# Preliminary Implications of COVID-19 on Long-Distance Traffic of Deutsche Bahn

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## Abstract

This paper summarizes the findings of Deutsche Bahn since the outbreak of the COVID-19 pandemic. The number of observed infections on trains is worldwide very low. This holds true for both passengers and employees. Relevant influencing factors such as the type of contact, air exchange rate and air flow can explain the low incidence. Air conditioning systems with a high air exchange rate and fresh air content as well as vertical air flow seem to have positive effects. Mask wearing and comprehensive testing of employees in suspected cases are additional precautionary measures. The focus here is on long-distance passenger traffic.

Keywords: SARS-CoV-2, incidence, airborne infections, air conditioning, long-distance trains, Wells-Riley equation

## 1. Introduction

With this document, Deutsche Bahn (DB) wants to contribute to a better understanding of the infection with the SARS-CoV-2 virus and in particular address the question of whether travelling on long-distance trains represents an increased risk of infection. It is our mission to do everything that is viable to make rail travel as safe as possible. Hence, we also document our findings for the expert audience and are grateful for hints and suggestions to further develop our protective measures.

As a globally operating enterprise, DB has been dealing with the “SARS-CoV-2” virus and the disease it causes, “COVID-19”, since January 2020. Since the outbreak in Italy in February 2020, efforts were intensified and, in particular, internal monitoring processes for diseases, measures to protect customers and employees, and measures to gain systematic knowledge about the virus were initiated.

This document summarizes the findings of our medical, technical and operational services.

## 2. Evaluation of available public transport studies

Measured against the large number of passengers and their diverse contacts, we see remarkably few infections with SARS-CoV-2 in trains[1]. To our knowledge, not a single contact tracing has been identified in Germany and Austria as having been triggered by an infection on the train journey. One reason for this may be that contact tracing is more difficult in this setting than in other settings and it is therefore generally more difficult to generate evidence. However, since the beginning of March, improved instruments for detecting infections in trains and buses have been available. DB had already added an online tool to its customer website at the beginning of March for passengers who feared they had become infected on the train. The German government has ordered the use of “railway disembarkation cards” in cases of suspected infection, first for cross-border trains and a little later also for domestic trains[2]. A follow-up of almost 4,700 proven cases of infection in Austria with regard to the concrete transmission routes showed “[...] no case histories [...] [through] the use of public transport” (translated from German)[3].

 

Own enquiries both with the heads of the medical services of the railways[4] worldwide and with the pandemic teams of the UIC-represented (International Union of Railways) railways[5] also did not yield any indications of proven SARS-CoV-2 infections in trains. In the study by Luo et al.[6] the highest incidence was measured with over 10% for contacts within a household. In public transport, one of the most frequently identified types of contact, an incidence of only 0.1% was calculated.

These surprisingly low infection rates in public transport have prompted us to analyze the available literature in greater depth. On the one hand there are studies on concrete transmissions (in the literature before 2020 of course only on pathogens other than SARS-CoV-2) and on the other hand mathematical-theoretical considerations on the risk of infection in enclosed spaces, such as vehicles.

Compared to international air and sea travel, long distance train journeys in Central Europe are rather short with an average duration of three hours. Infection clusters on cruise[7] and military ships received massive attention in the daily press. In airplanes, as in trains and buses, transmission seems to occur only rarely[8].

A meta-study from 2016[9] was looking at the transmission of influenza and corona viruses in means of transport, including train journeys. The authors conclude that there is little overall evidence in the scientific literature on the transmission of viruses in trains, although there is certainly a role for public transport in the spread of infectious diseases in general.

In London in 2018, a positive correlation between the length of subway journeys and station stops with the incidence of flu-like illnesses was identified.[10]. However, other authors concluded for London that people who regularly use public transport did not have an increased risk of influenza infection[11].

There are first studies on the risk of infection on trains in the current SARS-CoV-2 pandemic, but most of them are still in preprint status. Qian et al.[12] investigated over 300 outbreaks of COVID-19 in China with over 1,200 infected persons. To classify the outbreaks, they divided them into six categories, one of which is transport, including train travel. One third (108) of the identified outbreaks took place in the transport context, including transmissions in motorized individual transport, and the Chinese New Year with particularly heavy travel movements during the period under investigation (end of December 2019 to end of January 2020). A detailed breakdown of the distribution within the transport category by the authors is not available and cannot be derived. An important aspect addressed by the authors is the supply of fresh air in closed environments caused by ventilation, which plays a decisive role in the probability of infection. This will be discussed in chapter four.

For findings on train traffic from China, the long distances and associated excessive travel times in these cases must be considered. Cui et al.[13] describe an outbreak of influenza A (H1N1) in a train in China in 2009, with a total travel time of over 40 hours (about 2,500km, 28 stops). A total of 22 cases of infection could be linked to the train journey, eight of them among passengers (including the index case), five among the on-board staff and the rest through subsequent close contact between infected persons. The authors report that the infection rate in air-conditioned carriages was lower than in non-air-conditioned ones. Furthermore, the spatial proximity as well as the individual travel duration played a decisive role in the probability of infection. No infections occurred in persons on board with a stay of less than ten hours, four of the 13 infections occurred during a travel period of 10-30 hours and the remaining nine infections were only identified for a travel period of more than 30 hours.

The Wells-Riley equation has been established to calculate the probability $P$ of infection in enclosed spaces[14,15]

$$P(I,\, q,\, p,\, t,\, Q) \;\coloneqq\; 1 \;-\; e^{-Iqpt/Q} = 1 - \frac{1}{e^{\frac{Iqpt}{Q}}}$$

where $I$ is the number of infected persons in the room, $p$ is the average respiratory rate of a person, $t$ is the duration of stay or exposure and $Q$ is the ventilation rate ($p$ and $Q$ per volume per unit of time). $e$ is Euler's number. The parameter $q$ describes the *quanta*, which is the rate of infectious particles an infected person emits per unit of time. It depends on the specific pathogen and the intensity of the air emission (e.g. pure breathing as opposed to speaking or singing). In order to reduce the risk of infection, the rear part of the above term must converge towards 1. Thus, the number of infected persons in the room, the number of emitted infectious particles, the breathing rate and the duration of exposure have an increasing effect on the probability of infection. The ventilation rate has a protective effect. Issarov et al.[16], as well as Rudnick and Milton[17], discuss some limitations of the widely used Wells-Riley equation, such as the assumption of stationary conditions. Rudnick and Milton modify the formula in such a way that it can also be applied under non-stationary conditions.

In a study by Buonanno, Stabile and Morawska[18], the quanta of SARS-CoV-2 is estimated regarding the respective activity (breathing or speaking, both during rest or light work). A distinction is also made between natural and mechanical air exchange, with clear advantages for the latter.

Dai and Zhao[19] conclude that, e.g., when travelling in a train without physical exertion in the presence of an (asymptomatic) infected person, the probability of infection is about 1% for a three-hour stay. A shorter exposure time reduces the risk of infection accordingly. In their scenarios, the authors distinguish between the wearing and non-wearing of a medical surgical mask by all those present, assuming mask wearing to reduce the risk of infection by a factor of four. The probability of 1% above implies wearing of masks. Other recent studies also underline the positive effect of face masks while optimizing the circulation of fresh air. [20, 21]

Various authors have examined the role of air conditioning and ventilation of enclosed spaces in the transmission of airborne pathogens. A literature review can be found in Liu et al. 2018[22]. Overall, an air supply distributed as evenly as possible in the room reduces the risk of infection most strongly. The ventilation rate in closed rooms is also decisive with regard to airborne transmission, whereby the highest possible proportion of outside air is always favorable.

In summary, for train journeys two factors are of essential importance. (1) minimizing breathing air emissions from potentially infected persons and (2) maximizing fresh air circulation in the relevant areas. We will discuss these and further factors in chapters three and four. Measuring body temperature to detect previously undiagnosed infections, does not seem to be very practicable[23], since the rate of undetected infections is almost 50% and the false positive rate, i.e. healthy persons are detected as infected, is also relevant.

A particular hazard in long-distance trains cannot be deduced from the studies conducted to date, presented in the literature research. On the contrary, infections in trains, as in airplanes, are rarely observed.

## 3. Measures taken to protect passengers and staff

DB AG took measures to protect passengers and staff at an early stage on the basis of the recommendations of the Robert Koch Institute, the applicable regulations, the latest scientific findings and knowledge exchange with foreign partner railways. For example, as soon as the pandemic began to spread in Germany in March 2020, the cleaning cycles of contact surfaces in trains, stations and all DB working areas were increased. If suspicions are confirmed, trains and workplaces are disinfected subsequently. In suspected cases of COVID-19 infection in DB AG trains, a reporting process with the authorities was established and employees in customer contact were equipped with two FFP 2 (the European equivalent to N95) masks. One mask is intended for the suspected infection as external protection and one mask for the self-protection of the employee during support.

In order to protect DB AG employees, instructions on behavior during the corona pandemic have been drawn up for the various occupational groups and are continuously updated. In addition, employees are regularly informed about current developments and measures by means of internal communication channels specific to each professional group. The other main measures are the creation of additional lunch and disposition rooms to ensure sufficient distance in the event of prolonged contact with the same people, installation of spit guards and partitions, work in the home office where possible, provision of disinfectants, wearing of mouth-nose covers for work where the distance of 1.5 metres cannot be maintained, introduction of contactless ticketing, and other organizational measures (e.g. adjustment of shift schedules) to reduce contacts.

Particularly at the beginning of the pandemic, when no concrete regulations for mouth and nose cover existed, it was of central importance that sufficient space was made available for travellers to feel safe while travelling. For this reason, DB decided to continue to provide a comprehensive and stable basic service despite the decline in demand and the travel restrictions imposed.

In long-distance transport, the train frequency was reduced by about one quarter from the beginning of March to the beginning of April, but the coverage was never abandoned. No further reductions were made after the German government announced initial easing of the regulations on 15 April 2020. Based on the development of demand and the successive lifting of travel restrictions, the frequency was raised again and the load factor control was adjusted.

Within the context of train occupancy rate control, the number of reservations is limited in the booking portals so that there is enough space available throughout the train. For better orientation, new capacity utilization information has been introduced in the timetable information system. Travel connections with an expected load factor of more than half of the seat capacity are specially marked. For connections with a presumably very high load factor, ticket reservations will be restricted. As before, the booking process will continue to ensure that the train load factor is as uniform as possible.

Despite these measures, the 1.5 m social distancing rule in trains cannot always be respected as passenger numbers increase; this also emerges from a joint recommendation of the public transport industry to resume passenger transport during the COVID-19 pandemic. For this reason, with the introduction of the general obligation to wear masks as a further protective measure, DB has made it compulsory for employees to wear mouth-nose covers on board trains and strongly recommended that passengers wear them. Despite the initial scepticism of experts towards mouth-and-nose masks, they appear to significantly reduce the risk of infection in public areas and on trains[24, 25].

## 4. Discussion on the transmission path via air conditioning systems

According to current knowledge, the virus is mainly transmitted via droplets that are produced when coughing and sneezing and are absorbed by the person opposite via the mucous membranes of the nose, mouth, and possibly the eyes. It has not yet been conclusively clarified whether droplets are only able to carry a sufficient amount of virus to be infectious once they reach a certain size. An overview of this discussion can be found in a publication of the *National Academies of Sciences, Engineering, and Medicine*[26]. Larger droplets (>10 μm) presumably have a higher infection potential, but are less relevant for the question of air conditioning systems as they sink to the surface or to the ground after only about 1-2 m. As it seems more and more likely that infections can also occur via aerosols (droplets <10 µm)[27], two questions arise in connection with the basic functioning of air conditioning systems.

1. Can an air flow from the air conditioning system promote the distribution of droplets (especially droplets <10 µm)? [28, 29]
2. Can the air recirculation function distribute SARS-CoV2 through the system?

The way air conditioning in trains, planes and many buildings works is that a mixture of circulating air and fresh air is treated (cooled, heated, filtered, dehumidified, etc.) and fed into the passenger compartment. An essential design principle for the airflow in the passenger compartment is minimizing draft sensations for the passengers.

The air in an ICE train (**I**nter**c**ity **E**xpress, system of high-speed trains predominantly running in Germany, with train generations 1-4) is usually discharged close to the ground over the entire length of the passenger compartment and then reintroduced either close to the ground, at the windows or from the roof (cf. Figure 1). Only the circulating air for recycling is taken as free air flow at the end of the car. The air flow is therefore essentially vertical rather than horizontal, which makes direct distribution of the virus by the airflow rather unlikely[30].

A transmission of droplets via air conditioning systems with recirculation function has not been proven so far due to the very long ventilation paths, the drying of the air and the existing filters (filter class G4 in rail traffic, particles >10 µm are filtered). This is also more likely to be ruled out in a case study of an outbreak in a restaurant[28]. Nevertheless, this question has been investigated in more detail for the DB facilities.

Long-distance trains have a high air exchange rate per passenger: a complete air exchange with fresh air in an ICE 4 carriage takes place every 6-8 minutes. Per passenger, sensor-controlled 15-22 $m^3$/h are supplied. An active air volume control system, which is regulated by the $CO_2$ content, ensures that the fresh air supply is regulated depending on the occupancy of the trains and does not drop below this threshold even when the trains are fully loaded or in the event of extreme heat or cold.

For air traffic, the Boeing 737-800 has an air exchange rate for fresh air of “10-15” per hour[31]. Converted to the volume of the passenger compartment of approx. 200 $m^3$, this means an average air exchange in the 737 every 4.8 minutes. Calculated on the higher number of passengers per $m^3$ in air traffic, this means with an average load factor of 96% and with 189 seats (business figures of Ryanair 2019) per passenger between 11 and 17 $m^3$/h fresh air.

The air exchange rate in air and rail traffic is thus comparable and is significantly higher than in buildings (especially malls, restaurants or churches)[12].

In aircraft, usually finer filter systems (HEPA = High Efficiency Particulate Air filter) are additionally available. These are currently only designed for the air circulation and pressure requirements of air traffic and have not been technically applicable to land transport so far, since germ-free outside air can be taken in during flight in the aircraft, which does not represent a burden for fine filters, whereas the filter systems on the ground have to cope with the outside air with pollen and dust. However, in rail traffic, regular stops during a journey, especially at higher load factors, mean that additional fresh air is supplied by the passengers getting on and off the train. This effect has a positive impact, but varies greatly and is therefore not considered further in this study. DB is currently examining the use of extended filter systems for new train generations.

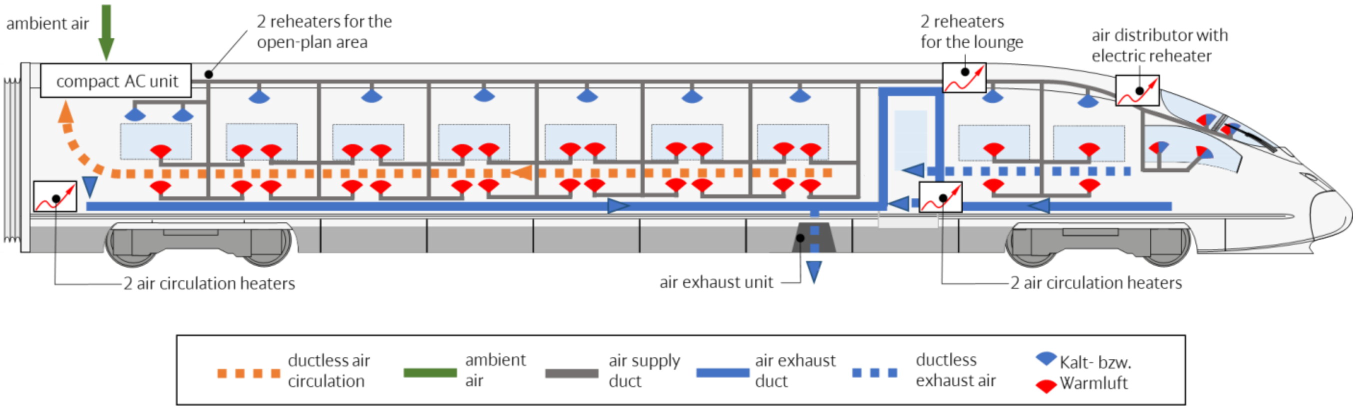


*Figure 1: Schematic diagram of air distribution in the ICE, Source: DB AG*

Overall, based on the theoretical findings from the literature in connection with the actual functioning of air conditioning systems in ICE trains, it cannot be assumed that this will increase the risk of infection. On the contrary, due to good ventilation, a reduction of the risk can be assumed. In connection with the incremental re-opening of our society, the population's need for mobility is also increasing. As the number of vehicles is increasing, we need to answer the question of whether the measures already taken are appropriate, sufficient and whether there is need for additional action.

Therefore, DB has decided to conduct a follow-up project with the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR) in railroad cars by means of simulation calculations and 1:1 tests, in the laboratory and on the original vehicle in which basic knowledge about possible infection paths.

## 5. Empiricism among the employees of Deutsche Bahn

### 5.1 Evaluation of the internal reporting systems

DB has systematically recorded all confirmed COVID-19 cases since the beginning of the pandemic.

| | Number of persons Age 20-66 | CoVID-19 positive cases Age 20-66 | Ratio |
|---|---|---|---|
| DB (only Germany) | 198,000 | 326 | 0,16% |
| DB FV | 17,300 | 30 | 0,17% |
| DB FV Board Service | 8,000 | 17 | 0,21% |
| German Population | 51,800,000 | 134,701 | 0,26% |

*Table 1. Evaluation of reporting system DB AG for confirmed COVID-19 cases, status 02.06.2020. DB FV = DB Fernverkehr*

It can be seen that the number of infected DB employees, in relation to the population of their group within the railways, within long-distance transport and within the train attendant service, is below the age-corrected proportion of COVID 19 cases in Germany. The train attendant service is of particular interest because this group of employees was on the trains during the entire pandemic phase and could therefore have come into contact with infected passengers.

### 5.2 Environment of the infection in sick persons in long-distance transport

As part of the systematic recording of confirmed COVID-19 cases, the environment in which the COVID-19 infection occurred was also recorded for the employees of DB Fernverkehr AG (German for: DB Long-Distance Traffic).

| Infection Environment | No. of cases train attendant service | Ratio | No. of cases DB FV w/o train attendant service | Ratio |
|---|---|---|---|---|
| Unknown | 8 | 47% | 3 | 23% |
| Private Environment | 8 | 47% | 5 | 38% |
| Professional Environment | 1 | 6% | 5 | 38% |
| Sum | 17 | 100% | 13 | 100% |

*Table 2. Evaluation of the infection environment of employees of DB Fernverkehr AG, status 02.06.2020*

The evaluation shows that in the area of train attendant service, the proportion of infections in the professional environment is significantly lower than the proportion of other occupational groups of DB Fernverkehr AG and the proportion of infections in the private environment is higher than the proportion of other occupational groups. However, the proportion of cases in the train attendant service in which the environment of the infection is unknown is higher than in the other occupational groups. Nevertheless, no increased risk of infection for employees on board long-distance trains can be deduced from these figures.

### 5.3 Study on infection risks and immunity of long-distance transport employees

Together with the Charité – Universitätsmedizin Berlin, DB will conduct a study on COVID-19 infection risks in long-distance transport from the end of June 2020 onwards.

In the study, at least 400 train attendants, 150 train drivers and 150 maintenance workers at the locations Berlin, Frankfurt, Hamburg and Munich will be examined for acute SARS-CoV-2 infections and COVID-19 immunity in three runs at four-month intervals. By comparing the infections and immunities in the three occupational groups, findings are to be gained as to whether

a. train crew on long-distance trains is exposed to a higher risk of infection with COVID-19 than other operational occupational groups,
b. there is a significant number of previously undetected COVID-19 infections at work,
c. further measures must be taken to protect company employees.

The selection of the test persons is based on a representative random sample per location and department.

The tests for acute COVID-19 infections are carried out by PCR nasal/venture swab, the tests for COVID-19 immunity by an antibody test by blood collection. Medical-epdimiological risk factors in the test persons are determined by means of a questionnaire. The scientific evaluation of the tests will be carried out in completely anonymous form and in compliance with all data protection requirements.

### 5.4 COVID-19 findings in the ICE plants in Munich and Berlin

Two confirmed cases of SARS-CoV-2 were reported at the Munich ICE plant at the beginning of May 2020. The immediate team colleagues as well as one person from a second team with direct contact to employees who tested positive went into quarantine and had themselves tested. In the course of this, two further SARS-CoV-2 infections were detected and a further 20 people were released from duty for quarantine measures.

In order to prevent the virus from spreading in the Munich plant and at the same time uphold production activity and take account of emerging uncertainties among the workforce, the plant management decided to carry out a large-scale, voluntary test offer for the employees of the ICE plant in Munich. After being contacted by the respective manager, the employees were able to decide for themselves whether or not they wanted to take part in the test, which was organized in cooperation with DB's senior physician and a medical service provider. The persons to be tested were prioritized on the basis of their proximity to or contact with the infected persons and their criticality for the operation of the ICE Munich plant.

The test offer was very well received by the employees and almost everyone addressed took part in the test. As part of the test, a total of 212 out of 812 employees were tested for acute SARS-CoV-2 infection via throat swab (PCR) over a period of two days. All 212 tests were negative. In the following week, due to a similar starting situation (two confirmed infections among employees), 81 employees at the ICE plant in Berlin-Rummelsburg voluntarily underwent a PCR throat swab test; here too, all test results were negative.

The results show the effectiveness of the work organization measures taken to prevent the uncontrolled spread of the virus. Especially in comparison to outbreaks in other industries it is shown that local outbreaks can be contained with appropriate measures. At the same time, an infection at the workplace cannot be completely ruled out. For this reason, the consistent implementation of work organization measures, e.g. compulsory masks for activities with close personal contact and adherence to distance regulations, is essential and mandatory. The procedures in Munich and Berlin have also shown that rapid testing of a large proportion of the workforce is an effective means of controlling a local SARS-CoV-2 outbreak and ensuring that production activities proceed.

## 6. Outlook

The vital question for the handling of COVID-19 over the coming months for DB is to analyze in detail and improve the measures taken. We need an understanding of what is sensible and can be improved and which measures, also in terms of travelers and employees, turn out to be less effective. We will also focus on understanding exactly where there are still gaps in our protection system and how these can be closed if individual cases become known among employees and travelers.

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