivery of mission-critical rail communications, digital interlocking system
Driver/Crew Skills and Knowledge	Same as for road sector (Table 1) Maintenance of on route driving skills, knowledge of new on board systems, Monitoring of the passenger exchange, detection and accomplishment of emergency conditions, supervision of the train's state.
Communication skills	V2I communication model, Wireless communication, ad hoc network, Wireless interface/connection and components, data transmission
Law skills	Legal framework and standards for the autonomous vehicle operation Liability issues in case of incident occurrence, Data generated by V2X infrastructures to be compliant with national or international law
Skills for workers in front line and network control, train driving	Rail vehicle setup and deconstruction skills and knowledge for a safe and efficient pre-journey, in journey and post journey autonomous train operation, Skilled rail network controllers
Safety management skills	Preparing for emergencies related to both safety and environmental protection, fatigue management
Remote Control Skills	Off site and remote fault support skills, Incident recovery procedures for autonomous trains and rail vehicles, including fault identification and rectification, remote operations, processing of large amount of data
Signaler	Knowledge of all new signaling technologies and systems, ready to intervene efficiently any time

Since the first two GoAs require the presence of the driver, he should have the skills and knowledge of a driver of an automated vehicle (Table 1) while network controllers should ensure safety by providing the right real time information to the driver [11]. Concerning GoA3, the driver becomes a remote control operator in strong cooperation and communication with the train attendant who is still in the train supervising passengers exchange and detecting emergencies [6]. Due to the large amount and complexity of data transmitted to the control center, remote operators are required to have high skills in big data analytics and problem-solving for maintaining high operation and reliability levels [12]. Manual intervention is still necessary in cases of any emergency situation occurred and the train operator takes over the train control remotely [13]. Remote operators and drivers should also have safety management skills for incident recovery including fault identification and fault rectification while on route driving skills should be maintained in case of emergency [11]. Technical and engineering skills [14]

are necessary for GoA3 and GoA4 for enabling driverless and unattended train operation respectively in terms of track and passenger transfer supervision as well as the train operation in event of disruption, (physical) obstacle detection for collision avoidance, existence of other trains on the route [15]. Furthermore, wireless signaling, sensors and communication technologies are also need to be designed and developed for enabling the data capture and transmission between the train, track and signals [6,11]. Since rail safety work is considered to be dangerous enough, skills and knowledge in human factors for ensuring health and safety of the workers and the passengers are also important [16]. Artificial intelligence and software and hardware skills are also required for efficient visual perception in case of driverless trains while skills in software and hardware assessment are necessary for ensuring safety. Augmented and virtual reality and simulation skills are a prerequisite for developing and testing a rail infrastructure and control or maintenance operations [11,16]. Regulations and guidelines should be also established in the rail sector in case of operation of trains of different levels of automation and if both semi and fully automated trains are using the same track [12]. Liability issues for driverless trains are necessary to be defined in terms of responsibility in case of incident or failure. The role of signaler will also be affected as they are required to have deep knowledge of all the new signaling systems, continuously monitoring the decisions the systems take and intervene when necessary [12].

4 Maritime Sector

The professional driver of an autonomous vessel is required to have technical and engineering skills for dealing with any malfunction or failure of the hull structure, the machinery and other systems [17]. In case of remote vessel control, skilled personnel in the shore control centre should understand and interpret the pertinent data transmitted from the various vessel sensors to the shore-based facility [6] as well as navigate it. Operation monitoring, emergency situations handling, autonomous ship surveillance and additional safety related tasks are performed in the shore control center. Data should be monitored and controlled via maritime broadband radio, and satellite communication [18]. Human intervention may be required at any time and under various conditions and as a result seafarers on the bridge or in the shore based center should maintain high levels of situational awareness [18]. Due to the fact that the centre may serve both autonomous and conventional vessels as well as different types of vessels, people involved should have interoperability skills and be able to distinguish the different principles governing each type [17]. The seafarer of the shore based center should have apart from maritime knowledge, digital and software engineering skills as well as data fluency and programming skills for interpreting large amount of data [18]. He would need to deal with various parties (i.e. shipyards, port authorities), in a way that differs significantly with the ship type and therefore communication skills are considered among the most important competencies [19]. One of the limitations and major concerns is the new legislation that has to be established and liability issues that should be solved as it is considered that existing legislation issues do not favour the existence and increase of the number of the autonomous vessels [20]. It is apparent, that AV

operators need to acquire knowledge about the legal framework associated with the autonomous vessels [19]. Programming, engineering and technical skills are also required for developing all the systems, sensors and technologies the autonomous vessel should be equipped with so that it can navigate itself on a specific route, detect obstacle or avoid collisions [21]. Fully autonomous ships will be equipped with automatic mooring and unmooring systems or with detachable bridge. For auto mooring the required infrastructure and communication infrastructure should be developed [21]. Besides, V2V and V2I connectivity and communication should also be enabled by developing sensors, platforms and systems such as maritime broadband radio or Global System for Mobile Communications (GSM) [6].

Table 3. Skills and Knowledge for AV operation in the maritime sector.

Skills	Description
Social Skills	Same as in the rail sector (Table 2), onboard and shore-based personnel
Programming and Computer Skills	Same as in the road sector (Table 1), augmented and virtual reality skills and knowledge
Engineering/ Technical Skills	Same as road sector (Table 1), obstacle detection, surroundings mapping, mooring and unmooring systems, HD Maps of the relevant port transport infrastructure, naval engineer, Testing and Simulation Skills, Airborne or underwater drones for hazardous inspection and maintenance tasks, either by remote control or autonomously
Driver/Crew Skills and Knowledge	Same as in the road sector (Table 1) Knowledge of new on board systems, Interoperability Skills, Docking skills, Coast water crews inner-port navigation the mooring skills, Monitoring of the passenger exchange, detection and accomplishment of emergency conditions, supervision of the vessel's state.
Communication skills	Satellite communication capacity and the bandwidth, advanced data transmission technology systems, communication network, V2V and V2I communication
Law skills	Same as in the road sector (Table 1)
Safety management	Preparing for emergencies related to safety/environmental protection
Remote Control Skills	Understand and interpret the pertinent data transmitted from the vessel to the shore-based facility in case of a machinery/equipment/hull damage event and any other case concerning safety, Distinguish the different principles governing each type -Interoperability skills, Mooring and unmooring operation skills, Complex engines and machinery aboard monitoring, Data analytic experts and system controllers

Maritime operations and ship maintenance can be performed remotely using robots creating safer conditions for the coastal workers. Data transmission networks, sensors, augmented and virtual reality and drone technology [22] can enable surface and under water communication, remote services and maintenance work. Cybersecurity is extremely important also in the maritime for supporting safe and secure shipping. Safety management skills are also required for an autonomous vessel operation "*related to both safety and environment protection*" [23]. Communication and team working skills are essential for the successful accomplishment of tasks by on-board crew depending on adequate instructions or assistance by a remote control centre [24]. Finally, quay

cranes driver will be upskilled with general knowledge on electronics and mechanics along with control panel handling skills [18]. Since each port or terminal may have different operational processes a docker is required to have deep knowledge of them and skills such as efficient planning, equipment dispatching or remote control of ship handling [18].

5 Aviation Sector

Monitoring the automation systems is a skill required also in the aviation sector when the state of autonomy is level 3 or 4. The pilot should be capable of detecting any system malfunction or suspicious performance as well as be ready to react properly in case of failure in order to avoid air crashes. In contrast to the car drivers, who can recall their driving skills even if automated systems are used, the basic flying skills of a pilot are not retained due to the complexity of the pilot tasks. Additionally, the pilot of airplanes of these autonomous levels is required to have a deep knowledge of the systems and appropriately distinguish the various kind of information received from them and take the right decisions accordingly. In the case of autonomous airplanes the pilot should have all the necessary and required skills and knowledge in order to efficiently and safely supervising remotely the airplane. Due to the fact that remote control is more difficult and demanding than the on board control and supervision, he should be completely aware of every system installed in the plane as well as its level of autonomation, its capabilities and limitations [25]. It is necessary that he is capable of promptly detecting any suspicious activities of the systems and any abnormal behavior of the plane and be prepared for handling any situation. Monitoring tasks are among the basic skills of a UAS operator including instrument monitoring, navigation, route and long term monitoring so that safety is ensured [25]. Additionally, in the future, one pilot may have to supervise more than one unmanned airplanes simultaneously and it is obvious that he should be high skilled and well trained. Different types of aircrafts have different types of systems [25], they follow different routes and they are flying on different airways and therefore the remote controller should ensure their safe operation and journey and conduct a preflight check of the systems of the plane Social skills are also considered important for an UAS operator such as decision making, risk assessment skills or team leadership and communication skills [25-27]. Similarly to the other transportation sectors, high levels of situation awareness should be preserved. Apart from the technical part, the operation of UAS needs the establishment of standards, regulations and operational rules. The Federal Aviation Administration [28] formulated rules for small unmanned aircraft systems in 2016 including operational limitations, Remote Pilot in Command Certification and Responsibilities, Aircraft Requirements and model aircraft. Towards the full automation of bigger airplanes, it is necessary that people involved in the technical and legal sector should be cooperated in order to formulate the appropriate legal and operation framework as well as rules for the safe operation of UAS. Drones are nowadays used for short range surveillance purposes and their operators should be able to identify obstacles and modify the drone route accordingly. In

the future, drones will also be used for transporting people and goods within urban environments and therefore they will cover longer distances.

Table 4. Skills and Knowledge for AV operation in the aviation sector.

Skills	Description
Social Skills	Communication, Team working, organization, skills in timetable management, problem-solving, slit-second decision making
Programming and Computer Skills	Same as in the road sector (Table 1)
Engineering/ Technical Skills	Sensors and systems development, hardware development, Robotics, electrical engineering, aeronautics, automotive engineering, safe navigation systems development ,Testing and Simulation Skills, Airborne drones can perform potentially hazardous inspection and maintenance tasks, either by remote control or autonomously (in cooperation with programming and computer skills).
Driver/Crew Skills and Knowledge	Same as for road sector (Table 1) Knowledge of new on board systems, Interoperability Skills, Monitoring of the passenger exchange, detection and accomplishment of emergency conditions.
Communication skills	Satellite communication capacity and the bandwidth, advanced data transmission technology systems, communication network
Law skills	Legal framework and standards for the autonomous vehicle operation, liability issues in case of incident occurrence, data generated by V2X infrastructures to be compliant with national or international law
Safety management	Preparing for emergencies
Remote Control Skills	Supervision, Detection of suspicious activities or abnormal behavior of the plane, Simultaneously monitoring and supervision of more than one unmanned airplanes, Knowledge of characteristics of different types of aircraft, the routes they follow, Preflight Check
Urban Environment Operation	Engineering/Technical/Programming Skills (Landing and take-off without a runway, obstacle detection and avoidance)

According to [29], the safe operation and performance of these aircrafts are based on three functions: the landing and taking off process will be executed without a runway, the aircrafts should be able to detect, see and avoid obstacles, like buildings and vehicles as they fly in low altitudes and last but not least the efficient management of emergency situations such as weather conditions. Similarly to all the other transport modes, engineering and programming skills are required for sensors (lidar, radar, cameras) and systems development, simulation modelling, software and hardware development and testing so that the autonomous aircraft will optimum perform the tasks of perception, decision/planning and execution. People involved in these processes should ensure that information is received from all systems and sensors and that this information is accurate and correct for achieving a safe flight. Finally, regulations and legislation should be established for their safe operation and efficient management of the airspace [30,31]. The guidelines should also include the characteristics and specific requirements of the drones. Finally, unmanned traffic management including sensors, communication systems and servers will be introduced for coordinating and monitoring

the large number of drones in an urban or rural environment as well as for receiving data and providing real time information [30].

6 Conclusions

The automated vehicles will severely affect the labor sector. Workers involved in the design, manufacturing and in the various stages of operation are required to be upskilled or reskilled. Drivers will have a new role based on the automation level. This research presented a taxonomy of skills and knowledge drivers, workers and other people involved in the field of autonomous vehicles. Road, rail, maritime and aviation sector were analyzed and all levels of automation were considered. The research revealed similarities in the need of social, programming, engineering and communication skills, as in all different transport modes the design of the vehicle, the development of its sensors and systems enabling the automated operation and the proper communication and information exchange among the vehicles and the infrastructure are required. Regulations should also be established while liability issues are necessary to be clarified. Among the differences are the various systems each transport mode needs for automated operation, as well as the remote control skills and knowledge required.

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