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## **Autonomous Transport as an Alternative for Public Transport in the City During an Epidemic Threat**

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**Abstract:**

*Autonomous transport functioning within the urban agglomeration becomes a reality. More and more companies introduce vehicles successfully moving in traffic. It seems that autonomous transport is inevitable in the imminent future. The article aims to consider the safety aspects related to the use of autonomous vehicles. Safety in this context can be understood in two ways. The first is: how secure the technology is? The second is the safety of travellers regarding the virus infection risk.*

*There are five categories in which we can divide the public transportation according to the level of autonomy, namely, a) vehicles without any automatics, b) assumes that there are driver assistance systems, c) capable of combining respective actions, d) conditional automation and e) do not need the presence of a driver during the ride.*

*This study's results could be implemented to secure autonomous transport safety, as it becomes a reality. More and more companies introduce vehicles successfully moving in traffic; therefore, the safety issue should be seriously considered. The safety issues taken into consideration in this study are also considering the COVID-19 implications.*

**Keywords:** *Autonomous transport in the city, epidemic, passenger safety.*

**JEL Code:** *L21, L27, N67.*

**Paper Type:** *Research in Security Studies.*

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## **1. Introduction**

Covid-19 is a contagious disease caused by SARS-Cov-2 coronavirus. The onset of the epidemic should be looked for in Wuhan's city in China in December 2019. Before the outbreak, Covid-19 disease and Sars-Cov-2 virus were unknown. Initially, it appeared that it was China's internal issue; nevertheless, very soon, it turned out that the followers of such theories were seriously mistaken. Notwithstanding the resignation from leaving for China, both for business and tourist purposes, the virus spread all over the world quickly. Apart from health-related effects, infections, and deaths, the epidemic caused many changes in people's behaviors worldwide.

People's fright, fear of getting infected, lockdown, and economy freezing also resulted in considerable public transport functioning limitations. In many countries, as in other economic sectors, public transport operates to a minimal extent. Fear of the unknown, anxiety about getting infected when contacting other people made the streets empty, and consequently, public transport is used by approximately 80% fewer passengers. Public transport was used only by those people who had to work during the epidemic: such as employees of the health care system, municipal maintenance services, grocery shops, etc.

This epidemic is not the first and not the last in our population. What makes it different from the others is its global extent. The epidemics in recent years were as follows: SARS (2002), Avian influenza (2006), Swine influenza (2009). Using public transport during the epidemic is not safe due to the prospective risk of infection. What can help us is the technology of autonomous vehicles, which may be used in public transport shortly. This is a new technology-supported strongly by investors who perceive great potential in it. This article aims to consider the safety aspects related to the use of autonomous vehicles. We look at this safety in two aspects. The first one is passengers' safety in the means of transport, and the other one is the safety of the technology. The research methods presented in this article include analysis, synthesis, and deduction.

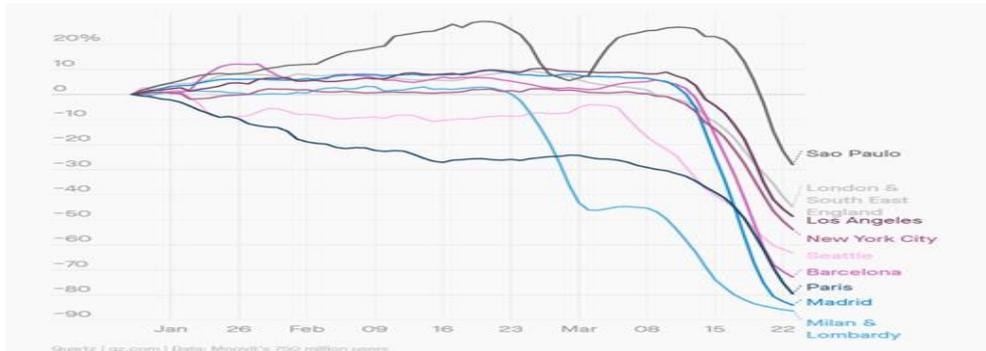
This paper consists of four parts. The first part is the introduction, including general information on Covid-19 in public transport and the possibility of using autonomous vehicles' new technology. Part number two presents public transport in various countries at the onset of the pandemic and safety rules introduced to protect passengers against infection. Then, the issue of autonomous vehicles was presented concerning their use in public transport. The study finishes with conclusions that summarise the considerations.

## **2. Public Transport During the Epidemic**

The pandemic of SARS-CoV-2 coronavirus led to the stoppage of 80% of public transport in the United States and Western Europe – as “Quartz” informs. On 23rd March, according to Moovit mobile application, using a bus, railway, underground, and bike dropped as much as by 86% in Milan and 84% in Madrid. As regards the

above, it is far better in New York, where traveling by underground decreased by 54%. This data is presented in Figure 1.

**Figure 1.** The percentage decrease in the number of passengers in various cities at the turn of February and March 2020



**Source:** Own creation.

However, Moovit data does not comprise all the cities and countries globally, including many Asian metropolises. Many places were blocked, thus their transit systems were open only for so-called critical employees or transporting urgent need goods.

The public transport management in London limited their services significantly and asked key employees to avoid, as much as possible, commuting to work in the mornings. More than 20% of the personnel were sick or isolated. In Italy, that is a country with the highest fatal rate (in the initial period) as a result of the pandemic, the decrease was by 80-90% in every larger city. In the Italian Peninsula, there were prohibitions imposed, which were the most stringent in the world, to limit the COVID-19 virus spreading. Buses, underground and trams in Rome stopped operating on 14th March at 09:00 p.m.

A similar situation was present at that time in Madrid. The capital city of Spain had the highest rate of people infected with SARS-Cov-2 coronavirus within the country. The center of historic Castile recorded a drop by 84% of public transport users. It was slightly better in the United States. The number of public transport passengers decreased by at least 40%, even by 65% in some centers. New York limited the underground and railway operations, reduced the number of customer service centers, and introduced the rule of getting on buses to relieve drivers. The group of American transport agencies applied to Congress for allocating at least 25 milliard dollars for supporting public transport in the federal package. The majority of people had to stay at home and resign from public transport to minimize the risk of SARS-Cov-2 coronavirus spreading. Nonetheless, these services must be available for health care

employees and first aid personnel and the employees of hospitals, pharmacies, and grocery shops. It was similar in Poland.

At the time of the most stringent restrictions connected with the pandemic, public transport vehicles in Poland transported only the air. Nevertheless, as the gradual de-freezing of the economy progresses, passengers come back, and many entities applied to the government for the parallel increase of limits imposed on public transport. - The limitations introduced at the end of March resulted in the reduction of the number of passengers who could use public transport at the same time by approx. 75-80%. To illustrate it, one 12 m long bus with a total capacity of approx. Merely several passengers could enter 100 places. This resulted from the fact that there are usually a few times fewer seats in public transport vehicles than standing places – and these are standing places which play the key role, especially in peak hours.

Ensuring passengers' safety became the carriers' priority. Keeping a safe distance, using masks and gloves, and disinfecting the means of transport was not enough to guarantee 100% protection against infection. It resulted, mostly, from the behaviors of some passengers who did not adhere to the carriers' recommendations. Many prospective passengers were so afraid of getting infected that they tried to avoid public transport and decided to travel by car or alternative means of transport, such as a bicycle, a motor scooter, or a scooter.

### **3. Autonomous Vehicles in Public Transport, Usage Possibilities**

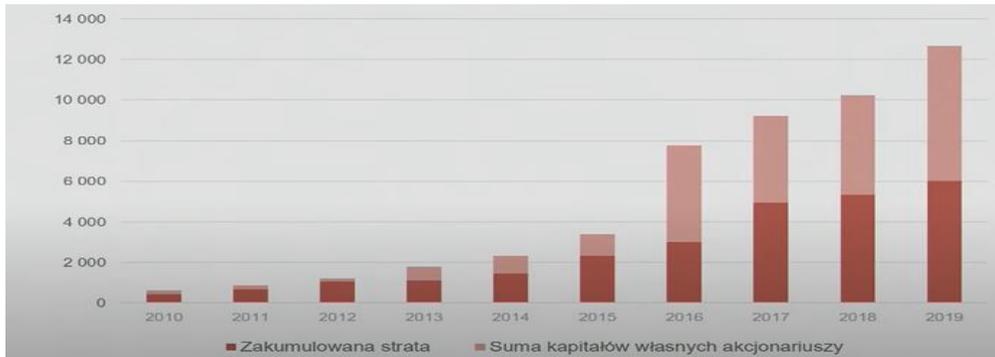
The history of autonomous vehicles is short, and it has military origins. In 2000, the Congress of the United States of America, hoping to reduce losses on the battlefield, implemented autonomous vehicles (robots). In 2002, Pentagon, DARPA (Defense Advanced Research Projects Agency), launched the competition called the Great Challenge, a race of cars without a steering wheel in the distance of 142 miles through the Deserts of California. The winner could get 1 million dollars. The race took place on 13th March 2004. 13 vehicles, constructed by the interested companies, universities, and research institutes, took part in that race. The route had plenty of terrain obstacles of various types, such as rocks, cliffs, riverbeds, reservoirs, etc. The effects were more than unsatisfactory. None of the vehicles covered more than 8 miles.

Another competition was arranged in 2005, and the amount of the prize was 2 million dollars. The winner was a car named Stanley, and Stanford University constructed it. Its advantage over the others was artificial intelligence, a special computer system that assessed a given situation and decided on further actions and riding direction. However, another stage in the autonomy of vehicles was a competition organized in 2007. The DRAPA Agency introduced another hindrance: traffic, and the competition was called "Urban challenge 2007".

The teams participating in that competition used a new device, Lidar, for detecting objects in the vehicle's surroundings. This device, which rotates 360° around its axis, sends laser beams reflecting on all the obstacles and returning to the detector. An

image of the surroundings (a map) is created from the reflected points, the environment's geometric mapping. As many as 6 out of 11 vehicles participating in the race covered the required route in that competition. Nevertheless, that was merely the first step in popularising autonomous technology. 6-hours ride without any collisions demonstrated the direction for technological solutions that must be headed so that autonomous vehicles could appear on roads. The DARPA Project initiated a completely new branch of the industry comprising vehicles and sensors' construction technology and creating software and computer systems. Even though this technology does not currently bring in any profits, and the autonomous control systems are still at the testing stage, investors spare much money on them, counting on huge profits shortly. The above thesis may be depicted by Fig. 5 (Autonomiczny transport przyszłości, 2020), which presents the investors' optimism towards one of the leading companies on the market of autonomous vehicles (Tesla, 2020)

**Figure 5.** the capital received by Tesla inc. from investors in the subsequent years in USD millions million USD



*Source: Own creation.*

Apart from Tesla, the companies with the best accomplishments in constructing autonomous cars are Google and Uber. Large-car combined are currently more and more interested in autonomous vehicles because they hope for high profits shortly.

#### 4. The Concept of an Autonomous Vehicle

One of the most general definitions indicates that an autonomous vehicle is a vehicle that is capable of moving with low involvement or without any involvement of a human (Jaworski, 2018). According to a different definition, autonomous vehicles are vehicles that, at different automation levels, enable driving such a vehicle without human involvement (Choromański and Grabarek, 2018). At present, despite the number of vehicle control systems, a fully-autonomous vehicle does not exist. The involvement of humans, who could take control over the vehicle, is still needed. Vehicle manufacturers working on autonomous vehicles apply, among others, such solutions as GPS, radars, image recognition systems, and odometry. The use of this type of technical solutions is to enable a given vehicle to collect information on the

surroundings during a ride in order to determine a correct track and behaviors on the road proper for given conditions, e.g., an autonomous vehicle, based on image recognition systems, may read speed limits from road signs and adjust its speed. It is also capable of avoiding obstacles so that transport is safe. The multitude of technical solutions makes assigning an unequivocal definition, which would refer to all the types of autonomous vehicles, difficult (Neumann, 2018).

The important thing is to determine the difference between an automatic vehicle and an autonomous vehicle. An automatic vehicle is equipped with technical solutions allowing a driver to delegate some activities to the vehicle control systems. In such a case, transport takes place with partial human involvement. An autonomous vehicle does not require human intervention, and a computer system controls a vehicle in a fully automated manner (Ibidem, n.a.).

Alongside the development of self-control vehicles, their various classifications have been created. The most frequently used classification, established in the United States by SAE (Society of Automotive Engineers), is called SAE J3016 Autonomy Levels and the classification assigned by NHTSA (National Highway Traffic Safety Administration) (Ibidem, n.a.). It comprises five levels:

**Level 0** - a vehicle without any automatics. These vehicles are common in road traffic. A driver controls fully the vehicle and its functions. There may be messages concerning the possibility of the occurrence of black ice or the necessity of checking the oil level in the tank.

**Level 1** - assumes that there are driver assistance systems. The example of such systems may be an adaptive cruise controller which maintains given speed and distance from a vehicle which is in the front. Electronics in the vehicle is capable of introducing some corrections concerning a ride, e.g.: soft acceleration or braking and turning slightly. A limitation characteristic for this type of autonomy level is the possibility of performing only one type of an action at a time (wyborkierowcow, 2020).

**Level 2** - assumes that vehicles with the 2<sup>nd</sup> autonomy level are capable of the same things as the 1<sup>st</sup> level cars but they may combine respective actions, e.g.: they may accelerate and turn at the same time. A driver must be always ready to take over the control (wyborkierowcow, 2020).

**Level 3** - means conditional automation enabling, in some conditions, taking the full control over driving a vehicle by the system. Some conditions, in this case, are understood as a broad road with clearly marked lanes. A driver must always be ready to take over the control of the vehicle (Ibidem, n.a.).

**Level 4** - is characteristic for no need of controlling a vehicle by human. A driver has the possibility of taking the control over. Usually this takes place in exceptional cases,

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such as adverse atmospheric conditions. When a driver ignores signals sent by the system to take control, the system will stop the vehicle safely on the wayside (Ibidem, n.a.).

**Level 5** - means that the 5<sup>th</sup> level autonomy vehicles do not need the presence of a driver during a ride.

Progress in machine detection technology and learning for perception tasks fostered the development of autonomous and semi-automatic vehicles. This progress enabled Google to create autonomous vehicles that covered 480 000 km without any accident. The vehicles of this company are totally autonomous, which means that driving does not require human involvement. Tesla's offer also includes semi-automatic vehicles. A software update enables this company to drive the already existing cars on one's own possible. It is not certain whether introducing semi-automatic vehicles is a good solution because when people become surer about car possibilities, their attention to the situation on the road may be reduced, which may lead to an accident. The first fatal accident with an autonomous vehicle tested by Uber took place in 2018 and made this issue often discussed. Apart from the above, there were a few fatal accidents in which the drivers of Tesla cars died because they did not follow its limitations.

## **5. The Core of Autonomous Behaviours**

In theory, the biggest advantage of autonomous vehicles, in the context of cargo transportation, is the absence of a driver in the transport process, which should reduce transport costs. To achieve that, a vehicle should adjust its actions (movement) to the current situation on the road. This increases transport reliability and safety. Generally, such actions may be perceived as autonomous behaviors.

Autonomous behavior is every driver's assistance action taken independently from a driver by the vehicle control system during a ride. The degree of the vehicle control system intervention depends on its autonomy level. The system adjusts vehicle behavior on the road, among other things, through the adjustment of speed (adjustment to permitted speed based on data provided to the vehicle by infrastructure elements), braking, or passing around obstacles.

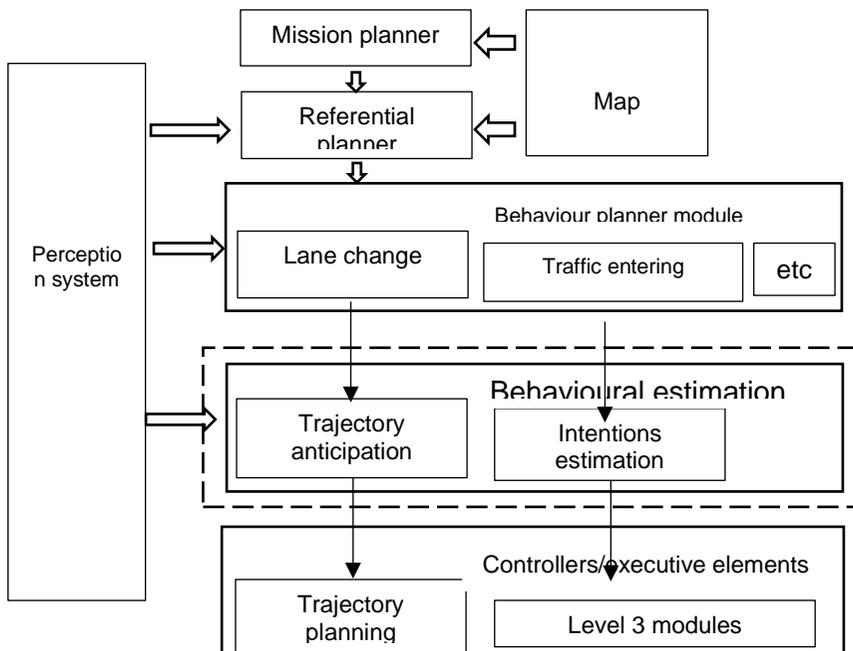
## **6. Anticipating the Behaviours of other Vehicles on the Road**

Currently, a commercial road autonomous vehicle does not exist. Along with the technological progress, the first vehicles of this type will be introduced and will participate in mixed traffic; that is, they will move on the road together with traditional vehicles. The present systems of the autonomous ride are not good in complex environments full of human-driven vehicles. The main reason for the above is that current systems are not capable of predicting intentions or the future motion of neighboring vehicles and responding appropriately. There are lots of different autonomous vehicle systems.

In most of them, two modules are generally responsible for autonomous behaviors – planning behavior and planning a trajectory. A behavioral planner module usually gives commands of a high level, such as “change a lane” or “turn left.” A trajectory planner module generates a given command performance plan, which can be implemented in the given conditions. Unfortunately, in most cases, a behavioral planner module is not capable of anticipating human behaviors on the road. It cannot communicate with human drivers to inform them of its intentions, e.g., changing a lane, etc. and the mutual adjustment of behavior on the road is not possible either (Dong, 2019).

Therefore, autonomous vehicles must have an additional module enabling their understanding of other traffic participants' intentions, anticipating the behaviors of vehicles driven by a human in mixed traffic (Ibidiem, 2020). Figure 6. presents a simplified architecture of the control system in the autonomous vehicle (Dong, 2019).

**Figure 6.** Architecture of control system in the autonomous vehicle



*Source: Own creation.*

This architecture does not consider detailed perception modules and control modules. The dashed table includes an additional module, added by C. Dong, which is not present in the traditional autonomous vehicle control systems - Behavioural Estimation module (Behavioural Anticipation or Behavioural Estimation), also

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referred to as a predictive engine. A prediction layer consists of different sub-modules with varied complexity and calculation requirements (Ibidiem, 2020).

For instance, such a command as “belt change” from the Behavioural Planner module will be sent to the Behavioural Estimation module. This layer activates a proper sub-module, e.g., Trajectory Anticipation, for all the vehicles near the vehicle performing a maneuver of lane changing. In the Anticipation process, the Behavioural Estimation module will select a proper module at the Actuator/Controller level. In the case under discussion, the anticipated trajectories will be sent to the Trajectory Planner sub-module to generate a joint road (path) plan of belt change. The last element is the performance of a maneuver (Ibidiem,2020).

Several factors may affect the behavior of a driver on the road. This entails difficulties in anticipating its behaviors. It also hinders modelling the impact of these factors on the driver’s behavior. These factors depend on and comprise others (Ibidiem, 2020) (Dong, Dolan, and Litkouhi, 2018). Current target, such as, e.g.:

- staying on the belt, changing a belt, entering traffic. A vehicle performing a manoeuvre should behave accordingly (e.g.: speed change), to achieve the target,
- Actions undertaken by other vehicles on the road, e.g.: one or a few vehicles in the surroundings change a belt. This may entail undertaking some actions by a driver which is nearby, e.g.: passing round the vehicle, etc.,
- Road traffic rules, signs and signalling devices, e.g.: if there is a “give way” sign on the crossroads, a driver, when approaching such a crossroads, should give way to other vehicles.

Since the said factors may occur simultaneously on the road, a driver's behavior becomes even more complex. For instance, in dense urban traffic, a vehicle intends to turn left on the next crossroads. The current objective is "turn left." When approaching the crossroads, a driver notices the lack of signalization (green arrows) on the crossroads. In such a situation, a vehicle standing at the crossroads must constantly monitor the vehicle approaching from the opposite direction, awaiting the state in which the requirements for turning left will be satisfied.

This requires the driver's understanding of other vehicles' intentions approaching the crossroads, preparing a reasonable forecast of their further behaviors, and finally performing a sequence of proper actions (responses). It does not easily create a single model that may include complex actions and interactions between various objects and may cope with all the possible scenarios, such as traffic entering, belt changing or, going through the crossroads. Nevertheless, the universal framework (application framework ) may serve as a solution for various scenarios with slight modifications or specific adaptation. Such frameworks' data basic task is devising an interaction between a host vehicle and other vehicles driven by humans. Then, it is possible to

generate a forecast of the behaviours and trajectories of behaviours of vehicles. Based on such a forecast, it is possible to plan the cooperative trajectory for vehicles.

Such a framework fills the gap between the trajectory planner sub-module and high-level tasks planner, especially in dynamic environments, where the trajectory planner sub-module needs future (anticipated) vehicle movements as a reference point. Since there are differences in downloading input data, the trajectory planner sub-module and high level tasks planner (e.g., referential planner sub-modules and mission planner sub-modules) may encounter conflicts in the process decision-making and their fulfilment. For example, a behavioural planner module may send a command for belt changing but due to dense traffic or aggressive drivers' behaviors, the trajectory planner sub-module cannot generate any feasible and collision-free path in the minimal area and time (Dong, 2019).

Generally, the behavioral planner module does not consider any failure of low-level planners (trajectory planners and controllers), and it also does not have any feedback mechanism when such low-level planners do not work properly. The solution to this problem has two aspects (Ibidiem, 2020):

- The behavioural planner module should consider more detailed information and have the possibility of anticipating environmental changes, e.g. the future trajectories of the surrounding vehicles, with limited uncertainty,
- The behavioural planner module should consider feedbacks from the trajectory planner sub-module and it ought to be ready at any time to take subsequent decisions.

The majority of the existing decisive and route planner algorithms do not provide future trajectories or accept a fixed model for all the factors. Such solutions are sufficient for a vehicle in simple surroundings (easy to be anticipated) with objects moving at low speeds. However, none of the above solutions is sufficient for autonomous vehicles, which must face more problematic situations, such as higher speeds, more dynamic surroundings, dense interactions between vehicles and between vehicles and infrastructure, as well as safety-related issues (Ibidiem, 2020).

As far as the autonomous transport system is concerned, we must consider vehicles and road infrastructure together.

Road infrastructure may support and lead automatic and autonomous vehicles using physical and digital elements. The Infrastructure Support Levels for Automated Driving (ISAD) may inform autonomous vehicles on road loads in some road sections. The environmental (surroundings) perception of autonomous vehicles is limited to board sensors' range and possibilities. The road infrastructure operators use several movements and surroundings detectors and provide information that may be used by autonomous vehicles. To classify and harmonize the road infrastructure's possibilities to support autonomous vehicles, a simple classification model was created, which is similar to the previously mentioned autonomy levels (SAE). These levels determine

the "readiness" of the road infrastructure to handle autonomous vehicles at various levels:

**Level A** - based on information conveyed in the real time concerning vehicles traffic, the infrastructure is capable of leading autonomous vehicles for the purpose of the optimisation of the overall road traffic;

**Level B** - The infrastructure is capable of recognising a given situation in the road traffic and providing such data to autonomous vehicles in the real time;

**Level C** - All the dynamic and static information concerning the infrastructure is available in the digital format and may be provided to the autonomous vehicle;

**Level D** - A digital map is available with stationary road signs.

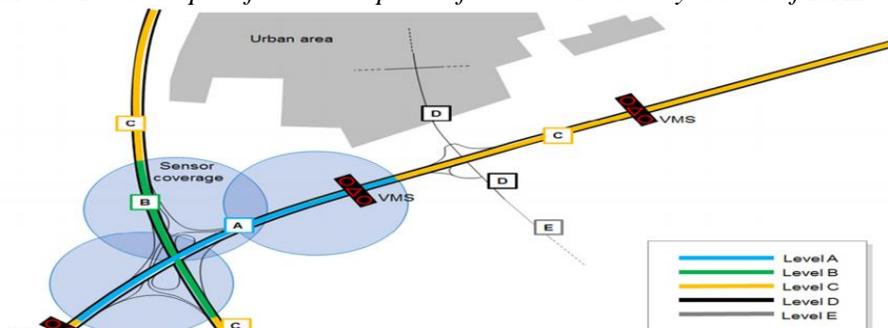
Map data may be supplemented with physical reference points (road signs). Traffic maps, short-term road works and variable message signs (VMS) must be recognised by autonomous vehicles;

**Level E** - Traditional infrastructure without digital information. Autonomous vehicles must recognise road geometry and road signs.

The infrastructure support levels are to describe given road or motorway sections and not the entire road network. This reflects a common practice within implementing the infrastructure: road traffic control systems (various sensors and VMSes) are usually used in motorway sections where traffic often reaches the capacity limit (e.g., in urban areas); whereas, other motorway sections do not require any fixed installations of traffic control because vehicle traffic is interrupted rarely (Carreras *et al.*, 2018).

Figure 7. presents an example of how ISAD levels may describe a changing level of infrastructure support in various motorway sections (Carreras *et al.*, 2018).

**Figure 7.** The example of the description of a road network by means of ISAD levels



**Source:** Own creation.

If dedicated sensors support a complex crossroads, it is possible to ensure situational awareness on the road at level B and even to navigate autonomous vehicles (level A). Other road sections only ensure support at level C, which comprises providing VMS data using digital interfaces. Furthermore, in the above example, a secondary road

network is partially under support for maps (level D); some rural areas do not support it. This example illustrates how ISAD levels may be used for the simple description of what vehicles with a different autonomy degree may expect in the given sections of road networks (Ibidiem, 2020).

Autonomous vehicles riding in the urban environment constitutes an interesting field for developing new concepts and technologies. Such a concept is interesting for scientists, among other things, due to the high density of other traditional vehicles in the urban traffic and various, specific for a given area, road traffic rules, which must be obeyed. There are many different projects as part of the research concerning autonomous vehicles moving on urban roads. The problem of an urban ride is both interesting and difficult because it needs tackling two crucial aspects – a complex environment in which a vehicle moves and increasingly higher speeds reached by vehicles (Pendleton *et al.*, 2017).

A development rate and the level of investing in autonomous transport-related technologies indicate that, shortly, autonomous transport will be such a precise and mature technology that it will be used commonly in passenger transport and cargo transport. Many companies in the world are currently researching the construction and use of autonomous vehicles. Also, in Poland, there is research on the use of autonomous vehicles for passenger transport.

Last year, in Gdańsk, microbus tests were carried out. In Cracow, an autonomous tram is being tested before the planned launch for use. Whereas, next year, in Rzeszów, there are tests planned on an autonomous bus which will go from the city center to the airport (Polish Economic Institute, 2020)

## **7. Conclusions**

This paper's objective was to consider the possibility of using autonomous vehicles in public transport to ensure safety during an epidemic threat. It was particularly about using vehicles that could replace present taxis, enabling passenger or passenger handling without contacting any operators. The issues connected with ordering and paying for a ride are already solved because many applications are available to this effect.

This paper's objective was achieved; the situation of public transport in given countries worldwide was presented in the hottest period of the epidemic, which is in January and February 2020. Furthermore, the topic of autonomous vehicles was discussed, and the principle of operation and interaction with the infrastructure. It has been demonstrated that there is a ready-to-use technology allowing for individual passenger transportation without contacting a driver and other passengers, which reduces the risk of virus infection significantly. Moreover, there are also works conducted on the use of autonomy in passenger transportation using a bus, tram, and underground.

In the event of a tram and underground, it is simply because they move along railways, which means that the road is predictable, and there are fewer problems to solve. Whereas, as far as vehicles are concerned, which participate in the road traffic in the urban agglomeration, it is necessary to use autonomous vehicles at the 5th autonomy level according to the SAE classification, which does not need human involvement.

The followers of autonomous vehicles claim that they may bring in the largest changes in transportation since horses have been replaced with cars. A driver is not needed to move from one place to another. Instead of having their own cars, people, if necessary, will be able to call one of the cars from the taxi fleet, which is constantly on the move. This will result in the reduction of the number of vehicles on roads and pollution generated by vehicles. This is also a solution for people without a driving license because their mobility will increase. It is also necessary to consider the construction of public transport vehicles consisting of modules where every passenger could have an allocated space. Such a solution would prevent the risk of infecting another person during an epidemic. Regardless of the structure and type of an autonomous vehicle, passengers' safety, due to the limitation or prevention of infections through a passenger's isolation, is unquestionable.

In recent years, the technology of autonomous vehicles has been developing dynamically because of artificial intelligence-based on analysis and learning algorithms. The 5th level autonomous vehicles, according to the SAE classification, are currently being tested. Although the tests are advanced considerably and tested vehicles covered a hundred thousand kilometers in extreme situations on the road without collision, they are not authorized for commercial use. This results from the presumption that technology must be 100% safe so that the lives of passengers and other road users could be entrusted to the machine. It is estimated that this technology will be popularised after 2030. Nonetheless, considering the ecological trends in the construction of cars and engines and the widespread automation and robotization of vehicles, and the dynamic development of artificial intelligence, it may be assumed that this will take place much sooner.

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