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COVID-19 and suburban public transport in the conditions of the Czech Republic

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ARTICLE INFO

Keywords:
Passenger transport
Integrated transport systems
Timetable design
Travel demand
COVID-19 pandemic
Vehicle capacity

ABSTRACT

This article focuses on possible approaches to safe regional public transport during the COVID-19 pandemic. The purpose of the research is examination the conditions for ensuring safe transport and the impact on the planning of transport services. The result is an assessment of the operation of regional public transport, consisting of the possibility of maintaining safe distances in public transport. Authors work on suburban transport cases in selected regions of the Czech Republic (Prague and Moravian-Silesian Region). Census devices in public transport, periodical transport surveys, Google mobility reports and data on fare sales from regional transport were used as data sources. Emphasis is placed on a safe distance between commuters, this condition leads to lower occupancy of the vehicle while maintaining the capacity of the vehicles. The value of this new occupancy is determined for selected vehicles and the coefficient that represents the maximum occupancy level to ensure safe transport is established. The capacity of the connections is examined in the period before and during the COVID-19 pandemic. Compared to the period before COVID-19, the daily variation of passengers is expected to change significantly, leading to different occupancy rates during the day.

1. Introduction

COVID-19 has unprecedentedly influenced everyday life in many areas. Public transport systems have responded differently to this unpredictable change, but the aim of all these approaches has been the same - to ensure the safe transport of passengers. The motivation for the research is examination the conditions for ensuring safe transport included the impact on the planning of transport services (Bucsky, 2020, Gkiotsalitis and Cats, 2021). The pandemic has had a major impact on public transport. Many passengers stopped using public transport temporarily (partial transitions to home office), some permanently (concerns about their health, risk of infection, transition to car driving). If public transport is to be a long-term safe and sustainable transport mode, it must deal with these risks and be able to face current challenges (Bucsky, 2020).

1.1. COVID-19 and its relation to public transport

Coronavirus disease (COVID-19) is an infectious disease caused by a newly discovered coronavirus. Most people infected with the COVID-19 virus have a respiratory illness, vulnerable people (older people, chronically ill people) belong to the risk group of the most endangered persons (World Health Organization, 2021).

There are three frequently accepted modes of viral transmission: via small airborne droplets (aerosols), via larger airborne droplets, and contact with a contaminated surface (Morawska et al., 2020). The best way to prevent and slow down the transmission of COVID-19 is to follow three basic rules: the protection of the nose and mouth using a mask, washing and disinfection of the hands, and the observance of safe distances to limit the spread of droplet infection. According to various studies and expert opinions, a distance in the range of 1.5–2 m can be set as a safe distance (CDC, 2021a).

Given the worldwide reputation of COVID-19, the authors consider that there is no need to recapitulate the general rules for handling the COVID-19 pandemic. Likewise, in the context of this article, authors do not consider it essential from a physical and medical point of view to describe the exact procedures by which droplets spread in the air and subsequently enter the body of prospectively infected persons. The following chapters will discuss the impacts of measures related to the protection against COVID-19 on public transport, the spread of COVID-19 in public transport and will propose specific measures in public transport to create a safe and credible environment (De Vos, 2020).

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https://doi.org/10.1016/j.trip.2021.100523
Received 23 August 2021; Received in revised form 29 November 2021; Accepted 13 December 2021
Available online 16 December 2021
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2. Methods

For better understanding of travel behavior and conditions prevailing during transport, the mobility analysis was carried out (Pawar et al., 2020, Gaskin et al., 2021). The capacity of the connections is examined, and the relative occupancy for specific sections and time slots in the period before and during the COVID-19 pandemic is assessed. Emphasis is placed on a safe distance between commuters, this condition leads to a significant reduction in the maximum occupancy of vehicles (Muller et al., 2020). This creates a new value that can be described as the maximum number of passengers to ensure safe transport in the spread of respiratory diseases. The coefficient that represents the maximum occupancy level to ensure safe transport is established.

The changes in mobility caused by the COVID-19 pandemic have had a significant impact on public funds. Public transport is standardly financed from fare revenues and finances (compensations) from public service obligations (PSO).

Fig. 1 captures the relation between the revenue and the expenditure components.

The Fig. 1 is divided into five parts, each describing a different case in terms of vehicle capacity utilization. The situation before the COVID-19 pandemic is shown on the left. The following columns describe the conditions during the COVID-19 pandemic, always emphasizing the observance of safe distances during transport.

Left column of the pair: fuels and all costs related to the volume of transport performance are the variable cost (red part of the column), and depreciation of vehicles and all costs related to the duration of the contract (PSO) are fixed costs (orange and yellow parts of the column).

Right column of the pair: compensation (in the term of PSO – public service obligation) means financial compensation to the carrier, which aims to subsidize traffic in order to provide transport in the public interest. Additional compensation means an increase in revenue related to the incurrence of additional costs or loss of sales.

The second pair of columns represents a situation, when there has been significant drop in passenger demand and the vehicle capacity is shortened. The additional compensation covers the loss of fare revenue reduced by variable cost.

The third pair of columns represents a situation, when there has been moderate decrease of passengers. The existing vehicle capacity is sufficient to ensure safe distances. The additional compensation only covers the loss of fare revenue.

The fourth pair of columns represents a situation, when there has been moderate decrease of passengers. The existing vehicle capacity is insufficient to ensure safe distances, minor strengthening of capacity is needed. The additional compensation covers the loss of fare revenue and capacity strengthening.

The last pair of columns represents a situation, when there has been no decrease of passengers (mobility is on the same level as before COVID-19 pandemic). The existing vehicle capacity is absolutely insufficient to ensure safe distances, major strengthening of capacity is necessary. The additional compensation covers the capacity strengthening. Significant capacity strengthening is threatened by infrastructure limits and the availability of the necessary number of vehicles for capacity strengthening.

2.1. Measures on public transport in connection with COVID-19

Much has been written about the basic rules for reducing coronavirus transmission, but there are still only a few studies that are focused on the specific spread of COVID-19 in public transport vehicles. Public transport vehicles are relatively confined and there is a higher density of passengers who usually travel for longer than 15 min. The basic rules are set out by the Centers for Disease Control and Prevention on their website, where the recommendations related to public transport are described in detail (CDC, 2021b):

- If possible, consider traveling during non-peak hours when there are likely to be fewer people;
- Follow physical distancing guidelines by staying at least 6 feet (about 1.83 m) from people who are not from your household;
- Consider skipping a row of seats between yourself and other riders if possible;
- Enter and exit buses through rear entry doors if possible;
- As much as possible, limit touching frequently touched surfaces such as kiosks, digital interfaces such as touchscreens and fingerprint scanners, ticket machines, turnstiles, handrails, restroom surfaces, elevator buttons, and benches;
- Use touchless payment and no-touch trash cans and doors when available;
- Exchange cash or credit cards by placing them in a receipt tray or on the counter rather than by hand, if possible;
- Do not eat or drink on public transit;

These recommendations are a cornerstone for achieving the safe and credible environment in public transport (Tirachini and Cats, 2020). These principles are the starting point for specific measures in public transport, which are furthermore supported by a study of the spread of coronavirus in highspeed trains in China (Hu et al., 2021), a study on the spread of coronavirus in New York subway network (Harris, 2020) and a study aimed at spreading COVID-19 in the urban bus (Zhang et al., 2021).

The conclusions of this study show that the probability of infection is approximately ten times higher within one row of seats than between individual rows Table 1. The probable effect is the separation of individual rows by tall backrests, as well as a higher risk of close contact when moving from the window seat to the aisle accompanied by touches.
on the armrests on adjacent seats. Other risks may be transmitted in common areas of the train (toilets, aisles) or the train staff may transmit the virus, but this in-fluence and its share are difficult to demonstrate (Hu et al., 2021).

The urban bus study dealt with modeling the spread of aerosols in an urban bus in many model situations, e.g. taking into account vehicle ventilation by opening doors, ventilation windows, or the effect of wearing masks. The amount of penetration of particles into the passenger’s respiratory system was observed. The conclusions of the study show that ventilation and regular opening of the doors have a positive effect on reducing the concentration of infected particles in the bus environment. There is an increased risk of infection only for passengers who are close to the air outlets of the vehicle. If the driver opens a ventilation window, it increases his risk of infection. With the proper wearing of surgical masks, almost complete protection against the infection can be achieved for 15 min of virus exposure (Zhang et al., 2021).

| Rows Apart | Columns Apart | 1   | 2   | 3   | 4   | 5   | Average |
|------------|---------------|-----|-----|-----|-----|-----|---------|
| Same row   |               | 0.21| 0.24| 0.23| 0.23| 0.20| 0.17    |
| 1          |               | 0.24| 0.14| 0.12| 0.10| 0.10| 0.11    |
| 2          |               | 0.23| 0.12| 0.12| 0.10| 0.10| 0.10    |
| 3          |               | 0.22| 0.10| 0.10| 0.10| 0.10| 0.10    |
| Average    |               | 0.17| 0.12| 0.12| 0.10| 0.06| 0.12    |

Table 1: The attack rate is defined as the percentage of coronavirus disease 2019 cases in close contact with index patients on the train. The numbers in parentheses are the 95% confidence interval of the attack rate (Hu et al., 2021).

The attack rate is defined as the percentage of coronavirus disease 2019 cases in close contact with index patients on the train. The numbers in parentheses are the 95% confidence interval of the attack rate (Hu et al., 2021).

The study connected to New York subway network describes the effect of coronavirus spread in relation to the limited operation of metro lines. The study concludes, among other things, that there is a link between the spread of coronavirus and the reduction of traffic, and it would be appropriate to double or triple the volume of traffic to alleviate the pandemic.

2.2. Mobility during COVID-19 restrictions

Public transport is an integral part of the mobility of the future, and the return of passengers to individual transport is a step back, and it will be necessary to reexpend energy and resources to change the modal split in favor of public transport (Drábek and Pospíšil, 2018).

A state of emergency has been declared in the Czech Republic and restrictions have been introduced to reduce the number of physical contacts. These restrictions had a significant impact on the decline in mobility in the first wave of the pandemic (March 2020), in the second wave of the pandemic (November 2020) and in the third wave of the pandemic (March 2021).

This decline in population mobility can be observed in several published data, and the trend is comparable across the Czech Republic and other European countries, such as Poland (Wierchowska et al., 2020). Based on the data of mobile network operators or users of the Waze application in the second largest city in the Czech Republic (Brno), it is evident that in the first week after the outbreak of the pandemic, mobility dropped sharply 60–70% within 7 days (Macioszek et al., 2017; Data.Brno, 2021). Data from counting facilities in the Prague metro network was used as a comparison, and the number of passengers dropped sharply by 80% within 7 days of the outbreak of the pandemic. Data about passengers were provided by the Prague organizer of public transport - the company ROPID (Ropid, 2021). Both dramatic declines of mobility clearly show that the population did not take the pandemic lightly and led to a truly unprecedented break of travel demand. This decline has been exacerbated by fears of public transport.

The second wave of the pandemic is also accompanied by a decline in mobility. The second phase culminated in the first half of November 2020. Given the less stringent measures, the number of passengers in the Prague metro fell by 67% compared to the average number of passengers in the pre-pandemic period. COVID-19 (Ropid, 2021).

In the third wave of the pandemic, the most stringent measures were formally introduced. The number of passengers in the metro network fell by 68% compared to the average number of passengers at the beginning of March 2020 (before the COVID-19 pandemic). The decrease in the number of passengers is comparable to the decrease in the number of passengers in the second phase of the pandemic in November 2020.

Data from March 2021 also include the use of urban bus and tram transport. Both modes of transport reduced by 63% year-to-year. Globally, in the first decade of March 2021, the number of passengers in public transport in Prague decreased by 64.8% compared to the period before the COVID-19 pandemic (Ropid, 2021).

For the comparison between the capital and regional centers, a comparison of mobility through the Google mobility report was made (Noland, 2021, Wagner et al., 2020). The comparison was made on the basis of data from the first and third waves of the COVID-19 pandemic, using reports from 29.3.2020 (Google, 2020) and 20.3.2021 (Google, 2021). Both reports are influenced by declaring a state of emergency and countrywide lockdown of schools, the vast majority of services, shops, and leisure activities. The reports are not comparable, as Google modified the methodology for calculating some variables during the processing of mobility reports. Table 2 shows the relative changes in user behaviour compared to their usual activities, which Google defines for the period from January 3 to February 6, 2020. Relative changes in user movement are processed for each destination or location occurrence in Table 2, considering the number of occurrences and the time spent in the locality.

The authors focus only on the Czech Republic due to the comparability of data. In particular, government restrictions are specific for every single country, and due to different approaches to restrictions travel behavior among countries cannot be objectively compared.

Based on Table 2 and Table 3, it can be concluded that comparison between the capital city of Prague and the Moravian-Silesian Region, the fluctuation compared to the pre-COVID period is more pronounced in Prague (variance for March 2020: 0.095 and March 2021: 0.072) than in the Moravian-Silesian Region (variance for March 2020: 0.080 and March 2021: 0.064).

We have established the hypothesis that there is less passenger turnover in the Moravian-Silesian Region than in the capital city of Prague with regard to the economic sector and the social status of the region. The hypothesis is based on the different sectoral structure of the economy of compared regions – the Moravian-Silesian Region is mostly oriented to industry and Prague is mostly oriented to the tertiary sector of services. The hypothesis of a smaller fluctuation in the Moravian-Silesian Region is confirmed by data on the number of passengers in regional bus transport. Backbone lines between Ostrava and Frydek-Místek in the Moravian-Silesian Region was analyzed. The assessed ratio of regional bus transport between the cities of Ostrava and Frydek-Místek decreased the number of passengers by 58.6% compared to the usual state. As a usual state authors used data set from 13.1.2020 to 17.1.2020. The authors used data set from the peak of the second wave of the COVID-19 pandemic, from 2.11.2020 to 6.11.2020, as a COVID period. Compared to the capital of Prague (decrease in the number of passengers dropped sharply by 80% within 7 days of the outbreak of the pandemic).
leads to a significant reduction in the capacity of the vehicles offered. This creates a new value that can be described as the minimum number of passengers to ensure safe transport in the spread of respiratory respiratory virus infection. While the study of the urban bus environment is focused on these bus lines.

2.3. Determination of safe vehicle capacity

While maintaining such spacing in public transport, this condition leads to a significant reduction in the capacity of the vehicles offered. This creates a new value that can be described as the minimum number of passengers to ensure safe transport in the spread of respiratory restrictions (Gkiotsalitis, 2021, Hörcher et al., 2021).

Based on the performed literature review, it is possible to identify the basic requirements for safe and credible public transport. The wearing of surgical masks or respirators can undoubtedly be identified as a basic way of protecting passengers’ health (Zhang et al., 2021). In particular, securing the distances between individual passengers during their journey by public transport vehicles can be considered as an accompanying measure to help reduce the remaining risk. Recommended physical distancing is at least 6 feet, which is equal to 1.83 m (CDC, 2021b). To ensure the physical distance between passengers, it is necessary to recalculate the maximum occupancy of the vehicle.

A comparison of the results of study about the long-distance trains in China (Hu et al., 2021) and the study about spreading coronavirus in the urban bus (Zhang et al., 2021) reveals a different approach to coronavirus infection. While the study of the urban bus environment is focused on the movement of aerosol particles, the study of the probability of infection in individual seats in relation to the infected passenger was based on data on 2334 infected passengers and their close contacts.

Additionally, the environment of an urban bus and a long-distance train is considerably different in its configuration. The urban bus is characterized by its spaciousness, minimal division of space by partitions or other objects and overall easy passage of air through the vehicle environment. Long-distance trains are characterized by arranging the seats one behind the other, the individual rows of seats are separated by tall backrests, and the flow of air in the space is thus limited.

The authors of this article have the ambition to ensure a safe and trustworthy environment in regional buses and trains. The environment of these vehicles can be characterized as a combination of the urban bus and long-distance train configuration. Compared to vehicles in urban transport, vehicles in regional transport are equipped with a larger number of seats, which usually have higher backrests. The one behind the other arrangement of seats is often used in buses dedicated to regional transport. The vis-à-vis arrangement of seats is often used for regional train units. An analysis of the vehicle fleet in the Moravian-Silesian Region was performed, and it was found that 95.08% of cars have a mostly vis-à-vis arrangement and only 4.92% of vehicles have a balanced seats arrangement (partly vis-à-vis and partly one behind the other) (KODIS, 2021a). It can be assumed that the free flow of air inside the vehicle will be partially prevented by dividing the interior by the seat backrests. Nevertheless, vehicles intended for regional transport will continue to be more spacious than long-distance vehicles, i.e. the individual rows of seats will not be carefully separated as well as in long distance arrangements. Compared to long-distance transport, regional transport vehicles have advantage, namely, the shorter average time spent in the vehicle.

With reference to the study (Hu et al., 2021), wherewith each additional hour the risk of infection in an adjacent seat is 1.5% higher, it can be concluded that for journeys of up to 30 min there should not be a higher risk of transmission than in the study (Hu et al., 2021).

The findings of the study (Zhang et al., 2021) are positive, because with use of surgical masks and a travel time up to 15 min, there was no exposure to the virus, which would cause infection of other passengers.

From the above-described point of view, the author team approached the definition of a safe distance, which is a key element in the prevention of COVID-19 virus infection, but is still conditioned by surgical masks, as follows:

- It is not permissible to occupy adjacent seats, as this is the riskiest place in the vehicle,
- In the case of vis-à-vis seating arrangements, it is not permissible to occupy a seat on opposite seats,
- In the case of aerial seating and full back arrangements, it is possible to seat two passengers in a row,
- Sitting is prohibited at a distance of 6 feet (1.83 m) from the driver’s head - a safe zone is created around the driver’s seat,
- In clear space, the minimum distance between the seating positions is 6 feet 1.83 m), the reference point being the presumed position of the mouth and nose on the seat in question.

Given the small difference in the seat spacing of vehicles in regional transport, these rules can be generalized to all types of vehicles used in regional transport, both bus and tram or rail vehicles.

It is clear from the above rules that this will lead to a significant reduction in the standard capacity of the vehicle. This results in the determination of the recalculated vehicle capacity, which is called the safe vehicle capacity for the purposes of this study.

The value of this new capacity must be determined by the standardized vehicle configurations from the floor plans of the individual vehicles. Subsequently, it is proposed to monitor the relationship between standard capacity and recalculated capacity. The aim should be to determine the coefficient, which represents the maximum occupancy rate, which is the ratio of the allowable number of passengers to capacity (Rüger, 1984).

2.4. Determination of the operational frequency to ensure safe transport

We propose a suitable frequency of service by the procedure of

| Table 2 | Relative changes in the movement of people in specific localities in comparison with the usual activity before the COVID-19 pandemic (Source: Google, 2020, edited by authors). |
|---------|---------------------------------------------------------------------------------|
| March 2020 | Retail and recreation | Grocery and pharmacy | Parks | Transit stations | Workplace | Residential |
| Prague | −77 % | −30 % | −58 % | −71 % | −38 % | +15 % |
| Moravian-Silesian Region | −72 % | −21 % | −14 % | −63 % | −27 % | +10 % |

| Table 3 | Relative changes in the movement of people in specific localities in comparison with the usual activity before the COVID-19 pandemic (Source: Google, 2021, edited by authors). |
|---------|---------------------------------------------------------------------------------|
| March 2021 | Retail and recreation | Grocery and pharmacy | Parks | Transit stations | Workplace | Residential |
| Prague | −63 % | +4 % | −30 % | −50 % | −19 % | +12 % |
| Moravian-Silesian Region | −62 % | −1 % | −19 % | −45 % | −4 % | +9 % |
determining the frequency of service depending on the number of passengers according to (Rüger, 1984). To determine the required supply of seats in time, we consider the input values of the standard capacity of one car \( K \), the maximum degree of occupancy \( \gamma_{\text{max}} \) and the force of transport current \( Q \) expressed in the number of persons per time unit. The output of the specified procedure is then the required number of cars to provide service in a given direction and per time unit \( F \).

\[
F = \frac{Q}{\gamma_{\text{max}} K}
\]

(1)

\( F \) frequency of operation per direction [connections/time unit]
\( K \) vehicle capacity [offered seats]
\( Q \) passengers flow [persons/time unit]
\( \gamma_{\text{max}} \) coefficient of maximum occupancy [--]

In the case of using the calculation in regional bus transport or where the service is provided only by single-vehicle train units, the number of cars \( F \) can be considered as the frequency of service \( f \).

\[
f = F
\]

(2)

In cases where the composition of the train units is not variable and the train units are multiple, the required frequency of service is obtained as follows:

\[
f = \frac{F}{n}
\]

(3)

where \( n \) is the number of wagons of the train unit.

In cases where the composition of the train multiple units is diverse, determining the frequency of service depending on the number of passengers is complicated. The frequency of operation is then obtained under the condition that the relative proportion of sets are constant over time, as follows:

\[
f = \frac{F \cdot k}{n_1 + n_2 + \ldots + n_k}
\]

(4)

where \( k \) is the number of sets included in the composition calculation and \( n_1, n_2, \ldots, n_k \) is the number of sets cars 1 to \( k \).

In other cases, it is necessary to approach the assessment individually and to consider the specific conditions of the case.

2.5. Comparison of daily variation before and during the COVID-19 pandemic

These capacities (standard and recalculated) will be used to verify the relative occupancy in the period before and during the COVID-19 pandemic. From the obtained comparisons, it is then possible to conclude whether it is possible to observe safe distances in public transport, or what the order of the sets would have to be or how the scope of ordered transport would have to change to comply with the distances. It is assumed that the individual measures will differ during the day, as it can be concluded from the assessed data that due to government restrictions. The variation in the demand for transport during the day has changed significantly. The measures taken have a significant effect on the daily rhythm of passengers, with the vast majority of journeys being commuting and the peaks being shorter and more intense than before COVID-19 (Anzai et al., 2021).

Data from the period before the first wave of the COVID-19 pandemic is considered the usual level, which corresponds to the provided data from the period from 13.1.2020 to 17.1.2020. Data distortion due to school holidays, public holidays or other macroscopic influences is not expected during this period.

The period significantly affected by the COVID-19 pandemic can be considered the period from 2.11.2020 to 6.11.2020, when the second wave of the pandemic culminated (MZCR, 2020), at the same time there was no data distortion due to public holidays. To clarify the form of the measures in the 2nd wave of the COVID-19 pandemic, key measures concerning the restriction of the mobility of the population are also listed.

In this case, we decided to compare the above-mentioned periods regarding the pandemic waves. Second period was in the pandemic period when government regulations were in force. These regulations had a very significant effect on the travel behavior of the population and emphasis was placed on comparing data from the period with serious impact. In the given situation, these representative time series describe the situation before and at the peak of the COVID-19 crisis. It is also necessary to state that data from the other time periods from previous years contain seasonal inequalities caused by public holidays, mass events and preparing for Christmas celebrations. Due to government regulations the influence of Christmas shopping, mass events and public holidays is recognizable, because activities connected with it were restricted.

In the selected period, the Government of the Czech Republic declared a state of emergency. Primary schools, secondary schools, and universities were closed, and teaching occurred in a distance form. Restaurants, retail, services, leisure, culture, and sports were also closed in most cases. Only health services and grocery stores and other necessary assortments remained open. Industrial production was almost unlimited. A curfew was introduced between 21:00 and 05:00, except for travel to or from work (VLÁDA, 2020a; VLÁDA, 2020b; VLÁDA, 2020c; VLÁDA, 2020d).

3. Results

We defined the research task: We want to assess the seating arrangement in the interior of vehicles, with an emphasis on creating a space that will have a positive effect on reducing the transmission of respiratory infection. The aim is to restore passenger confidence in public transport and to restore confidence in safe commuting on public transport vehicles.

The authors of the research applied the described methods to determine the \( \gamma_{\text{max}} \) coefficient to determine safe vehicle capacity. The authors assessed the \( \gamma_{\text{max}} \) coefficient for a suburban bus and for a characteristic suburban railway car or part of a multiple unit.

3.1. Determination of safe vehicle capacity

The rules defining the safe distance during public transport have been taken over from the Methods section:

- It is not permissible to occupy adjacent seats, as this is the riskiest place in the vehicle
- In the case of vis-à-vis seating arrangements, it is not permissible to occupy a seat on opposite seats
- In the case of an aerial arrangement of seats and full back, it is possible to seat two passengers in a row
- Sitting is prohibited at a distance of 6 feet (1.83 m) from the driver’s head - a safe zone is created around the driver
- In clear space, the minimum distance between the seating positions is 6 feet (1.83 m), the reference point being the presumed position of the mouth and the nose on the seat in question.

Given the small difference in the seat spacing of vehicles in regional transport, these rules can be generalized to all types of vehicles used in regional transport, both bus and tram or rail vehicles. To assess the impact of this measure in real operation, model vehicles were chosen. These are widely used in regional transport in the Czech Republic.

The IVECO Crossway LE Line 12 M (IVECO, 2020) was chosen as a model regional bus. The vehicle of this configuration has a length of 12 m, a two-door layout, and 45 seats, which are with tall backrests (Lineo type).

The application of the defined rules selected the places near the window because they are the most distant from each other within one
The interior configuration of the vehicle, as shown in Fig. 2. The number of marked seating positions is based on the distance, because with sufficient row separation, the risk of droplet spread is significantly lower (Hu et al., 2021). In the rear of the car, one row of seats has been omitted, as there is unevenness in height and there is no seat back protection from the previous row (the passenger would exhale directly on the passenger’s head in front of him). The first row of seats in the bus is also omitted, because it is in the driver’s safety zone. By applying the rules for determining safe seating positions with a view to reducing the risk of COVID-19 infection, a total of 16 seats were identified in the vehicle. The number of marked seating positions is based on the interior configuration of the vehicle, as shown in Fig. 2.

A similar recalculation principle can also be applied to regional rail vehicles. Single-decker multiple units are widely used in regional rail transport, with 640 and 650 series vehicles being used as models (Skoda Transportation, 2020). Although it is not a standardized vehicle in terms of exclusive representation of vis-à-vis arrangement, the selected series of railway vehicles have a characteristic arrangement of seats in terms of spacing. These vehicle series are suitable for demonstrating the need of occupancy reduction in Czech conditions.

The 650 series unit is a two-car single-deck electric unit with a total capacity of 147 seats. The vehicle is made with aisle between seats, a significant part of the seats is in a vis-à-vis configuration and tall backrests design. The application of the defined rules selected the places near the window because they are the most distant from each other within one row of seats. Regarding the use of seats with tall backrests, the seats have been occupied in each row. In the case of a vis-à-vis arrangement, only one is selected from each of the four seats. In places where the space is open or the seats are arranged longitudinally, a rule of a minimum spacing of 6 feet (1.83 m) between the seats has been applied. By applying the rules for determining safe seating positions with a view to reduce the risk of COVID-19 infection, a total of 47 seating positions were identified in the 650 Series vehicle. Thus, for a typical regional two-car unit, the original seating capacity of 241 was converted to a safe vehicle capacity of 74 seats. The number of marked seating positions depends on the inner layout of the vehicle, as shown in Fig. 4 (Anzai et al., 2020).

The monitored parameter is the $\gamma_{\text{max}}$ coefficient, which represents the maximum occupancy rate, which is the ratio of the allowable number of passengers to capacity. Table 4 shows the values of standard capacity and recalculated capacity, from which the value of the $\gamma_{\text{max}}$ coefficient is subsequently obtained by calculation.

Table 4 shows that the $\gamma_{\text{max}}$ coefficient varies from vehicle to vehicle. The main determining parameter of the $\gamma_{\text{max}}$ coefficient is the arrangement of the seats in the vehicle. Regarding the rules set out in the Methods chapter and adherence to the recommended spacings, only one of the four seats can be used when arranging the seats vis-à-vis, while one of the two seats offered can be used when arranging the seats in a row. It follows from the above that if the interior consisted only of seats in a vis-à-vis arrangement, the $\gamma_{\text{max}}$ coefficient could take on a maximum value of 0.250. If the seats are arranged in a row, a $\gamma_{\text{max}}$ factor of up to 0.500 could ideally be achieved. It can be seen from Fig. 1 that in a regional bus, the seating arrangement behind it predominates, while in train unit no. 640 is used to the maximum extent possible in a vis-à-vis arrangement.

3.2. Determination of the operational frequency to ensure safe transport

In the model case, the relation of regional bus transport between the cities of Ostrava and Frýdek-Místek was assessed. The assessment included the lines of the Integrated Transport System of the Moravian-Silesian Region ODIS, specifically lines 351, 353, and 980, which are operated in the same connection between the mentioned cities (KODIS, 2021b). Data on passenger transport in the period before the outbreak of the COVID-19 pandemic and during the 2nd wave of the COVID-19 pandemic in the Czech Republic was analyzed.

The data provided for both periods were used to analyze the frequency of service. The frequency of service was calculated for each operating hour separately to assess the compliance of the offered capacity with the necessary capacity to ensure safe and reliable transport in different parts of the day.

Table 5 shows the average daily numbers of passengers in the relevant operating hour at the border of the regional capital Ostrava. Subsequently, the theoretical frequency of service is calculated based on the values given in Table 5 and Table 6 - ie, the standard capacity of the regional bus of 45 seats, in the period of the COVID-19 pandemic, a $\gamma_{\text{max}}$ coefficient of 0.356 is applied. The planned frequency of the service column shows the number of connections in the respective operating hour according to the standard timetable. The column Actual frequency of service shows the number of connections regarding the introduced emergency measures in transport, which aimed to reduce the costs of public transport due to a significant reduction in sales.

It is evident from Table 6 that by reducing the volume of traffic, the $\gamma_{\text{max}}$ coefficient was exceeded in many operating hours, which is evident from the insufficient frequency of service. To ensure the carriage of

![Regional bus – 16 safe seats](image)
passengers at the recommended distances, it is necessary to provide at least as many connections as indicated by the theoretical frequency of service. The frequencies of connections in the respective operating hours are highlighted in bold when there is insufficient service in the assessed session. For such connections, it is then appropriate to deploy more capacitive vehicles, if such vehicles are available, or to increase the frequency of service on a given route to ensure the recommended distances between passengers. Table 7 shows the values of the $\gamma$ coefficient for individual connections during the COVID-19 pandemic. The $\gamma$ coefficient is the general occupancy coefficient, which is described as the ratio of vehicle capacity $K$ to the actual number of passengers in the vehicle (column “Passengers per bus”).

With the note canceled, canceled connections are an extraordinary measure in transport. It can be noted that the connections immediately preceding or immediately following the canceled connection often have the value of the $\gamma_{\text{max}}$ coefficient exceeded. It follows from the above that in the assessed area it can be clearly recommended to maintain the planned scope of transport to ensure the transport of passengers with the recommended intervals. Furthermore, the $\gamma_{\text{max}}$ coefficient is exceeded in the direction of Ostrava at 5o’clock in the morning.
3.3. Comparison of daily variation before and during the COVID-19 pandemic

It is interesting to compare the daily variations in the period before and during the COVID-19 pandemic. The already known data sets from January 2020 and November 2020 were compared. Figs. 5 and 6 show that the load distribution on the Ostrava – Frýdek-Místek route has undergone fundamental changes. Regarding the closure of schools and a large part of retail and services, the decline in peak travel periods and its shift to more marginal parts of the day is evident. The largest share of passengers arrives in Ostrava before 6 am and leave Ostrava after 4 pm. The most obvious change in behavior relates to the interrupted commuting to schools. Differences in daily variations are also substantiated by the composition of passengers according to travel documents. In the period from 7 a.m. to 8 a.m. and in the period between 1 p.m. and 3 p.m., students usually predominate, while now, according to the respective direction. A very significant flattening of the curve is evident, which are less significant in relation to the off-peak hours.

In Fig. 7 the smallest loss of passengers is around 5 a.m., because the morning shift usually begins at 6 a.m. This is followed by the most dramatic decline throughout the day, associated with the lack of students and staff working in services and administration, who often because the morning shift usually begins at 6 a.m. This is followed by the workers from large industrial enterprises dominate among commuters. The most obvious change in behavior relates to the interrupted commuting to schools. Differences in daily variations are also substantiated by the composition of passengers according to travel documents. In the period from 7 a.m. to 8 a.m. and in the period between 1 p.m. and 3 p.m., students usually predominate, while now, according to the respective direction. A very significant flattening of the curve is evident, which are less significant in relation to the off-peak hours.

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In Fig. 7 the smallest loss of passengers is around 5 a.m., because the morning shift usually begins at 6 a.m. This is followed by the most dramatic decline throughout the day, associated with the lack of students and staff working in services and administration, who often study or work from home. In other parts of the day, the loss of passengers is rather proportional.

4. Discussion

To ensure safe and reliable public transport, it is necessary to respect the value of the $f_{\gamma_{max}}$ coefficient. The Results chapter shows several approaches to achieve this. In the event of a reduction in transport demand, for example due to the introduction of measures related to the COVID-19 pandemic, a reduction of the $\gamma$ coefficient below the $f_{\gamma_{max}}$ level can be achieved in a relatively natural way.

A limitation of the research is the focus on suburban regional transport, which has its own specificities in terms of commuting time and vehicle interior layout. Given the completely different passenger movements in urban transport vehicles, these results cannot be objectively applied to public transport vehicles. The findings are also applicable to a limited extent to long-distance rail transport.

4.1. Measures leading to meet the coefficient of safe transport

If the loss of passengers is significant and the value of the $\gamma$ coefficient is significantly lower than $f_{\gamma_{max}}$, it is also possible to consider savings in costs incurred in providing public transport. In this case, it is appropriate to reduce the value of $F$, ie the number of cars per time unit. The reduction can be achieved in two ways, either by reducing the number of vehicles in the set (by shortening the train set or by using a unit with fewer cars), or by reducing the frequency of connections per given time.
unit. In the first case, a reduction in the capacity offered, and therefore in costs, can be achieved without a significant reduction in services. In the latter case, there is a risk of overflowing some connections or losing network connections (Falchetta and Noussan, 2020, Dedík et al., 2020).

The third option considered is then characterized by a less significant decrease in passengers or maintaining their number or increase. In such a case, the \( \gamma_{\text{max}} \) coefficient is significantly exceeded, because we usually assume a significantly higher value of the \( \gamma_{\text{max}} \) coefficient than in the period of the COVID-19 pandemic. In this case, vehicles are overloaded, and it is necessary to find a way to reduce the relative use of vehicles. In this case, it is possible to strengthen the set with additional cars or create new connections. Both measures are associated with another significant increase in costs. There may be a limit on infrastructure capacity or a shortage of vehicles.

### 4.2. Economic aspects of the proposed measures

From an economic point of view, the effort to comply with the recommended distances in public transport is a significant intervention in the economics of traffic. The determination of the \( \gamma_{\text{max}} \) coefficient depends on the internal layout of the vehicle, with the usable capacity of the vehicle being in the range of 0.250 to 0.500. The question is whether reducing transport efficiency is affordable in long-term. The way of securing the financing of public transport also plays an important role.

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**Fig. 5.** Daily variation of passengers – direction to Ostrava (Data source: KODIS, 2021b, edited by authors).

**Fig. 6.** Daily variation of passengers – direction to Frýdek-Místek (Data source: KODIS, 2021b, edited by authors).
The impact is directly proportional to the share of revenues in the overall economic balance of the service. Services with low revenue coverage, where the dominant part of the revenue consists of public transport customer compensation, are not as fundamentally affected by the loss of sales as services that are operated purely at the carrier’s commercial risk. Despite more or less drastic revenue shortfalls, the simple loss of passengers is only a shortfall on the revenue side.

In a situation where, on the contrary, there will be no significant decline in demand for transport, it will be necessary to ensure the recommended spacing by strengthening the sets or adding connections. In this case, there is a risk not only of a decrease in revenues, but also of an increase in costs.

These increased costs are difficult to justify economically but can be seen as part of a marketing campaign aimed at returning passengers to public transport. The return of passengers to public transport is essential, as the return of the modal split of public transport to the level of 2019 is one of the biggest challenges of the post COVID-19 agenda.

The limits of the research can be considered to be the focus on selected regions of the Czech Republic. Furthermore, the research focused only on selected types of vehicles, which, however, appropriately represent a typical vehicle fleet in selected regions. The detail of the research is based on the current state of knowledge that prevailed at the beginning of 2021. Detailed information on the effects of the pandemic on the public transport sector is still not available, given the

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**Fig. 7.** Passengers per hour – direction to Ostrava (Data source: KODIS, 2021b, edited by authors).

**Fig. 8.** Passengers per hour – direction to Frýdek-Místek (Data source: KODIS, 2021b, edited by authors).
From the point of view of a contactless and safe environment in the vehicle, it is necessary to approach the process of check-in and stay in the vehicle with an innovative approach aimed at minimizing the contact of passengers with surfaces inside the vehicle interior. It is necessary to focus on limiting the use of buttons for opening and closing doors, (boarding doors and doors separating compartments for passengers or toilets). Furthermore, we focus on the possibility of contactless check-in on the train using modern methods of check-in using a mobile phone or payment card. These measures should follow the recommendations for better targeted cleaning of vehicles, incl. surface disinfection - from nano spraying to ozone disinfection of the vehicle interior.

5. Conclusion

In addition to the constraints associated with government regulations, there is a general lack of confidence in the safety and credibility of public transport. A shift in user preferences towards less crowded and more flexible transport solutions is highly probable. The perceived level of risk will be an important factor in choosing the mode of transport.

Public transport operators and authorities face the challenging task of restoring confidence in public transport. It must minimize the risk throughout the transport process, although the use of masks will undoubtedly continue to be common for some time. The transport offer must be flexible enough to meet the needs of passengers while maintaining a safe distance. New technological solutions will be important and will include the introduction of contactless systems from cashless payments to automatic control of doors or waste bins.

Currently, the development in the post COVID-19 period is difficult to predict. However, it can be assumed that the importance of teleworking will increase, and the population momentum will probably decrease after years of steady growth. Financing of public transport in the future is another challenge to be concerned. If the trend of greater individualization of transport persists, it will be difficult to finance public transport in its current form. Raising fare prices or a reduction in the range of transport services will rather have negative effects, deepen the decrease in the modal split of public transport and become a threat to sustainable mobility in the future.

The value of the \( \gamma_{\text{max}} \) coefficient is closely related to the seat configuration in the interior of the vehicle. A higher value of \( \gamma_{\text{max}} \) coefficient is achieved by a seating arrangement in a row (as in airplanes), than by a vis-a-vis seating arrangement.

From the previous chapters it can be concluded that it is advisable for operators and public transport organizers to use vehicles with a higher \( \gamma_{\text{max}} \) coefficient on capacity-exposed services. If there is a possibility to arrange vehicle circuits alternatively, then assign vehicles with the highest \( \gamma_{\text{max}} \) coefficient on the busiest routes. This will maintain the perceived safety of suburban transport at a lower cost, there is no need to strengthen train or add additional services.

At the same time, increasing the public funds invested to public transport is a real challenge for the sustainability of public transport in its current form. Taking into account safe distance among passengers, an increase in transport subsidies from public funds is almost inevitable, because in all cases mentioned in Fig. 1 sustainable public transport becomes much more dependent on public financial sources. Whether they will be used to rehabilitate fares or they will be used to co-finance capacity strengthening.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments and/or funding resources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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