EUROPEAN UNION AGENCY FOR RAILWAYS

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Travel safety during COVID-19 for passengers travelling long distance by train and other modes

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Abstract

Available information suggests clearly that European citizens are concerned about travelling by train and other forms of collective transport during the COVID-pandemic. Many people seem to have switched from using trains to travelling by car in 2020. As always in times of uncertainty, mathematical models based on available evidence can help to estimate the actual risks and add to more objectivity.

That is why ERA develops in this study a first mathematical model to estimate the COVID-19 risk when travelling long-distance by train in order to provide the necessary knowledge that can be used by decision makers and the public. The mathematical model reflects the current status of knowledge about the COVID-19 disease and its pandemic effect. As such the primary study question focuses on what the incremental risk of COVID-19 infection during travel for travellers using collective means of transport. The core of the analysis is focused on the case where vaccines are not widely available. However, consideration has also been given to determining the potential influence of vaccines on risks for travelers.

The focus in the study is on the travel itself (involving travelling seated passengers). The time to reach the transport means, boarding and disembarking is excluded. Given the currently available empirical evidence on risk transmission on trains, we only consider the long-distance train travel. The primary personal risk considered is the risk of death from the SARS-CoV-2 virus infection, while the secondary risk considered is hospitalization (ICU and non-ICU) as they imply measurable disability over an extended period. Both require the knowledge of the risk of (virus) infection transmission and the case fatality.

Two travel options are considered: a) all seats fully occupied, but no passengers standing in the aisle; b) 50% loading factor for train and coach / middle seat empty for air. For both options there are no passengers standing in the aisle.

Our findings shows that despite a relative high risk of COVID-19 infection during rail travel, the accident risk for car travel is still higher. Moreover, if rail travel takes place with a 50% loading factor the overall fatality risk for rail is significantly lower than the one for car. In the context with vaccines being rapidly distributed the overall picture is even clearer in terms of the ranking of overall fatality risk between rail and car. This demonstrates the significant (accident) risk that continues to persist for car travel.

The results obtained are valid for the assumptions stated, such as that all passengers wear a face mask that is highly effective in blocking the virus spread. Further validation has been undertaken using sensitivity tests confirming the robustness of the results

CONTENTS

DISCLAIMER

In this study, ERA develops the first mathematical model to estimate the travel safety during COVID-19 for passengers travelling long distance by train and other modes. It aims at providing the necessary scientific tool that can be used by decision-makers and the public at their discretion and risk.

It should be noted that the mathematical model reflects the current status of knowledge about the COVID-19 disease and its pandemic effect. But the available knowledge is evolving thereby emphasising the inherent uncertainty in analyses linked to virus transmission and risk of infection (e.g. linked to new variants). Moreover, the risk of infection in trains will be increasingly reduced by the ongoing vaccination programmes across Europe and the rest of the World.

The Study has been reviewed by experts from the European Commission, the European Union Aviation Safety Agency (EASA), and the European Centre for Disease Prevention and Control (ECDC).

1. Introduction

The COVID-19[1] pandemic has led to questions regarding the potential risk of SARS-CoV-2 exposure, which may lead to virus transmission amongst passengers on board a train, in relation to the safety of travellers. Several outbreak investigation reports have shown that COVID-19 transmission can be particularly high in crowded, confined indoor spaces [1], whereas poor ventilation in these environments is associated with increased transmission of respiratory infections and COVID-19 specifically [2]. At the same time, documented cases of COVID-19 transmission in collective means of transport are so far rare (although it is possible that there could have been undocumented cases). In Germany, they represent a mere 1.5 per thousand of all documented cases, and 2.5 per thousand of documented outbreaks, as per data published by Robert Koch Institute [3]. This finding is also mentioned in a recent review study undertaken by UIC [20].

There are three main modes of virus transmission on board of a train:

i) ***Contact and droplet transmission*** *– through infected secretions such as saliva and respiratory secretions or their respiratory droplets (droplets >5-10 µm in diameter), which are expelled when an infected person coughs, sneezes, talks or sings [2-10].*

ii) ***Short-range airborne transmission*** *- spread of an infectious agent caused by the dissemination of droplet nuclei (aerosols) (droplets <5µm in diameter) that remain infectious when suspended in air over long distances and time. They are spread through aerosols in indoor settings with poor ventilation.*

iii) ***Fomite transmission*** *– through surfaces contaminated by respiratory secretions or droplets expelled by infected individuals [4].*

It is currently impossible to quantitatively compare and conclude which transmission route is the most significant in a given situation. Infection may occur via all routes to different degrees depending on the specific exposure circumstances.

Currently available evidence suggests that SARS-CoV-2 is primarily transmitted between people via respiratory droplets and contact routes and that transmission of COVID-19 is occurring from people who are pre-symptomatic or symptomatic to others in close contact (direct physical or face-to-face contact with a probable or confirmed case especially with a distance less than one meter and for prolonged periods of time), when not wearing appropriate personal protective equipment.

The distance between the infected and “to be infected” healthy passengers is one of the key risk factors in virus transmission. The meta-analysis of Chu (172 observational studies across 16 countries and six continents) in The Lancet [5] yields the approximation that infection risk is about 13% given physical contact with a contagious person, and that it falls by essentially a factor of two as the distance from that person increases by one meter.

As with other risk factors, the risk of virus transmission depends on time (exposure duration), yet how exactly remains still to be determined. Notably, the meta-analysis of Chu found that the time risk factor varied considerably across studies, from any duration to a minimum of 1 hour. The US Center for Disease Control and Prevention (CDC) insists that the data are insufficient to precisely define the duration of time that constitutes a prolonged exposure and uses the 15 minutes of close exposure as an operational definition. This also corresponds to the empirical experience from other infectious diseases.

In this study, an assumption is made on the role of time in virus transmission. This assumption has been operationalised in the modelling and is detailed out later in the paper. This element may need to be updated when new scientific evidence becomes available.

[1] COVID-19 = Corona Virus Disease; SARS-CoV-2 = Severe Acute Respiratory Syndrome Coronavirus 2

It should be noted that as a general observation that the available knowledge concerning COVID-19 is still evolving thereby emphasising the inherent uncertainty in analyses linked to virus transmission and risk of infection (e.g. linked to new variants). Moreover, the risk of infection will increasingly also be influenced by the ongoing vaccination programmes across Europe and the rest of the World.

2. Study questions

This study has one general primary question:

- ***What is the incremental risk[2] of COVID-19 infection (during travel) for travelers using collective means of transport?***

Ultimately, secondary questions of interest are also:

- ***What is the risk of death or hospitalization of an uninfected passenger when travelling in the same means of transport with a passenger infected with COVID-19? and***
- ***What is the COVID-included fatality risk for a passenger on board of aircraft/train/coach/car?***

The core of the analysis is focused on the case where vaccines are not widely available. However, Section 13 examines the potential influence of vaccines on risks for travelers.

3. Scope

In this study we focus on the travel itself (involving travelling seated passengers). The time to reach the transport means, boarding and disembarking is excluded (see Figure 1 in Appendix 1). Given the currently available empirical evidence on risk transmission on trains, we only consider the long-distance train travel.

The primary personal risk considered is the risk of death from the SARS-CoV-2 virus infection, while the secondary risk considered is hospitalization (ICU and non-ICU) as they imply measurable disability over an extended period. Both require the knowledge of the risk of (virus) infection transmission and the case fatality.

Both incremental fatality risk from COVID infection and the overall fatality risk on board have to be estimated in order to deliver the answers to the study questions.

Two travel options are considered: a) all seats fully occupied, but no passengers standing in the aisle; b) 50% loading factor for train and coach / middle seat empty for air. For both options there are no passengers standing in the aisle.

4. Method[3]

To estimate the risk of being infected for an uninfected passenger by a passenger carrying COVID-19, it is necessary to consider three main questions and several sub-questions:

What is the probability that a given passenger on board is contagious with COVID-19?

- *What is the general population prevalence?*
- *What is the probability of an infected person to be on board?*

[2] The incremental risk would in the context of this study refer to the increase in (fatality) risk for travellers due to COVID-19 over and above other existing risks, notably transport accidents.

[3] The analysis in the following sections 4-12 focus on the context where vaccines are not widely available. In Section 13 the potential influence of vaccines on travel risks are considered.

What is the probability of a spread of the virus from an infected person to an average healthy person (a so-called attack rate measure[4])?

- *How does the risk of infection depend on the locations on board of both the contagious and uninfected passenger?*
- *How does the risk of infection depend on the exposure duration (here duration of travel)?*
- *What is the probability that universal face masking, physical distancing and other measures can prevent a contagious passenger from spreading the disease?*

What is the COVID-19 case fatality among infected persons?

What is the observed case-fatality ratio; eventually, what is the case-hospitalization ratio [22]?

The general formula to estimate the incremental personal risk is:

$$P = Q_c * Q_s * Q_i$$

where P is the probability that a particular uninfected passenger contracts COVID-19 during the journey and subsequently dies (or becomes seriously ill) from the infection

Q_c is the probability that a given passenger on board is contagious with COVID-19

Q_s is the probability of the spread of infection from an infected person to a healthy person

Q_i is the probability of dying (or hospitalisation) from the disease

whereas:

$$Q_c = U * q_t$$

U is the infection prevalence among the general population

q_t is the conditional probability that a person travels on board given that the person is contagious

and:

$$Q_s = (Q_{m1} * Q_l + Q_{m2} * Q_a + Q_p) * e_t$$

Q_{m1} is the probability that universal mask-wearing on board fails to prevent contact/droplet transmission of COVID-19

Q_{m2} is the probability that universal mask-wearing on board fails to prevent short-range airborne transmission of COVID-19

Q_l is the conditional probability that a contagious passenger transmits COVID-19 to the uninfected one if the mask fails

Q_a is the conditional probability of a short-range airborne transmission if the mask fails

Q_p is the probability of an indirect virus transmission via surfaces on board

e_t is the exposure duration correction coefficient for given co-travel time

[4] The attack rate is globally defined as the risk of getting the disease during a specified period. Several attack rates can be calculated though the focus in this study concerns the probability of infection during travel. Further information available from this link:
https://www.cdc.gov/csels/dsepd/ss1978/lesson3/section2.html

and:

$Q_i = D * c_d * c_m$

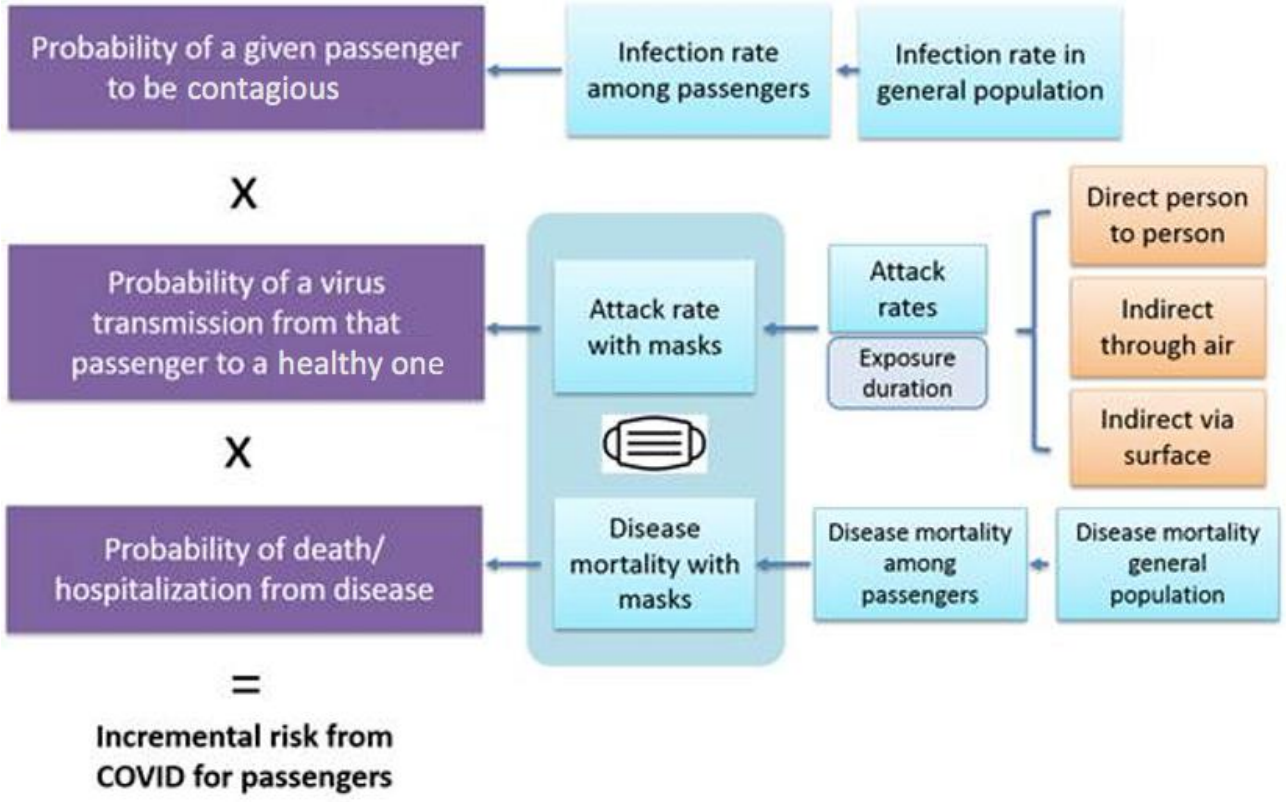
D is the disease mortality rate

c_d is the assumed adjustment coefficient for the higher survivability of passengers compared to general population

c_m is the correction coefficient for the ability of masks to reduce disease mortality (or hospitalization)

This model can be visualised as follows, see Chart 1 (further details of the model are given below and in Appendix 2):

Chart 1. Modelling the incremental risk from COVID for passengers



5. Main assumptions

a. The number of actual cases of COVID-19 in the EU is a large multiple of the number of confirmed (positively tested) cases. However, asymptomatic carriers of the disease are considerably less contagious than pre-symptomatic and symptomatic ones, and travellers are possibly less likely to be contagious than the citizenry as a whole (e.g. due to adherence to COVID-19 restrictions in place in different EU countries). It is also implicitly assumed that all infected persons transmit the disease with the same probability.
b. All passengers are wearing masks during the journey, and masks are highly effective at preventing transmission of COVID-19. This assumption should be qualified as there could be periods where passengers wearing masks are in fact not doing so (e.g. during meals). This specific element has not been modelled in the study.
c. An uninfected passenger is directly threatened with COVID-19 by a contagious passenger sitting in the same row, the row ahead, or the row behind. The risks posed by other passengers are of secondary importance (assumed zero in this study).
d. The prolonged exposure is considered to be equal to at least 15 minutes of co-travel time, whereas the proportion of passengers travelling unseated (standing) for this type of journey is considered nil. We further assume that there is a rather limited risk of infection from a contagious passenger not seated nearby (e.g. a passenger passing one's row en-route to the lavatory or to the bar coach). Limits on this kind of movement may also be encouraged by the railway undertakings.
e. An indirect transmission (airborne, fomite) is limited by air filters in air ventilation systems and regular surface disinfection respectively. (Air filters are known to reduce the airborne presence of viral particles. The reduction of airborne particles by collection in the air filters should also reduce the deposition of viral particles on surfaces that are necessarily or inadvertently touched.)

   Note that at present there is insufficient evidence for the efficacy of forced ventilation or circulation as a mitigation measure against COVID-19 virus spread. Therefore, this has not been incorporated into the calculations. However, the impact of HVAC systems is being investigated and could be incorporated into the model when sufficient quantitative evidence becomes available.

f. Passengers on-board are assumed on average to be healthier than the general population and thus having higher survivability in case of infection considering higher mobility levels being potentially associated with higher improved overall health. This assumption is only made for air and long-distance rail passengers.

It should be remarked that the resulting risk estimates are influenced by the above assumptions. These assumptions are underpinned by relevant available empirical studies. Careful validation has been undertaken as part of the study and key uncertainties / study limitations are considered in the concluding section of the paper. Moreover, the robustness of the results have been assessed through sensitivity testing of key assumptions. The findings from the sensitivity testing are reported later in the paper. As a general remark it is noted that given the evolving knowledge re. COVID-19 the modelling assumptions may require to be adjusted even in the short term in order to remain of validity. Therefore, the resulting risk estimates should be carefully interpreted.

6. Estimation of the probability that a passenger on board is contagious (Qc)

For a given passenger, the risk of contagiousness is estimated in several steps:

a. First, one estimates the rate of confirmed new COVID-19 infections in the given jurisdiction over the last seven days. The ECDC publishes the 14-day case notification rate per 100,000 population [6], so this number is divided by two. Seven days is chosen because that is the approximate length of the contagiousness period for someone experiencing COVID-19, although the length of this period may be longer according to the available evidence. (The average of such period is a bit below seven days in asymptomatic cases and higher than seven in symptomatic ones) [7, 8].
b. In accordance with recent empirically established estimates, one multiplies the 7-day notification rate (above) by the infection prevalence ratio to approximate the actual number of new infections in the country over the previous week. Based on the empirical evidence [9], the following empirically estimated function is applied:

$$i = 16 \times \sqrt{p} + 2.5 \quad \textbf{(I)}$$

Where:

i is the infection prevalence ratio

p is the positivity rate

In the absence of an EU wide positivity rate, an infection prevalence ratio of 10 corresponding to 22% positivity rate and reported by several national media is used. This means that the prevalence is assumed to be 10X more than the reported incidence.

One recognizes that persons with COVID-19 who get on board are presumably either asymptomatic, pre-symptomatic, or mildly symptomatic. (Those with severe symptoms are unlikely to be travelling). Because of evidence that asymptomatic COVID-19 carriers constitute about 40% of all carriers and are only about 40% as contagious as the others [10], one multiplies the prior product by a factor of 0.76. (This factor of 0.76 arises because the number of contagious passengers with COVID-19 is approximately 0.4*0.4 + 0.6*1 = 0.76 of the number of passengers with the disease.)

7. Estimation of the probability of person to person transmission (Qs)

We first estimate the probability that universal mask-wearing on board **fails** to prevent the transmission of the virus, in the situation where all passengers are wearing masks. The meta-analysis in The Lancet by Chu et al [4] estimated that mask wearing cuts transmission risk given contagiousness from 17.4% to 3.1%, a reduction of 82%. Ignoring the possibility that the masks under study were more effective than those worn by passengers, we estimate Q_m as (1 - 0.82) = 0.18.

Second, we estimate the **infection transmission risk** between an infected person and a healthy person on board. A given passenger can get infected by droplets from a contagious passenger seating nearby, whereas the risk depends on the distance between the two passengers. The meta-analysis by Chu et al [4] yields the approximation that infection risk is about 13% given physical contact with the contagious person, and that it falls by essentially a factor of two as the distance from that person increases by one meter.

The equation reflecting this pattern of exponential decay is:

$$R_t \approx 0.13 * e^{-0.69d} \quad \textbf{(II)}$$

where d = distance in meters between contagious and uninfected person.

Finally, we incorporate the **effect of travel duration** on the risk transmission likelihood. The study by Hertzberg et al. [11] and Brundage [12] suggested that infection risk depends on the duration of exposure to a contagious person in an open environment. The impact of exposure duration is believed to be even more

important in confined places, such as train coaches, coaches and planes. The available evidence on the relation between exposure duration and risk of transmission of the COVID-19 virus on board of trains is limited. To our knowledge, only Hu et al. (2020) modelled the risk of virus transmission on trains [13].

For high speed trains in China, for all seats, the correlation between COVID-19 attack rate and the duration of co-traveling with an index patient followed a quadratic, but close to linear, relationship, whereas the average attack rate increased by 0.15% (*P* = .005) per hour of co-travel for an average attack rate of 1.5% for the passenger on the same row. This would roughly correspond to a 10% increase in infection risk per each additional hour of travel.

This finding could be integrated into our model as follows:

$e_t = 1 + 0.1 * T$ **(III)**

where T is the length of co-travel in hours

For train coaches:

The seats layout on train coaches is not standardized in the EU and many variants exist. However, the typical arrangement is 2+2 seats per row and 2+1 seat per row. Similarly, the size of seats and their average distance differ and is difficult to estimate precisely. At the same time, the TSIs[5] contain minimum distances between seats, providing a first guidance. In our study, we take two TSI compliant coaches used for running passenger services across the EU, notably Thalys R8 type and Bombardier AEB-13, which to us appears sufficiently representative for their class.

Hereby we consider two basic layouts:

A) 2+2 seats per row with all seats are oriented the same way (e.g. inter-regional standard class)
*B) 2*2 grouped seats facing each other (e.g. intercity standard class)*

For simplicity reasons, neither first class layout (e.g. 2+1 seats), nor commuter train coaches are considered. They would both likely have relatively lower / higher infection transmission probability than the average of the two variants considered. Given the fact above and their relatively low relative share, we would consider them to cancel out their effects at this stage. Further studies could examine the risk associated with commuter train travel as well as travel with other coaches.

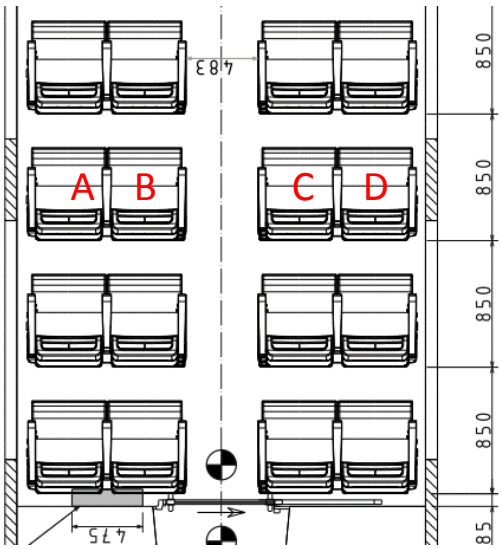
Under the "fill all seats" policy on a full train, all four of the ABC/D seats will be occupied. Assuming that **(II)** refers to passengers without masks, one can use it to estimate the transmission risk posed by others in the same row to an A-seat passenger, given that the contagious passenger's mask fails (as happens with probability Q_M):

The infection transmission probability Q_i is then established per row as an average of single seats transmission probability values.

For the A variant:
$Q_i = AVG [(R_T(A,B)+R_T(A,C)+R_T(A,D)) ; (R_T(B,A)+R_T(B,C)+R_T(B,D))]$

Note that it is sufficient to establish the probability for seats A,B since the seats C,D are mirroring the A,B.

[5] TSI stands for Technical Specifications for Interoperability; further information available from: https://www.era.europa.eu/activities/technical-specifications-interoperability_en



Using the distances from the drawing above and applying equation **(II)**, the probability across all the passengers in a given row is estimated:

VAR A: Long distance high speed

	A-B	A-C	A-D	SUM
d (m)	0.475	1.433	1.908	
R	0.0937	0.0484	0.0348	**0.1769**
	B-A	B-C	B-D	
d (m)	0.475	0.958	1.433	
R	0.0937	0.0671	0.0484	**0.2092**
		AVG		**0.1930**
		1.5*AVG		**0.2895**

Q_i= AVG [0.177 + 0.209] = 0.193

Hertzberg et al [8] concluded from their computer simulations that, for droplet mediated respiratory diseases, contagious passengers pose appreciable transmission risk to uninfected travellers within one meter. Therefore, they concluded that, beyond the same row, transmissions can occur from passengers in the row ahead of an uninfected passenger and in the row behind. This observation was also confirmed by Hu et al (2020), who identified infection transmission over 3 rows. Here we concur that passengers in the two neighbouring rows pose first-order transmission risk. Hertzberg et al. further advanced that all contagious passengers within one meter pose equal levels of transmission risk, regardless of whether they are in the same row as the uninfected passenger. However, the authors noted that they did not consider the possibility that seatbacks would impede transmissions between rows. Here we do not ignore that possibility. While seatbacks may block droplets from a contagious passenger, they are presumably less effective than plexiglass, which all but eliminates transmission. Lacking available studies about the benefit conferred by seatbacks, in combination of unidirectional orientation of seated passengers, we make the assumption that they are about 3/4 as effective as plexiglass. More specifically, we assume that: When the service is full, the four passengers one row ahead of the uninfected passenger collectively pose 1/4 the transmission risk of the three passengers in the same row. If this factor-of-four reduction overstates the effectiveness of the seatbacks against contagion, then our risk estimates tied to neighbouring rows could well be too low.

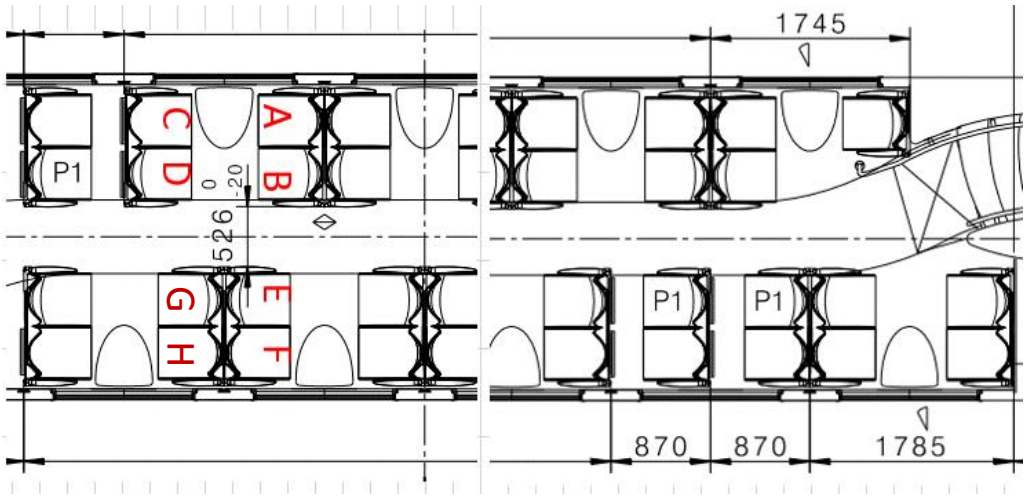
Under these approximations:

Q_I (full service) = 1.5 x Q_I (full service, same row) = 0.29

For the B variant:
The probability of infection transmission (without face masks) for the B variant is estimated in a similar way. Although the rows are now shifted, the passengers are seated almost in a line due to the bilateral seats orientation.

The general formula applicable in this case is:

$$Q_i = AVG\ [(R_T(A,B)+R_T(A,C)+R_T(A,D)+R_T(A,E)+R_T(A,F))+R_T(A,G)+R_T(A,H)) ;$$
$$(R_T(B,A)+R_T(B,C)+R_T(B,D))+R_T(B,E)+R_T(B,F)) +R_T(B,G)+R_T(B,H)) ;$$
$$(R_T(E,A)+R_T(E,B)+R_T(E,C))+R_T(E,D)+R_T(E,F)) +R_T(E,G)+R_T(E,H)) ;$$
$$(R_T(F,A)+R_T(F,B)+R_T(F,C))+R_T(F,D)+R_T(F,E)) +R_T(F,G)+R_T(F,H))\ ]$$



In the case of Variant B, the seatbacks between seats are assumed to reduce the risk of virus transmission by 75%, also owning to the orientation of the seats (back to back). Thus the R is adjusted by factors 0.75 and 1.25 respectively for all back-to-back seats.

VAR B: Intercity regional train

	A-B	A-C	A-D	A-E	A-F	A-G	A-H	SUM
d (m)	0.455	1.44	1.98	1.7	2.05	1.9	2.2	
R	0.095	0.048	0.033	0.040	0.032	0.035	0.028	
R*	0.119	0.060	0.033	0.040	0.032	0.009	0.007	**0.300**
	B-A	B-C	B-D	B-E	B-F	B-G	B-H	
d (m)	0.455	0.99	1.44	1.25	1.7	1.35	1.72	
R	0.095	0.066	0.048	0.055	0.040	0.051	0.040	
R*	0.119	0.082	0.048	0.055	0.040	0.013	0.010	**0.367**
	E-A	E-B	E-C	E-D	E-F	E-G	E-H	
d (m)	1.7	1.25	1.85	1.4	0.48	0.25	0.6	
R	0.040	0.055	0.036	0.049	0.093	0.109	0.086	
R*	0.040	0.055	0.036	0.049	0.093	0.027	0.021	**0.323**
	F-A	F-B	F-C	F-D	F-E	F-G	F-H	
d (m)	2.05	1.7	2.2	1.75	0.5	0.6	0.25	
R	0.032	0.040	0.028	0.039	0.092	0.086	0.109	
R*	0.032	0.040	0.028	0.039	0.092	0.021	0.027	**0.280**
							AVG	**0.317**

For the B variant, the probability across all the passengers in a standard set of seats is estimated as 0.317, slightly higher value compared to Variant A. This is not surprising given relatively lower distances between seated passengers.

Seeking to obtain an average for representative seats arrangements across Europe, we assume 1/2 of passenger coaches to have the A layout and 1/2 having the B layout. This leads to Q_L =0.304. This means that

the conditional probability that a contagious passenger transmits COVID-19 to the uninfected one if the mask fails, in train coaches as described above is 0.304.

(In addition, one could assume a 50% occupancy rate in trains (corresponding well to the currently observed rates for EU rail travel)[6], in which case the Q_L would decrease substantially, by a factor of 2.5 approximately, in case of passengers well distributed across the coach). It should be noted that this context has also been modelled in this study (see below).

For commercial aircraft:

In the case of aircraft, we replicate the scenarios and calculations by Barnett [15], who considered two internationally prevalent commercial aircraft and two occupancy rate scenarios (full flight and middle seat empty policy on board). In each coach row in a Boeing 737 or an Airbus 320, the individual seats are approximately 18 inches wide, while the aisle width is about 30 inches. Under the "fill all seats" policy on a full flight, all six of the ABCDEF seats would be occupied. Under "no middle seats", A/C and D/F will be occupied on a full flight but not B/E. Assuming that (II) refers to passengers without masks, one can use it to estimate the transmission risk posed by others in the same row to an A-seat passenger, given that the contagious passenger's mask fails (as happens with probability Q_M):

$$Q_L(A \text{ same row}) \approx \begin{cases} R_T(A,C) + R_T(A,D) + R_T(A,F) \text{ under middle seat open} \\ R_T(A,B) + R_T(A,C) + R_T(A,D) + R_T(A,E) + R_T(A,F) \text{ under "fill all seats"} \end{cases}$$

where R_t(A,X) = transmission probability absent masks given a contagious passenger in seat X of a given row and an uninfected passenger in seat A of that row Equation (III) taken literally treats infections caused by passengers in different seats as mutually exclusive events. But they are not mutually exclusive: it is possible that contagious persons are seated in both seats 16C and 16F. The actual assumption, consistent with data, is that Q is small enough that having several contagious people close to one another is a second-order effect, with probabilities involving Q2 or higher powers of Q. In practical terms, therefore, the events of interest are mutually exclusive.

We therefore make the approximation that: $R_t(A,X) \approx 0.13 * e^{-0.69d(A,X)}$

where d(A,X) = distance from a person's head in the middle of seat A to another person's head in the middle of seat X. For the jets under consideration, the quantity d(A, B) is about 18 inches, while d(A,C) is 18+18= 36 inches, d(A, D) =36 + 9 + 30 + 9 = 84 inches, d(A, E) =84+18= 102 inches, and d(A,F) = 102 + 18= 120 inches. Because a meter is equal to 39.37 inches, d(A,B) in meters is 18/39.37 = .457 , etc. Analogous expressions arise when the uninfected passenger is in the B, C, F seat. One can then use (II) to obtain:

[6] See e.g: https://amadeus.com/en/insights/blog/trains-get-back-on-track-as-covid-19-restrictions-lift.

$$Q_L(A\ same\ row) \approx \begin{cases} 0.115 & \text{under middle seat empty} \\ 0.232 & \text{under "fill all seats"} \end{cases}$$

Using similar reasoning, one can likewise determine that:

$$Q_L(B\ same\ row) \approx .282 \text{ under "fill all seats"}$$

$$Q_L(C\ same\ row) \approx \begin{cases} 0.155 & \text{under middle seat empty} \\ 0.291 & \text{under "fill all seats"} \end{cases}$$

$$Q_L(D\ same\ row) = Q_L(C\ same\ row);$$
$$Q_L(E\ same\ row) = Q_L(B\ same\ row);$$
$$Q_L(F same\ row) = Q_L(A\ same\ row);$$

Averaging across all the passengers in a given row yields:

$$Q_L(same\ row) = \begin{cases} .268\ under \text{ "fill all seats"} \\ .135\ under\ middle\ seat\ empty \end{cases}$$

As before, we consider that seatbacks can somewhat block droplets from a contagious passenger, they are presumably less effective than plexiglass, which all but eliminates transmission. Lacking available studies about the benefit conferred by seatbacks, we make the assumption that they are about 3/4 as effective as plexiglass. More specifically, we assume that:

- When the flight is full, the six passengers one row ahead of the uninfected passenger collectively pose 1/4 the transmission risk of the five passengers in the same row.

- When the flight follows “middle seats empty” but is otherwise full, the four passengers one row ahead of the uninfected passenger collectively pose 2/3 the transmission risk of the six passengers in that row had the flight been full.

Again, if this factor-of-four reduction overstates the effectiveness of the seatbacks against contagion, then our risk estimates tied to neighbouring rows could well be too low.

Under these approximations:

Q_I (full flight) = 1.5 x Q_I (full flight, same row)

Q_I (middle seat empty) = Q_I (middle seat empty, same row) + 2/3 x 1/2 x Q_I (full flight same row)

Thus

$Q_{L,A}$ = 0.268 x 1.5 = 0.402 (full flight)

$Q_{L,B}$ = 0.224 x 2/3 x 1.5 = 0.224 (middle seat empty)

The above summarizes the experiences reported in disparate studies, probably not fully reflecting the exact conditions in a EU jet flight two hours long (assumed average internal EU flight duration). Notably, in these studies, some passengers actually wore masks, so the equation proposed may not fully reflect the reality. This means that the conditional probability that a contagious passenger transmits COVID-19 to the uninfected one if the mask fails, in a full airplane is 0,402, with middle seat empty is 0,224.

For road coaches:

A basic model seat layout is considered 2x2 seats on each side of an aisle. In each coach row, the individual seats are approximately 18 inches wide, while the aisle width is about 30 inches (at this stage taken from the aircraft cabin arrangements described earlier).

Under the "fill all seats" policy on a fully occupied coach, all four of the AB/CD seats will be occupied. Assuming that (II) refers to passengers without masks, one can use it to estimate the transmission risk posed by others in the same row to an A-seat passenger, given that the contagious passenger's mask fails (as happens with probability Q_M):

$Q_{L,A}$ (A same row) ≈ $R_T(A,B)+R_T(A,C)+R_T(A,D)$ (A variant and all seats occupied)
$Q_{L,B}$ (A same row) ≈ $R_T(A,B)+R_T(A,D)$ (B variant and all seats occupied)

Applying the same distances between seats as assumed earlier for the train A-layout:
$Q_{L,A}$= 0.193 x 1.5 = 0.29
This means that the conditional probability that a contagious passenger transmits COVID-19 to the uninfected one if the mask fails, in a full road coach is 0,290.

8. The estimation of probability of short-range airborne transmission (Qa)

Although there continues to be a vivid scientific discussion about the role of short-range airborne transmission, first specific studies in transport field indicate a close to zero probability of short-range airborne transmission through ventilation systems in case of aircraft, due to the efficiency of the air ventilation system, notably the presence of efficient HEPA filters and regular disinfection [14].

HEPA filter functionality and prior guidance from the Centre for Disease Control and Prevention for SARS-CoV-1 suggest theoretical efficacy for HEPA filters to decontaminate airborne SARS-CoV-2, although direct studies for SARS-CoV-2 have not been performed [17].

Unlike in commercial aircrafts, transmission through the air is more likely in coaches (both train and road), and, given the presence of draught (due to possibly open windows and doors connecting adjacent coaches (in case of trains). Furthermore, the air ventilation system might be less efficient and equipped with less sophisticated industrial filters. Last, but not least, the season would play a role regarding natural and forced air ventilation on board.

However, we were not able to identify any specific studies or empirical evidence, which would allow us to integrate the short-range airborne transmission into our model at this moment. Therefore, we are currently constrained to assume zero transmission probability, which results in an underestimation of the total risk. This transmission route has though been considered as part of sensitivity testing where the probability of short-range airborne transmission was set at a level above zero (set at 5% and 25% of the person-to-person transmission respectively). In the light of ongoing research into the importance of short-range airborne transmission future updates of this study could be considered relevant.

While evidence for short-range airborne transmission of COVID-19 is currently incomplete, several hospital-based studies have performed air-sampling for SARS-COV-2, including one published paper (Ong et al. 2020), one early-release paper (Guo et al., 2020) and 5 papers still in pre-print at the time of writing (Chia et al., 2020, Ding et al., 2020, Jiang et al., 2019, Liu et al., 2020, Santarpia et al., 2020). Four of these studies found several positive samples for SARS-CoV-2 genome (RNA) in air using polymerase chain reaction (PCR) testing (Chia et al., 2020, Jiang et al., 2019, Liu et al., 2020, Santarpia et al., 2020), two found very small numbers of positive samples (Ding et al., 2020), and only one (Ong et al., 2020) found no positive air samples. Further new evidence of short-range airborne transmission is highlighted in a recent paper (Kriegel & Hartman, 2021) showing the variation in this transmission risk in different contexts, incl. public transport. This evidence at least demonstrates a potential risk for short-range airborne transmission of SARS-CoV-2.

9. The estimation of the probability of fomite transmission (Qs)

Available research indicates that virus transmission is possible via common surfaces [4]. Disinfection of those significantly reduces this probability. Although the disinfection is likely less frequent in coaches than in an aircraft cabin, partly due to the size of the equipment and the disinfection costs, it is probably still more frequent compared to other closed places, where such spread was studied so far. Considering that all passengers are required to wear a face mask implies a significant reduction of the transmission probability, since the mask represents a barrier to virus entry into respiratory ways.

We are therefore constrained to assume zero fomite transmission probability at this stage.

10. Estimation of the disease mortality/hospitalization (Qd)

The mortality (and hospitalization) from the disease is estimated by following the WHO methodological recommendations [16].

Mortality from disease as well as hospitalization for notified infected persons is available from the ECDC. Besides considering the ICU (intensive care unit) hospitalization, the general hospitalization rate is considered.

The rates are first adjusted for un-notified cases since the risk is estimated for the general population.

Finally, a correction is made for specific population on-board, which is believed to have a slightly lower mortality than the general population, as more-at risk persons may travel less. Note that this is likely partly compensated by the reduction in travel of healthy persons in productive age. Lacking any empirically estimates, we use a conservative correction coefficient of 0.8. Furthermore, it is noted that the probability would also be influenced by the reduction in travel of healthy persons in productive age (e.g. use of remote working).

To obtain the overall incremental mortality (hospitalization) rates, the rates are then multiplied by Q_c (probability of infected passenger on board) and Q_s (probability of infection transmission).

Two cases are considered for the disease mortality / hospitalisation: a) case where vaccines are not widely available for the adult population in the EU / EEA countries (see Section 11); b) case where vaccines are widely available for the adult population in the EU / EEA countries (see Section 13). The main modelling for this paper was undertaken where vaccines were not widely available. Additional analysis has been included in order to provide information about the second case where vaccines are widely available. For this second case the following assumptions have been used: 1) the efficacy of COVID-19 vaccines against serious illness is 95% [24]; 2) the overall proportion of the adult population vaccinated against COVID-19 is in the short-term (end of Q3 2021) reaching 75%.

11. Assessment of the overall travel risk without vaccination

The overall passenger fatality risk is estimated as the sum of safety risk and COVID-19 risk and compared for different modes of transport. Here we focus on the fatality risk for which data are available [18]. The (safety) fatality risks estimated for the 2014-18 period, as published in the Agency's report on progress with safety and interoperability are considered.

The incremental COVID-19 fatality risk is a significant proportion of the accident fatality risk, however in the case of rail, the overall fatality risk for a passenger on board is less than the fatality risk of a car occupant

traveller[7]. It can be observed that the total fatality rate per distance travelled for train is now relative close to the one for car albeit lower. However, this fatality rate is estimated using an assumption of full occupancy for trains (which is unlikely to be the case currently during the pandemic).

Fatality rate per distance travelled	Aircraft	Train	Coach	Car
Safety fatality rate (per billion km)	0.0316	0.0513	0.2217	1.9125
COVID on board fatality rate (per billion km)	0.1834	2.025	2.064	0
Total fatality rate (per billion km)	0.215	2.0763	2.286	1.9125

Those results can also be used for a model trip of two hours, whereas the average distance covered in two hours is assumed to be 120 km for train, 140 km for coach, 160 km for passenger car and 1,750 km for a commercial aircraft. This allows estimating the total fatality rate for a journey.

Per 2hrs trip $*10^{-9}$	Accident fatality risk	Incremental COVID fatality risk	Total fatality risk	Proportion of car fatality risk
Aircraft passenger	55	321*	376	1.23
Train passenger	6	243*	249	0.81
Coach passenger	31	289*	320	1.05
Car occupant	306	0	306	-

*) All seats filled

As the typical loading factors for rail and other public transport are below 100% (especially during and in the post-pandemic phase) the risks have been recalibrated with lower factors, notably: a) middle seat empty for air; b) 50% loading factor for rail and coach. The results from this recalibration are shown below.

Per 2hrs trip $*10^{-9}$	Accident fatality risk	Incremental COVID fatality risk	Total fatality risk	Proportion of car fatality risk
Aircraft passenger	55	179*	234	0.77
Train passenger	6	97**	103	0.34
Coach passenger	31	116**	147	0.48
Car occupant	306	0	306	-

*) Middle seat empty; **) 50% loading factor

In this scenario, the relative total fatality risk for rail travel is now significantly below the corresponding one for car travel.

Although the main focus in the study has been on long-distance travel preliminary results for the travel risk for rail compared to car over shorter distance (1hr), in the context with 50% occupancy, seems to confirm the above risk ranking. Further studies would need to examine this aspect further.

12. Sensitivity analysis

Given the structure of the model, the three main probabilities have the same impact on the overall COVID-19 risk. Below, the key switching values are estimated for a scenario under which the overall fatality risk (per km) is equal for train and car. The analysis is undertaken using the risk estimates with a 50% loading factor for rail as the baseline.

Infection (incidence) rate general population	0.0065 > 0.0108	+66 %
Probability of mask failure	0.18 > 0.30	+66 %
Death rate - 14-days - per 100,000	1.05 > 1.74	+66 %

[7] The safety fatality risk for car occupants used here is limited to long-distance journeys (longer than 80 kms).

Additional sensitivity testing has been undertaken in order to provide considerations to three core elements (considering the extent these would influence the overall risks for train compared to car travel). Again, the additional sensitivity testing is undertaken using the risk estimates with a 50% loading factor for rail as the baseline:

- *Lower infection prevalence ratio (a ratio of 5 has been tested instead of the one used in the modelling of 10)*
- *Possibility for non-zero probability for short-range airborne transmission based on available evidence (e.g. [22} and [23]). In the sensitivity testing this probability is set at 5% and 25% of the person-to-person transmission*
- *Potential for higher probability of person to person transmission_associated with new COVID-19 variants (an increase of 50% in this probability is used in the sensitivity testing)*

This sensitivity testing involves two approaches: 1) individual analysis per element; 2) additional the above elements are considered jointly. On the basis of the analyses it is likely that:

- *Lower infection prevalence would reduce the overall fatality risk for rail travel (compared to the main modelling results)*
- *A non-zero probability for short-range airborne would not affect the order of fatality risks for rail compared to car*
- *A higher probability of person to person transmission would not be sufficient to affect the order of fatality risks between rail and car*
- *In case all three elements are considered together the resulting train travel risk would be significantly lower than the fatality risk for car travel*

Detailed results of the sensitivity testing are provided in Appendix 3.

13. Assessment of the overall travel risk with vaccination

The assessment of the overall travel risk is undertaken for rail and compared to the car based travel risk. In particular, the risk estimates are shown for the 2 hr model journey used above. Two estimates for rail have been calculated: a) with full loading factor; b) with a loading factor of 50%.

In both cases, the results demonstrate the influence that widespread vaccination has on the relative total fatality risk for rail compared to car travel. The risk associated with rail travel is now less than 30% of the risk associated with car travel and in particular with a 50% loading factor on rail the risk is less than 15% of the car travel risk.

Per 2hrs trip $*10^{-9}$	Accident fatality risk	Incremental COVID fatality risk	Total fatality risk	Proportion of car fatality risk
Train passenger	6	70*	76	0.25
Car occupant	306	0	306	-

*) All seats filled

Per 2hrs trip $*10^{-9}$	Accident fatality risk	Incremental COVID fatality risk	Total fatality risk	Proportion of car fatality risk
Train passenger	6	28*	34	0.11
Car occupant	306	0	306	-

*) 50% loading factor

14. Conclusions

Travelling on board of shared means of transportation at times of high COVID-19 infection prevalence among the general population implies a new specific mortality risk to passengers. This risk is a few-fold higher than the basic safety risk (fatality risk from an accident). The overall fatality risk for passengers on board is then expressed as a proportion of the car fatality risk. However, in all scenarios modelled for rail and at the current infection prevalence in population, it remains somewhat lower compared to the overall travel risk for individual travellers, here notably those travelling in a passenger car. This finding is obtained in the case of full occupancy for trains. Our analysis also extended to a 50% occupancy rate for rail where it is demonstrated that the risk would be significantly lower compared to car travel.

The results obtained are valid for the assumptions stated, such as that all passengers wear a face mask that is highly effective in blocking the virus spread. At the same time, the COVID-19 fatality risk on board of public transport modes would decrease substantially if a more favourable scenario on-board is considered, such as middle-seat free policy in case of aircrafts, or 50% occupancy rate on trains. In these scenarios, observed in current times across Europe, a direct side-to-side physical contact between passengers is eliminated, which drastically reduces the direct (and thus overall) virus transmission. This may also explain the very low on-board infection statistics for different modes of transport [3]. As a reminder, in this study, we considered the least favourable standard scenario (all seats filled), which by observation is unlikely in times of higher infection prevalence in the population. This was complemented with analysis in the context of lower occupancy rates for rail, air and coach.

Further analyses demonstrated also the substantial influence on the risk comparison between rail and car in the case with widespread vaccination programmes. In this case the total fatality risk associated with rail travel is significantly lower than the fatality risk associated with car travel.

15. Limitations

In this study, we have not yet been able to quantify the probability of the short-range airborne and fomite transmission, lacking sound empirical evidence (although short-range airborne transmission was considered as part of the sensitivity testing). The absence of the former may have a limited impact on infection transmission on aircrafts, due to presence of HEPA filters, while a more important impact though on bus and train coaches equipped with standard filters only. At the same time, wearing face masks may likely reduce the infection transmission risk, significantly.

The quantification of risk in this study relies on numerous assumptions made by the authors, based on the latest available empirical evidence. Moreover, for a simplification reason, only a mid-value is used, when the assumptions concern a numerical input into the calculation model, ignoring the underlying distribution.

The study excludes commuters and short-distance services from the analysis. Those travellers would have a shorter journey and thus shorter COVID risk exposure, their exclusion may lead to the underestimation of the overall risk evaluation for the following reasons:

- *i) the length of travel would often be more than 15 min (US CDC close exposure operational definition),*
- *ii) the daily volume of commuting travellers in densely-populated areas (e.g. Benelux countries) would represent a significant number in the EU, and*
- *iii) the geographical location of commuting users is close to main urban and sub-urban areas which can reach a high level of COVID-19 incidence during an outbreak wave.*

This study does not address the contribution of the spread of the infection during an epidemic wave, but is rather a mathematical assessment in given conditions for individual risk. It does not represent a full contextual assessment aboard a means of transport nor does it provide recommendations on contact tracing

after identification of cases in such means of transport. It is noted that each individual would in practice face different risk of hospitalisation or death.

Under the assumption of unchanged probability of the spread of infection from an infected person to a healthy person in long distance service trains, and in the event of widespread community transmission at the departure area, the probability that a given passenger on board is infected with COVID-19 increases, even though it remains low in an absolute manner, but in regions with a high population density or in connections between national/regional capitals, there may be a noticeably higher number of events of transmission.

Overall, given that the available knowledge concerning COVID-19 is still evolving there is an inherent uncertainty in analyses concerning virus transmission and risk of infection. This inherent uncertainty also applies to the analysis undertaken in this study and the resulting risk estimates should be considered with that perspective.

16. Discussion points

Given that actual infections are estimated to be up to ten times more than the confirmed ones, roughly 976,000 new infections arose per day among the 448 million Europeans in early 2021 (218 estimated infections per 100,000 population). That works out to a daily infection probability of 976,000/448,000,000, which is 1/459. Assuming 16 hours awake, the chance of infection over a two-hour period would be approximately (2/16)*(1/459) = 1/3672, which is quite close to our infection risk estimates for a two-hour journey. It should be noted that the figures given for number of daily cases used here are based on information about the 14-day notification rate from ECDC [6] covering weeks 5 and 6 of 2021.

The overall reference risk used in this paper is the individual travel in passenger cars. However, the individuals often travel accompanied as shown in data from the EEA [19], which suggest an occupancy rate of between 1.5 and 2 per passenger vehicle across Europe. While it can be argued that those passengers accompanying the driver often live in the same household (and would become infected at home), an accompanied travel often involves other individuals who can potentially be infected and thus representing a risk of transmission. Considering this potential incremental COVID risk on board of passenger cars would increase rather significantly the overall risk experienced by those individuals (on average) and make this form of travel by far the most dangerous one. Obviously, this risk would though be mitigated as widespread vaccination is ongoing across Europe.

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Appendix 1:

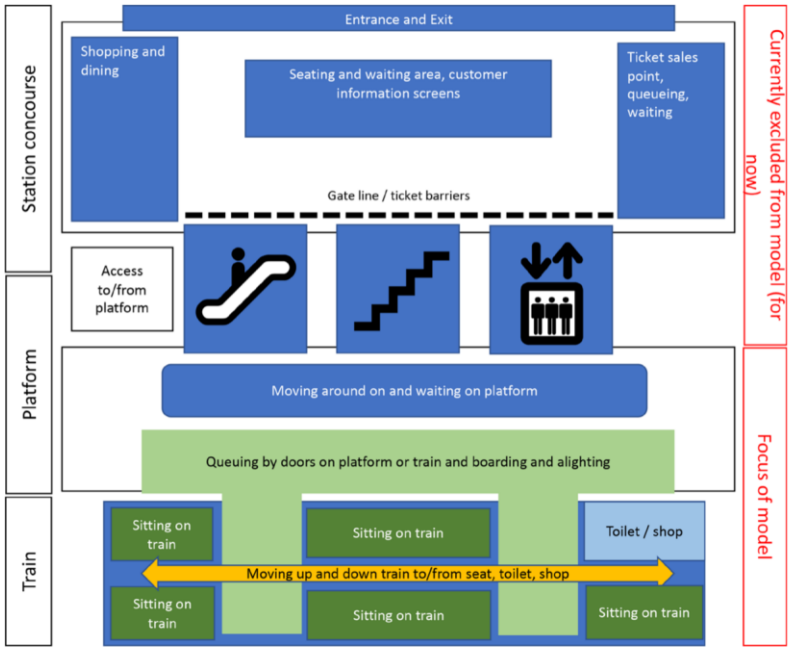

Figure1 : Scope for the analysis

Appendix 2: Calculation model

I. Infected onboard passenger			
14-days notification rate - per 100,000	U_{14}	130.6	ECDC
7-days notification rate (infections per population)	u_7	**0.00065**	
Positivity rate	p	0.22	ECDC
Estimated infection prevalence ratio	i	**10.00**	
Infection prevalence - general population	U	**0.00653**	
Conditional probability infected person onboard	q_t	0.75	Own estimate

$$u_7 = \frac{U_{14}}{2} \times \frac{1}{100{,}000}$$

$$i = 16 \times \sqrt{p} + 2.5$$

$$U = u_7 \times i$$

Probability that a given passenger on the trip is infected with Covid-19	**Qc**	**0.0049**

II. Attack rates			
Probability that universal mask-wearing onboard fails to prevent contact and droplet transmission of Covid-19	Q_{m1}	0.18	Studies
Probability that universal mask-wearing onboard fails to prevent short-range airborn transmission of Covid-19	Q_{m2}	0.18	Studies
Conditional probability that a contagious passenger transmits Covid-19 to the uninfected one if the mask fails	Q_L	0.304	From sub-model
Conditional probability of an indirect aerosol virus transmission if the mask fails	Q_A	0	From sub-model
Conditional probability of an indirect virus transmission via surfaces onboard if the mask fails	Q_P	0	From sub-model
Exposure duration (min)	t	120	Own function
Correction factor for exposure duration	c	**1.0**	

$$c = 0.3 \times \ln(t) - 0.43$$

Probability of the spread of infection from an infected person to a health	**Qs**	**0.055**

III. Probability of dying/ hospitalization/IHC		
Death rate - 14-days - per 100,000	1.05	ECDC
Case fatality among notified infected (per infected daily)	**1.13%**	
Case fatality among all infected	**0.11%**	
ICU hospitalization rate (notified cases)	8%	ECDC
ICU hospitalization rate (all cases)	**0.80%**	
Hospitalization rate (notified cases)	21%	ECDC
Hospitalization rate (all cases)	**2.10%**	
Adjustment coefficient for mortality among passengers	0.8	Own estimate
Deceased infected passengers	**2.43E-07**	
IHC hospitalized infected passengers	**1.73E-06**	
IHC hospitalized infected passengers	**4.53E-06**	

IV. Overall travel risk		
Fatality risk (safety) for passenger on average trip	6E-09	Sheet Travel Risk
Overall fatality risk	**2.5E-07**	

Appendix 3: Sensitivity test results

Test 1 - Infection prevalence ratio of 5 (instead of 10)

Per 2hrs trip $*10^{-9}$	Accident fatality risk	Incremental COVID fatality risk	Total fatality risk	Proportion of car fatality risk
Train passenger	6	49*)	55	0.18
Car occupant	306	0	306	-

*) 50% loading factor

Test 2 - Non-zero probability for short-range airborne transmission (5% of person-to-person transmission probability)

Per 2hrs trip $*10^{-9}$	Accident fatality risk	Incremental COVID fatality risk	Total fatality risk	Proportion of car fatality risk
Train passenger	6	102*)	108	0.35
Car occupant	306	0	306	-

*) 50% loading factor

Test 3 - Non-zero probability for short-range airborne transmission (25% of person-to-person transmission probability)

Per 2hrs trip $*10^{-9}$	Accident fatality risk	Incremental COVID fatality risk	Total fatality risk	Proportion of car fatality risk
Train passenger	6	121*)	127	0.42
Car occupant	306	0	306	-

*) 50% loading factor

Test 4 - Higher probability of person to person transmission associated with new COVID-19 variants (50% increase assumed for variant B 1.1.7)

Per 2hrs trip $*10^{-9}$	Accident fatality risk	Incremental COVID fatality risk	Total fatality risk	Proportion of car fatality risk
Train passenger	6	146*)	152	0.50
Car occupant	306	0	306	-

*) 50% loading factor

Test 5 – All assumptions from Test 1, 3, 4

Per 2hrs trip $*10^{-9}$	Accident fatality risk	Incremental COVID fatality risk	Total fatality risk	Proportion of car fatality risk
Train passenger	6	91*)	97	0.32
Car occupant	306	0	306	-

*) 50% loading factor

COMPLEMENTARY INFORMATION SOURCES:

Estimation of COVID-19 infection risk from short-range airborne transmission during classroom teaching, available at: http://COVID-exposure-modeler-data-devils.cloud.duke.edu/

Rail still safer than road during COVID-19, RSSB featured story, available at: https://www.rssb.co.uk/what-we-do/Insights-and-News/News/Rail-still-safer-than-road-during-COVID-19

https://ehjournal.biomedcentral.com/articles/10.1186/s12940-018-0427-5

ITF: https://www.itf-oecd.org/COVID-19

- Exhaustive and well-structured info on Transport and COVID19 – responses and resources

UIC: https://uic.org/

- UIC COVID-19 Task Force

EUROPEAN COMMISSION: https://ec.europa.eu/transport/media/news/2020-04-29-coronavirus-package-measures-support-transport-sector_en

- package of measures to support transport sector
- European Research Area (ERA) corona platform, a one-stop shop for information on coronavirus research and innovation funding
- the Coronavirus Global Response initiative

UNECE: data sources on Coronavirus impact on transport

- https://wiki.unece.org/display/DSOCIOT/Data+Sources+on+Coronavirus+impact+on+transport

EURNEX: http://www.eurnex.org/wp-content/uploads/2020/05/COVID-19_Rail_Final_EURNEX.pdf

TRANSCOM (Aircraft Virus Spread)
https://www.ustranscom.mil/cmd/docs/TRANSCOM%20Report%20Final.pdf