

Impact of COVID-19 on the Functioning of Passenger Rail Transport

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Summary

The article presents an overview of the transport situation on Polish railways during the first and second waves of the COVID-19 pandemic. The emerging trends in the use of rail transport are characterised. In order to meet market needs, rail transport should be open to any technical solution that reduces the possibility of horizontal transmission of infections to, both, travellers and transport workers. Examples are given of measures which improve safety during transport in this respect, as a fundamental condition for the systematic return of travellers to the railways.

Keywords: rail transport, COVID-19, passenger rail transport

1. Introduction

The COVID-19 pandemic has caused a major upheaval that is having undesirable economic effects throughout the world. It negatively affects both people's work and the functioning of institutions and enterprises, regardless of their size. Among the industries most vulnerable to this impact is transport, and the rail sector in particular – both passenger and freight.

In passenger transport, volumes are negatively affected by limiting the number of travellers, and the possibility of staff becoming infected, etc. The concerns of freight carriers include a decrease in the number of orders, longer payment processing and restrictions in international traffic. It should be stressed that the problems concern all links in the transport chains, affecting railways, freight forwarders, logistics companies, as well as shippers and receivers. Railway infrastructure managers and operators of various service infrastructures will also bear the financial consequences. This article concerns rail passenger services.

Analysing the many forward-looking EU programmes based on the development of railways, any negative impact of a pandemic must be considered in the context of strategies for sustainable transport development, social and economic integrity, the transition to clean mobility and high transport efficiency. Rail transport has a key role to play in both delivering the above strategies and achieving the Green Deal objectives, as it is the most sustainable and environmen-

tally friendly mode of transport. Regardless of this, work on digital transformation or the full opening of the rail market may be delayed.

One paper [3] indicates that (...) *Digital technologies and data have an important role to play in combating pandemics. Mobile apps can improve infectious contact tracing strategies and support public health authorities in monitoring and reducing the spread of the virus. Artificial intelligence and robotics can also help to monitor physical distance in accordance with data protection law or to facilitate disinfection, (...).*

Observing the performance of the rail sector in the first quarter of 2020, it has been concluded that passenger demand throughout 2020 will be significantly below levels from 2019. It is worth quoting [17] that *“to mitigate the effects of the pandemic, ambitious multi-domain policy measures are implemented. In this context, the current Regulation aims to complement the existing rail framework to enable national authorities and rail stakeholders to deal more easily with the range of negative impacts of the COVID-19 pandemic and to meet the urgent needs of the rail sector throughout the impact period. These measures shall concern in particular the cancellation, reduction or deferral of charges for access to railway infrastructure and the cancellation of reservation fees. They shall cover a reference period from 1 March 2020 to 31 December 2020, for which the charges may be modified by way of derogation from Article 27 of Directive 2012/34/EU, according to which the network statute (including applicable charges) shall*

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be published no less than four months in advance of requests for infrastructure capacity.” Actions in this direction have been supported by rail industry organisations [16, 22].

The initiative of the European Commission in this regard coincided with the activities undertaken by the Polish Ministry of Infrastructure. It is worth mentioning the measures introduced to mitigate the financial impact of the pandemic on carriers. The national railway infrastructure manager, PKP Polskie Linie Kolejowe, on the basis of the SARS-Cov-2 procedure, suspended the collection of reservation fees for abandoning the allocated capacity and the collection of penalties for launching trains by operators with a different traction vehicle than the scheduled one or with an increased gross weight of the train. These conveniences were intended to favour the activities of carriers affected by the abandonment of transport services by travellers.

The aim of this article is to give an overview of how rail transport operated during the COVID-19 pandemic, as well as to show the impact of restrictions on technical solutions to reduce the virus emissions in vehicles and increase travel safety.

Regardless of the existing pandemic, many questions arise about the future of passenger rail transport. What role will these services play in Poland's passenger transport? Will the pandemic affect the types of the rolling stock and its purchase plans? How do potential travellers perceive the use of rail services in the future and how will this relate to current development strategies? There are more similar questions and concerns about the future affect the operating transport companies, the state authorities as well as a wide range of potential travellers.

2. Operation of passenger rail transport during the pandemic

As a result of the first wave of the pandemic, rail passenger and freight transport has decreased significantly due to the restrictions imposed as well as lower demand. Temporary restrictions on travel between EU Member States have had a great impact on the sector: most international passenger trains have been suspended, and domestic passenger transport has decreased significantly compared to 2019 figures. This has also translated into declining revenues for the rail infrastructure manager, which is responsible for maintaining the rail network and investments.

A number of new entrants to the rail market had to cease operations, and well-established rail freight companies reported losses in transport services [14]. Nationally, rail passenger services proved to be fairly

resilient during the pandemic crisis. However, trains did run, albeit on a limited basis, and rail services were run with every precaution. This resilience of the railways is of great importance to regional, national and EU economies.

The first quarter of 2020 saw widespread public abandonment of public transport services, resulting in a reduction in rail volumes. This resulted in a lower implementation of rail services. Despite the declared state of the epidemic, all passenger rail operators maintained services on domestic routes. As long-distance coach services were significantly reduced, some people started using rail transport. Despite this, the number of people using rail services per day was at a record low (Fig. 1). As claimed by the Office for Railway Transport (ORT), during this period there were regions where the number of travellers transported was 95% lower compared to the volume of services a year ago. *“In the transport peak it was about 16% and off-peak: 9%. At weekends it was around 7–8%. The lowest daily average traffic so far was recorded on Easter Sunday (12 April) – just 4.5%”* [23]. This resulted in a reduction in the number of trains running.



Fig. 1. Common view of a platform during the first wave of the pandemic [photo by A. Szkocki]

According to the ORT data, an average of around 65% of the trains originally included in the timetable were run daily, and some rail operators introduced special timetables. It was already predicted at the time that this situation would have a major impact on the profitability of the railways. Carriers operating under PSO agreements have significantly reduced the number of routes and frequency of services due to falling demand for transport services. At the same time, *“they completely suspended their activities in the territory of Poland: Leo Express (operating on the Praha Hl. N. – Kraków Główny route on the basis of a granted open access decision), České dráhy (operating on the Jindřichov ve Slezsku – Glucholazy – Mikulovice*

route on the basis of an international agreement) and ODEG Ostdeutsche (operating on the Hagenwerder – Krzewina Zgorzelecka – Hirschfelde route on the basis of an international agreement). (...) In March 2020, a total of 2338 trains on the national infrastructure manager's rail network were cancelled, 1353 more trains than in the same period of 2019. Odeg Ostdeutsche (785 trains, 33.6% of all cancelled trains) cancelled the largest number of trains. At the same time, the POLREGIO carrier cancelled 480 trains, Koleje Dolnośląskie 343 trains, PKP Intercity S.A. 153 trains, České dráhy 137 trains, Koleje Śląskie 113 trains, Koleje Mazowieckie and Koleje Wielkopolskie 108 trains each. Other operators cancelled less than 100 trains" [23].

The national railway infrastructure manager PKP Polskie Linie Kolejowe, on the basis of COVID-19 procedures, suspended the collection of reservation fees for abandoning the allocated capacity and the collection of penalties for launching trains by operators with a different traction vehicle than the scheduled one, or with an increased gross weight of the train. These measures were intended to favour the activities of carriers affected by the abandonment of transport services by passengers [23].

The situation after the first wave of the pandemic has been aptly described [13]: "In rail transport, a deep decline in traffic occurred on interregional and international routes operated primarily by PKP Intercity, as well as in regional traffic operated by many carriers."

The summer holiday season saw the return of passengers to the railways. As in previous years, travellers

trusted the railways when planning their holiday trips. Daily journeys between the place of residence and the place of work increased systematically, and carriers resumed some routes to guarantee an adequate transport offer. The numbers of cancelled trains in individual months of third quarter 2020 are presented in the table 1.

In the third quarter of 2020, carriers operated a total of more than 419,000 passenger trains, more than 104,000 more trains than in the second quarter, during which we felt the spring lockdown and its effects (2,900 passenger trains were cancelled at the same time) [19].

According to the Office for Railway Transport, after three quarters of 2020, the result in the passenger sector is 33 per cent lower than in the same period before the outbreak. A total of 164.9 million passengers used the services [25]. According to a forecast of train attendance developed by the President of the Office for Railway Transport, by the end of the year, the number of rail passengers should be between 208 and 240 million. The outbreak will reduce the number of travellers using rail services by around 100 million compared to 2019 [8].

Despite the introduction of a number of travel restrictions, it can be concluded that the COVID-19 pandemic has confirmed the previous thesis regarding the rail system being the most resistant to pandemic disturbances. Without railways, public transport, especially in non-urban areas, would not be available in many regions. Information on train punctuality in the third quarter of 2020 is provided in Table 2.

Table 1

Number of train cancellations in the third quarter of 2020

Parametr	July	August	September	Third quarter
Total number of canceled trains	991	1013	912	2916

[Based on data from the Office of Rail Transport (UTK)].

Table 2

Data on punctuality of passenger trains in the third quarter of 2020

Parameter	July	August	September	Third quarter
Punctuality on arrival, with delays of over 5 min 59 sec	94.33%	93.64%	93.83%	93.93%
Total number of running trains	139 927	138 606	140 942	419 475
Total number of on-time trains	114 404	111 794	112 845	339 043
Trains delayed up to 5 min 59 sec	17 588	18 001	19 398	54 987
Trains delayed from 6 min to 59 min 59 sec	7 525	8 358	8 271	24 154
Trains delayed from 60 min to 119 min 59 sec	296	352	319	967
trains delayed by more than 120 minutes	114	101	109	324

[Based on data from the Office of Rail Transport (UTK)].

3. Trends in potential traveller behaviour and its impact on transport service forecasts

In 2019, the number of travellers transported by rail reached almost 336 million people. Interesting information in terms of passenger rail transport in 2020 was determined by the ORT [7]. Four options have been adopted in the forecast of the number of passengers in rail transport.

- The first (optimistic) variant assumes a slowdown of the downward trend by the third quarter of 2020. The observed slight upward trend is expected to be halted in November and December. In this variant, the number of rail passengers at the end of the year can reach 240 million people.
- Option two takes the results for 2019 minus the standard deviation of January – August 2020 for the remaining months of the year. This option provides a transport volume of 231 million passengers.
- In option three, the assumed scenario predicts a decrease in the number of travellers between September and December, similar to that between January and August. In this option, the transport volume may reach 220 million people.
- The fourth (pessimistic) variant predicts a reduction in the number of travellers in November and December similar to the declines in April and May, with a total estimated volume of 208 million passengers in 2020.

The full-year decreases compared to 2019 ranged from nearly 29% in the optimistic option to more than 38% in the pessimistic variant. By comparing these assumptions with the actual situation, it can be concluded that option four was the closest to reality. According to ORT data [30], rail transported 209.2 million people last year. This result was 126.7 million fewer people than in 2019.

The drop, forest during the first wave of the pandemic, of around 100 million travellers compared to 2019 shows the scale of the impact of the restrictions caused by the epidemic. It should be noted that travellers are attracted by the lucrative offers of railway carriers ensuring the safety and convenience of travel. This is indicated by the results of the following months and the increasing number of travellers from 6 million in April 2020 to 20 million in August 2020 [8]. The transport restrictions introduced during the first and second waves of the pandemic have changed previous approaches to the role of public transport. The need to maintain distance as a protection against the threat will stay with us longer than the current pandemic.

Remote working could become revolutionary for transport. Statistics concerning such work before the

pandemic showed that it applied to a few percent of the workforce. That is nearly three times less than in Europe's most developed countries, not to mention the US, where this form of work began to spread in the late 1980s. Nowadays, a search for a good professional is very often combined with the provision of housing and a correspondingly high salary. In the German model, it was common for such workers to commute daily even more than 150–200 km. This was facilitated by high-speed rail combined with the reimbursement of travel expenses. Hence, many companies were primarily looking for employees in the immediate vicinity of their headquarters.

The economic and social lockdown has, in many cases, presented businesses with a fait accompli. The Anti-COVID-19 Act, issued in March 2020 [31], introduced a provision stipulating a period of 180 days during which an employer could instruct its employees to work away from their regular place of work. As the pandemic developed, this period was extended and replaced by the so-called hybrid model. It divided employees into those working remotely and in the office. This type of work is being systematically extended.

Labour market analysts describe a new phenomenon concerning labour markets. Thanks to remote working, companies in large towns and cities are not looking for employees from the immediate vicinity, as remote workers can be hired from other regions, very often with lower salary requirements. This also applies to company headquarters, which can be smaller and less imposing under such conditions. In addition to remote working, a new phenomenon has emerged in many companies concerning the teaching processes associated with distance learning. It is likely that this form of teaching will persist for longer. These kinds of behaviour, which have not yet been practised, have a major impact on the volume of transport services [22].

An interesting study on this topic is the report of Klaster Luxtorpeda 2.0, which conducted a survey among travellers [15]. Of all the respondents, around 57% said they used the railway at least once a week before the pandemic broke out, while 22.2% used this mode of transport several times a month.

The respondents were then asked whether they would use rail services during the second wave of the pandemic (Fig. 2). 8.4% were negative about such trips, while 40.9% were optimistic that they would use this mode of transport at least once a week. The respondents clearly declared that an increase in infections would slightly affect their decision to travel by rail in Poland.

The respondents were also asked to identify additional post-pandemic circumstances that would prompt them to use rail in Poland faster. It was possible to mark several answers to the question. Most people chose the option "improvement of transport

services – increasing the number of links and a convenient timetable”, which was indicated by 27.7% of respondents. The second most popular response was “lower ticket prices” – 18.4%.

The respondents were also asked to identify their most frequent destination by rail. As many as 58.8% of the respondents indicated that they commute to work or school. Private trips – 23.4% – came in second place. Tourism (10.0%) and business travel (7.8%) were the least common responses. With regard to business travel, an important factor is work policy, which in many cases is increasingly based on remote working and external contacts maintained in the same way.

It is also worth quoting from the study on safety assessment and risk identification. (...) *When assessing the safety of train travel (...) the respondents most often indicated a neutral opinion on the train travel safety (29.6%). A more optimistic assessment (...) was indicated by 22.3% of the respondents, while a pessimistic assessment (...) was indicated by 20.6% of the respondents. (...) Among the areas constituting the greatest risk when travelling by train, the most frequently mentioned was a “crowded train” (52.4%) and “non-compliance with the restrictions by passengers” (49%), which allows the conclusion that, in the opinion of passengers, the greatest threat to their safety are other passengers and their behaviour*” [14].



Fig. 2. Empty platforms of the SKM Warsaw passenger train stop during the second wave of the pandemic [photo by M. Szymajda – Rynek Kolejowy]

4. Travel behaviour and new quality needs for superstructure

Preliminary analyses of public transport in Europe indicate that the decline in demand for this segment of passenger transport will be permanent. This will happen as a result of the much greater use of remote working by employers than before, as well as the fear

of using previously operated transport vehicles and their technical equipment. The pandemic will also lead to many changes in supply.

Even before the pandemic, many transport companies organised tenders for the purchase of new transport rolling stock. The procurement process is lengthy. For obvious reasons, tenders could not take into account many, completely new requirements that appeared during the pandemic. Such requirements are specified not only in relation to the COVID-19 pandemic, but also due to similar threats that may occur in the future. This includes the application in passenger vehicles of:

- UV-C light to reduce the spread of viruses;
- Special ventilation and air-conditioning systems;
- Special wall, handrail and push button coatings which prevent the deposition of bacteria and viruses (so-called self-disinfecting surfaces);

And also:

- Changes to the standards concerning the maximum capacity of vehicles, their interior layout and appropriate seating arrangement options.

4.1. UV-C light to reduce the spread of viruses

UV-C light is commonly used for sterilisation. This short-term, easy-to-implement and inexpensive method should also be used in public places, e.g. on trains (toilets, passenger areas during stops at turning stations, etc.). Simple measures, such as frequent hand washing, face masks and other physical barriers are commonly used to prevent virus transmission. However, their effectiveness can be limited, especially in shared indoor spaces where, in addition to the airborne transmission of viruses, small items used, such as push buttons, door handles and handrails, can also be virus transmission media. Hence, additional measures are needed to limit the transmission of the virus when people re-enter schools, colleges, and workplaces, which is associated with direct contact. Among the available alternatives, UV-C light meets the requirements for a rapid, widespread and economically viable application. Its deployment is limited only by the current production capacity, the expansion of which requires rapid intervention by industry and the authorities.

It should be emphasised here that UV-C light kills 99.9 % of the COVID-19 within seconds. So it can significantly help to limit its spread. The light can be safely used in high-traffic areas – hospitals, means of transport or schools (Fig. 3). In China, UV light is already widely used to disinfect buses and other public facilities. In the near future, this method of disinfection can be used much more frequently. This technology will be made widely available to lighting manufacturers [25].

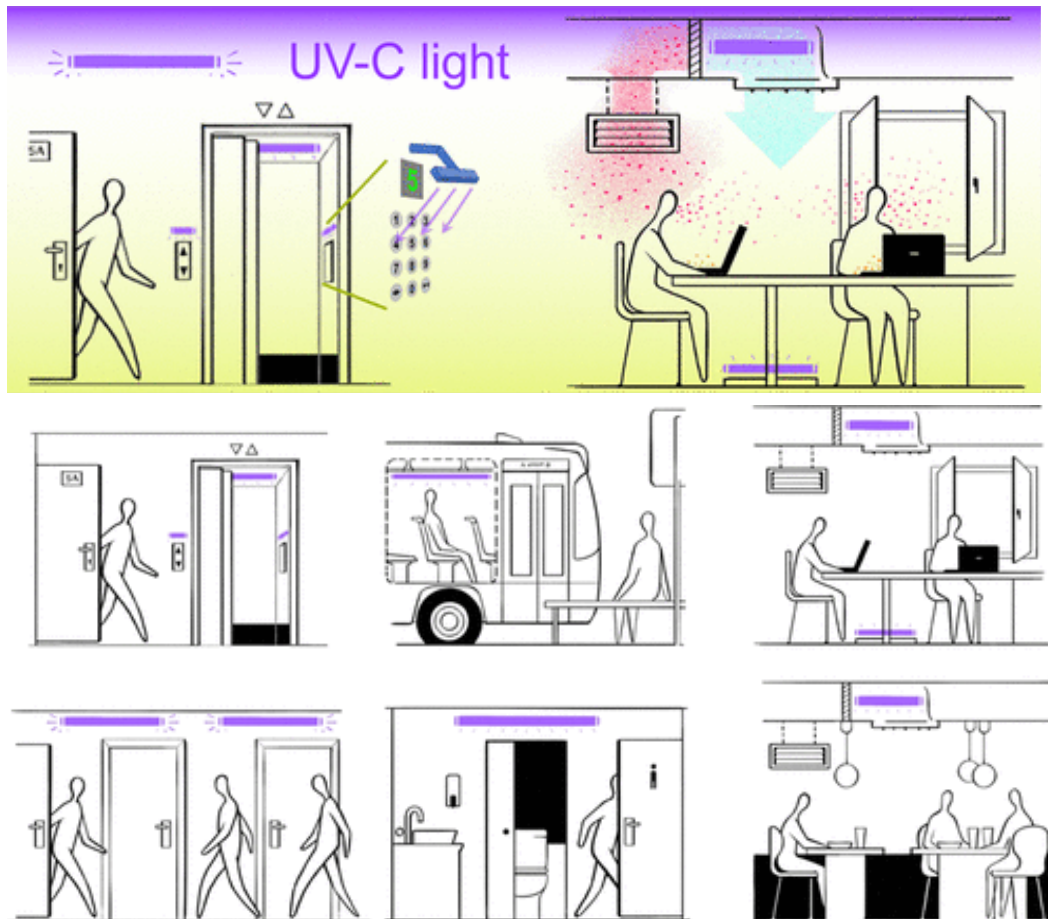


Fig. 3. UV-C light in real-life scenarios [1]

Ultraviolet radiation (UV) is invisible to the human eye and is divided into UV-A, UV-B and UV-C radiation. The wavelengths of UV-C radiation are in the range from 100 to 280 nm. The wavelength of 265 nm has the strongest bactericidal effect. Low-pressure UV-C radiators produced by various lighting manufacturers emit mainly 254 nm wavelengths, the effect of which on DNA is 85% of the so-called peak value. This makes them extremely effective in breaking down the DNA and RNA of microorganisms. This means that bacteria and viruses cannot replicate and cause disease. It is worth noting that this technology has found its way into applications for microbiological contamination risk. It has been used safely and effectively for over 40 years. It has not yet been applied to passenger rail vehicles and, in the interests of safety in this branch of transport; these protection should be taken into account by manufacturers of rolling stock. Figure 4 shows the wavelength range of UV light against the full light spectrum.

This method has already been deployed in the New York City underground system [28] and is being deployed on New York City commuter trains. As the transport fleet has not been not equipped with spe-

cial UV-C lamps, portable equipment is used during night train stops. Work in this area is being performed by Columbia University's Center for Radiological Research. One of the effects is expected to be the development of solutions constituting permanent equipment of the railway rolling stock [28].

4.2. Special ventilation systems for passenger trains and their services

The ventilation of passenger wagon space is an important way to reduce the concentration of any airborne pathogens. There is evidence that people in a poorly-ventilated room are at greater risk of developing the disease compared to those in a well-ventilated room. This is because people in a poorly-ventilated room are exposed to a greater concentration of airborne pathogens, and the risk increases the more time they spend in such an environment. Limiting the risk of airborne infection is possible through:

- Shortening the time spent in a given location, which, unfortunately, is not possible when travelling by train over a longer distance;

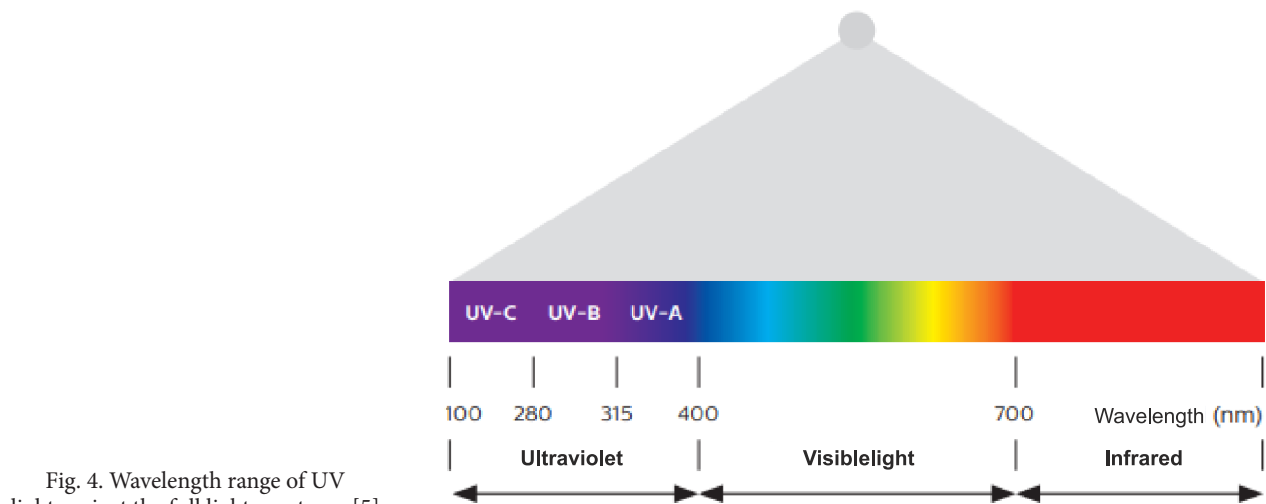


Fig. 4. Wavelength range of UV light against the full light spectrum [5]

- Reducing the concentration of infectious material in the air inside a wagon;
- Reducing the risk of the virus spreading by regularly washing hands, cleaning surfaces and reducing the build-up of infectious particles.

The capacity and effectiveness of ventilation play a role in both exposure to infectious particles and the rate of their deposition [29]. For example, the French High Council for Public Health (HCSP) has issued two recommendations on COVID-19, which must also be followed on trains. The document says that outside air should be used to replace indoor air as often as possible and that indirect airflow systems are preferable.

The high-efficiency ventilation systems used in modern trains meet the first recommendation because they routinely exchange indoor air with outdoor air. The ventilation system draws in air from inside the train, filters it and then mixes it with filtered air from outside the train. This mixture is heated or cooled (depending on the season) and distributed in-

side the train. The exact proportion of outside air varies depending on the type of train. On board the high-speed TGVs INOUI and OUIGO, the mixture contains about one-third outer fresh air and two-thirds inner air, which is filtered again every three minutes. This means that the entire air volume is replaced every nine minutes. On TER regional trains, the mixture contains, on average, 40% outer air and 60% inner air, so the entire air volume is exchanged every five to eight minutes, depending on the train design [15].

The second public health recommendation is to avoid direct airflow. French experts wondered if direct airflow could spread COVID-19 by pushing droplets from an infected person towards others and transmitting the virus to them (if they don't wear masks). But as there is no direct airflow on the trains in operation in France, this scenario has been ruled out. To ensure passenger comfort, SNCF trains use light, indirect flows that direct the air from the floor upwards, reducing the risk of infection. At the same time, air filters are replaced more frequently and air inlets and ducts are disinfected (Fig. 5).

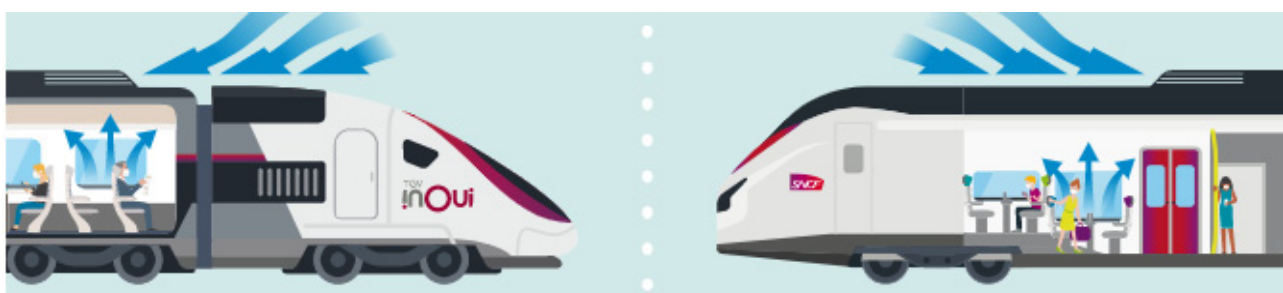


Fig. 5. Ventilation or air conditioning air is pumped from below towards the wagon ceiling to reduce the horizontal exposure to the virus [15]

At the same time, many specialist groups are perfecting systems to filter out particles as small as coronavirus from air conditioning systems. This is primarily used in cruise ship cabins, but will also find application in air conditioning solutions for passenger compartments in wagons [27].

In Poland, manufacturers of passenger rolling stock, widely operated by railway companies, have developed recommendations on the use of heating, ventilation and air conditioning installed in trains. This is helpful for haulage companies as there is no legislation on this. The restrictions introduced concern the number of passengers and the obligation for them to cover their noses and mouths. The regulations do not apply to the use of air conditioning systems. An example is PESA Bydgoszcz S.A, which included the following in its recommendations [4]:

- Before starting to transport passengers, the vehicle interior should be pre-heated or cooled to limit the closed-circuit airflow when there is a large difference between the setpoint and measured temperatures, the so-called delta.
- More frequent filter replacement than usual.
- If the filters used are class G3, the filters can be replaced with class G4 (for the duration of the pandemic). If possible, it is permissible to temporarily replace the filters to ePM10 class $\geq 50\%$, but the filters must be checked for contamination and changed much more frequently. When replacing them, care should be taken and personal protective equipment used to protect the respiratory tract and eyes.
- It is recommended to clean, at least once per week, the air conditioning system (interior of air conditioners and ducts) with ozone generators (high efficiency), UV lamps, and specialised chemicals, according to the instructions of the manufacturers of these chemicals.
- It is recommended to switch the HVAC³ equipment on in heating mode on a daily basis (at the end and before the start of the transport operation) so that air of maximum temperature flows through the ducts. In the case of heating based on water heating equipment, the unit should be switched to the heater mode (maximum water temperature) and the fresh air supply should be closed.
- It is recommended to disinfect the interior of passenger and driver compartments at least twice a day and ventilating them as intensively as possible after hygiene and sanitary treatment.

With regard to vehicle interior ventilation and air conditioning, specific recommendations have been issued by the EU Railway Agency in a special brochure [3]. It indicated, inter alia:

- In the event of a defective interior ventilation system on a passenger train, passengers must be evacuated whenever possible;
- Ventilation or air conditioning systems should not be switched off when transporting passengers;
- If possible, the HVAC system should be supplied with 100% fresh air;
- Check with the manufacturer or by means of a test that the units can be operated with a 100% supply of fresh air, and if this is not possible, adjust the fresh air supply accordingly and familiarise yourself with the maintenance of the system;
- If it is possible to open the windows, the locks should be unlocked to allow fresh air to enter in the event of large numbers of passengers or damage to the ventilation system;
- If the route of the train runs through long tunnels, an analysis of the airflow in wagons together with the operation of the ventilation must be performed for each type of train;
- The use of the same air by the ventilation system should be limited;
- Follow the maintenance recommendations of the HVAC system and use appropriate filters recommended by the manufacturer.

4.3. Materials and coatings to prevent the spread of viruses

Some vehicle surfaces, such as walls, handrails and handles, appliance buttons, and door handles etc., act as a repository for micro-organisms favouring the transmission of diseases that can spread to anyone who comes into contact with such items. It is therefore important to develop technologies that deal with the reduction of transmission by travellers touching infected elements.

Various materials from which these elements can be made can be modified to obtain the so-called bactericidal effect. Chemical or physical changes to a surface can provide an antibacterial effect. Chemicals such as antibiotics or biocide can be added to materials to give them antimicrobial properties. However, a balance must be maintained between these properties and biocompatibility as the materials will be in direct contact with a user's body, which may raise concerns about toxicity.

³ HVAC is the sanitary engineering industry. The abbreviation is a combination of the first letters of the words heating, ventilation and air conditioning.

Some materials have antimicrobial properties. They do not need an antimicrobial load to exert their activity because the material itself has the natural ability to eliminate microorganisms. The best known natural materials with antimicrobial properties include metals: silver, copper or zinc, and polymers, such as chitosan. In the case of many metals with antimicrobial properties, the ion form has a higher bactericidal effect than an elemental metal. Silver and copper are good examples of this. Surfaces made of antimicrobial copper are already used in airports, railway stations and healthcare facilities around the world. They help to reduce the spread of infections by supporting key infection control measures, such as good hand hygiene and regular cleaning and disinfection of surfaces [21].

Self-disinfecting surfaces are a step forward into the future of infection control policy. More research needs to be carried out on a self-disinfecting surfaces to fully use their potential to improve infection control and safety strategies. Reports of the use of these materials in healthcare facilities show promising results, and already many companies supplying products with self-disinfecting properties indicate that investing in prevention may be the best way to reduce the huge problem of infection spread [18]. It should be stressed that the applications of such solutions in public transport are mediocre.

Light-activated surfaces are also an example of recently developed self-disinfecting materials. Various companies have recently developed different antibacterial coatings that disinfect surfaces against viruses. For example, antiviral coatings have been developed using nanoparticles of copper and other metals. Instead of metals, the coating products can contain active chlorine stabilised by an innovative polymer. Such products can be used for coating walls, floors, partition walls and surfaces in railway stations, airports, and railway wagons, etc. The coatings are transparent and can be sprayed or painted without damaging the coated surfaces. Stabilised chlorine is intended to prolong the life of the coating [11].

In the summer of 2020, modern protection of the internal surfaces of transport rolling stock was applied by Koleje Śląskie, which introduced permanent antibacterial and antiviral protection of its rolling stock. Thanks to the cooperation with a company that produces such coatings, the process of coating all trains (over 60 units) with a special coating based on titanium dioxide nanoparticles has begun. After application, they permanently bind to the substrate, forming a system of photocatalytic coatings that activate when exposed to light and eliminate viruses, bacteria, fungi and moulds through a natural physical and chemical process [9]. The process of applying the antimicrobial coating is shown in Figure 6.

It is important to note that once the special product has been applied to the surface, the titanium dioxide

nanoparticles penetrate the surface structure, creating a durable coating with self-disinfecting properties that last for a minimum of 12 months even on high-use surfaces, such as door handles and switches. In addition to their antiviral and antibacterial properties, nanoparticles also clean the air, neutralise odours and eliminate volatile organic compounds (VOCs). They do not penetrate the body and are safe for human health and the environment. The product is odourless, colourless, completely invisible to the eye and does not change the structure and colour of the surface. Its presence and activity is periodically confirmed by specialised control tests. It can be used on all surface types, such as glass, steel, plastic, ceramics, textiles and even concrete or wood [9].

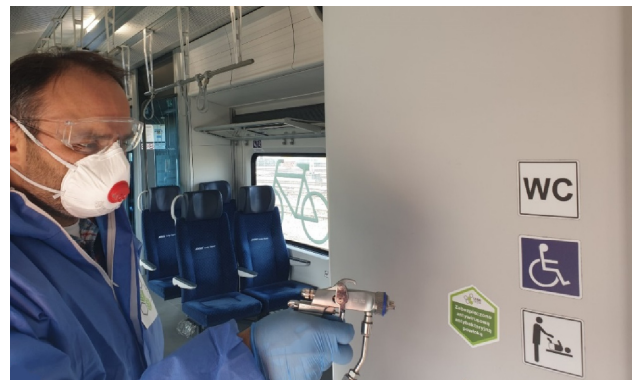


Fig. 6. Applying an antimicrobial coating to wagon walls [12]

4.4. Other technical solutions to limit the spread of viruses

Recently, a number of rolling stock manufacturers have started working on virus containment solutions. One example is the 3D printed door handle add-ons produced by Siemens Mobility, including for toilet doors and driver's cabins on the new Lastochka trains operating in Russian metropolitan areas, as well as on KDP Sapsan high-speed trains. Handle-mounted components allow the door to be opened with the elbow or forearm, reducing the risk of spreading germs or viruses [19]. An example of the handle is shown in Figure 7.

New requirements for upgraded or new rolling stock are constantly emerging. There is an increasing need to place additional doors in the driver's cab to ensure that the cab is exited without having to pass among travellers.

In the proceedings preceding the purchase of new rolling stock, the need, and indeed the necessity, to include in the vehicles factory-fitted dispensers for disinfectant liquids, to ensure that all train doors can be freely opened and closed by the driver, and to install containers for the selective collection of waste are increasingly frequently indicated.



Fig. 7. Wagon or driver's cab door elbow-opening handle [8]

Work is also underway on a new door-opening system using, instead of a hand-adapted button as before, a special foot-operated button. The difficulty is not in its design, but the placement within the door space both inside a wagon and outside the door. A biocidal film is an immediate measure to protect handles and handrails in means of transport. This is a new innovative solution against bacteria, viruses and fungi that multiply on various vehicle surfaces. The protective film is transparent, self-adhesive and suitable for any high-contact surface. It works by inhibiting the growth of microorganisms and provides long-lasting protection for surfaces that are frequently touched. It guarantees users a high standard of hygiene and safety by reducing the risk of infection [26]. The film-covered handrails are shown in Figure 8.



Fig. 8. Wagon handrails covered with the antibacterial film [26]

Interesting trial devices were installed in Poznań's trams and buses. During movement, this device suspended from the ceiling (Figure 9) filters the air, removing viruses, bacteria, allergens, fungi, mites and dust. While moving, the devices filter the air with filter systems, separating viruses, bacteria, allergens, fungi, dust mites and dust. When the vehicle is in motion, air changes inside it every ten minutes or so. The efficiency of the filters used in "catching" particles of the

size of the COVID-19 coronavirus is at least 99.99%. Additionally, when the vehicle is not in use, the devices disinfect the interior with ozone, which effectively removes accumulated viruses, bacteria and allergens also from the surface of the air separation filters [11].

In addition to the technical solutions discussed, vehicle designers face a number of challenges for the future due to the current pandemic. New functional solutions in such commonly used electric or diesel multiple units should protect both the carrier's employees and passengers. The additional entrances from outside the vehicle into the driver's cab, the interior layout, the placement of handles limiting the concentration of travellers in one place, and finally the seating arrangement, should be crucial in designers' efforts in the years to come. In view of the probable permanent phenomenon of the lower popularity of public transport, it will become more important to ensure appropriate travelling comfort, inter alia, through changes in vehicle capacity standards. Besides this, rail is crucial to the decarbonisation of the transport sector and contributes to the EU's green economic recovery [6].



Fig. 9. The device mounted on the ceiling of a tram car in Poznań [10]

Rolling stock manufacturers should be open to such comprehensive measures. It also raises the cost of vehicles. Hence, especially with regard to large contracts, a legal mechanism should be introduced for their qualitative and quantitative verification.

5. Conclusions

Activities related to the reactivation of economic activity, building a development concept, as well as the preparation and introduction of system and institutional reforms require initiative from expert circles, including scientists [13]. In view of the very large social and economic losses caused by the COVID-19 pandemic, which translated into passenger transport volumes, innovative measures on the railways (technique, technology, organisation) will be of fundamen-

tal importance for the transport effects obtained, but not leading to such a view as in Figure 10.



Fig.10. Crowded train of Koleje Mazowieckie [Source: Super Ekspres]

Given the lack of knowledge about the prospects for ending the ongoing pandemic, as well as the possibility of similar phenomena recurring in the future, rolling stock designers and transport organisers are faced with important tasks. They should concern the design of the transport fleet, the layout and equipment of the passenger area together with the application of appropriate technical and technological solutions. This may affect the revision of orders already placed for new transport rolling stock or the extent of its upgrade. The profitability of public transport will decline. The rolling stock will have to be operated differently, which in many cases will be associated with lower profits. We cannot count on the fact that these means of transport can be replaced by other, cheaper ones. Cities will also fail to stretch transport routes so that everyone can travel by individual car transport [22], reducing the use of public transport. Over time, the role of rail transport will steadily increase, although it is difficult to forecast when it will reach the results of 2019.

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