# Post COVID-19 public transport accessibility changes: Case study of Ostrava and Hradec Králové regions

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***Abstract:*** *Public transport faced various challenges during the COVID-19 period due to a large ebb in passengers during the pandemic waves, COVID-related restrictions, employee sickness, and economic pressure to balance transport supply and demand. The study assesses the impact of the timetable changes on the accessibility between 2019 and 2021 in the hinterlands of two Czech cities – Hradec Králové and Ostrava. The research question is if there are considerable changes in public transport accessibility during this period which were influenced by the pandemic. Municipal accessibility is determined by the share of inaccessible municipalities, average travel time, population weighted average travel time, and average number of transfers under conditions suitable for seniors. Optimal trips to all municipalities are established with a local OpenTripPlanner server using all public urban and regional timetables including peak and off-peak hours, workdays, and non-working days. Unlike Ostrava, the pattern of accessibility of the Hradec Králové hinterland is influenced by the railway networks and bus transport corridors. Mean accessibility in 2021 slightly improved in the Hradec Králové region and slightly worsened in the Ostrava region. Some municipalities, however, showed grave decline. The most sensitive indicator is the share of inaccessible municipalities adapted for seniors' needs. The study confirms the importance of choosing a time of departure/arrival for the results of accessibility assessment. The most significant differences in the accessibility of municipalities are visible only for one of the selected departure times. Only a few municipalities show differences for both departure times, indicating variable effects on accessibility depending on the time of day-situation. The results did not confirm the anticipated general deterioration of public transport accessibility in the hinterlands of regional capitals during the pandemic period.*

***Keywords:*** *accessibility, public transport, temporal changes, seniors, OTP, GTFS*

## Introduction

Evaluation of accessibility for different regions and countries is a popular topic due to its important role in assessment of regional development, public transport policy, and social equity studies. The period of the COVID-19 pandemic brought massive changes in commuting patterns (e.g., Pozo et al. 2022). Ridership declined significantly during the pandemic due to the businesses closures, home offices, and fear amongst transit users of possible transmission (Liu et al. 2020, Cho and Park 2021). Lower transit demands were reflected in a shortage of transit services such as adapting timetables, switching to a holiday regime or limiting service coverage together with sanitization procedures to decrease the risk of infection (Tirachini and Cats 2020, DeWeese et al. 2020). The majority of regional transport studies have declared a substantial reduction of transport services during the COVID-19 pandemic. E.g., transit supply in US cities measured in vehicle revenue miles dropped by 10 % in 2020 compared to 2019 (Kar et al. 2021). The research questions are how important are transit changes in urban areas in this time period, and whether the offer of transit changed substantially.

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The expected changes of public transport (PT) accessibility might affect various groups of people in different ways. Some residents are more vulnerable to these changes due to their higher dependency on PT and lower possibility of car transport substitution (usually due to poor social conditions or student status), or due to their decreased ability to adapt to quick and dramatic changes. Seniors are among the most vulnerable groups. Elderly seniors, namely those 75+, generally decline to drive cars and become more dependent on other drivers (usually family members) or on public transit availability (Edwards et al. 2010, Chen et al. 2018, Joukl et al. 2022). Also, they are less adaptable to changes in timetables and changes of transit organisation. This may impact to their spatial mobility, independence and well-being (Lättman et al. 2019).

The paper is organised as follows: the theoretical background recounts approaches for accessibility assessment and evaluation of temporal changes of accessibility. The following chapter describes the selection of pilot areas, data sources, parameters of conducted accessibility analysis and explanation of indicators used for description of transit accessibility. Results contain the evaluation of accessibility status in 2019 to provide an overall evaluation of accessibility in the pilot areas and an understanding of the behaviour of applied indicators. The evaluation of changes between 2019 and 2021 follows. The findings are discussed in the context of the research questions.

## Theoretical background

Accessibility is a cornerstone of many studies including those on transport policy and planning, public service quality assessment, transit providers' behaviour (Lättman et al. 2016), and relationships between transport and social equity (Galster and Sharkey 2017, Bernard 2022). A general view specifies accessibility as the "potential of opportunities for interaction" (Hansen 1959, Merlin 2017). These opportunities must reflect a synergy of four basic components to fulfil the interactions (Geurs and van Eck JR 2001): land use, transport, temporal and individual benefits explained by the theory of rational choice or the theory of planned behaviour (Rasouli and Timmermans 2015). This more holistic approach is reflected in the definition of accessibility "the extent to which land-use and transport systems enable individuals to reach activities or destinations by means of a (combination of) transport mode(s)" (Geurs and van Wee 2004) where only the temporal aspect is not explicitly anchored.

Differences in the understanding of accessibility are reflected in a plethora of accessibility measures. Geurs and van Eck JR (2001) provided categorization of these approaches and distinguished five main groups of methods of accessibility measurement (Rosik et al. 2021): infrastructure-based accessibility measures, distance-based accessibility measures, isochronic-based accessibility measures (cumulative accessibility), person-based accessibility measures (e.g., Cheng et al. 2018) and potential-based accessibility measures.

Selection of suitable accessibility measures depends also on the transport mode (e.g., Liu and Zhu 2004). The main difference is between individual (car) accessibility and PT accessibility assessments. While car accessibility assessment is more continuous across time, PT accessibility is usually discontinuous. Thus, PT accessibility assessments highly depend on the time of departure, though, usually, only one time is assessed.

Accessibility assessment also differs in scale. Some scholars combine different scales into one study to provide a more complex view of accessibility, e.g., Olsson et al. (2016) evaluates three different spatial levels – within the municipality, to another municipality within the functional region, or to another region. Regional and countrywide studies usually neglect the first and last mile (walking to and from transit stops, or a parking lot), which are essential for accessibility studies within a city.

Share of PT accessibility measures utilise timetables. Timetables are obviously intended for passenger routing, but they can also serve to optimise PT operation such as by reducing idle times of buses and crews (e.g., Martin et al. 2008), analysing PT networks (Coffey et al. 2012, Farber and Fu 2017), structures of PT, and utilised for accessibility measures (Achuthan et al. 2010, Benenson et al. 2011, Salonen and Toivonen 2013, Petersen 2016, Farber and Fu 2017, Cheng et al. 2018, Kujala et al. 2018, Boisjoly et al. 2020). Utilization of timetables substantially increases with the wide dissemination of the General Transit Feed Specification (GTFS) data format, which has become an unofficial standard including for accessibility studies (Tao et al. 2014, El-Geneidy et al. 2016). Unfortunately, scholars usually do not combine regional with urban transport time schedules, despite the fact that urban transport usually covers the hinterland of a city, and, due to frequent connections, offers better transfers and sometimes also more favourable price.

For PT timetable analysis, the frequency of transit connections or departures/arrivals is one of the most popular indicators used as a proxy of interactions between origin and destination (Hůrský J. 1978, Grégr 1994, Seidenglanz 2007, Yigitcanlar et al. 2007, Michniak 2008, Cebollada 2009, Currie 2010, Květoň and Marada 2010, Květoň et al. 2012, Horňák et al. 2013). However, such measures do not reflect the differing capacity of connections and suitability of directions (Květoň et al. 2012, Bernard 2022).

PT timetables enable enumeration as well as other suitable indicators such as the number of transfers. High number of transfers can also obviously decrease the comfort of travel (which is a sensitive aspect for some groups of passengers) as well as increase waiting time which is often negatively perceived (Petříček et al. 2022).

The typical problem for PT accessibility is dependency on travel (departure/arrival) time. Accessibility rapidly changes over time according to departure time compared with conventional drive-time analysis for car travel (Martin et al. 2008).

Another problem is how to include walking (Ivan 2009, Djurhuus et al. 2016), mainly for transfers and a first/last mile solution (Bergmann et al. 2020, Stam et al. 2021, van Kuijk et al. 2022).

To address these issues, in this study, the regional and urban timetables are combined, several time windows are searched for trips, and an all-combinations approach was applied due to the anticipated strong mutual relationships in the hinterland of the regional capitals.

Changes in accessibility are frequently explored to understand changes in PT offers, commuting and spatial interactions. Usually, similar measures as for the accessibility status are used in change analyses. It is, however, necessary to distinguish if the observed differences are driven by land use changes, by transport offers, or by demand changes. The transport component of accessibility can be evaluated by simple indicators such as changes of connection or departure frequency (e.g. Marada et al. 2010, Květoň et al. 2012, Horňák et al.2013).

Changes of accessibility in the period of COVID-19 had not been studied in Czechia. The pandemic brought tremendous impacts to the everyday life of society, including the job market and economy (Dzúrová and Jarolímek 2020). Permanent changes in PT accessibility will affect mainly vulnerable group of users such as seniors.

## Methodology

The accessibility analysis is conducted in two Czech regions distinguished by geographical position, historical development, population density, urbanization and industrial level.

Study areas were established with a circular selection from the regional capitals of Ostrava and Hradec Králové to the distance of 30 km. This represents the broader hinterland of regional capitals. The Ostrava region (OVR) contains 199 municipalities (population 1,088,000), and the area is not perfectly circular due to the proximity of the Polish border and the Olomouc

region border which lacks available data. The core of the OVR represents an industrial and continuously strong urbanized area between Ostrava and Karviná. Except for Ostrava (population 290,000), many other important towns with a population in the tens of thousands are distributed throughout the region (i.e. Opava, Nový Jičín, Frýdek-Místek, Havířov, Český Těšín, Třinec), as well as important employers (e.g., Hyundai in Nošovice) which supports development of transport connections and capacities. The OVR is peripherally located within Czechia, but is well linked via transport to Slovakia and Poland (fig. 1).

The Hradec Králové region (HKR) is evidently circular and includes 405 municipalities (population 567,000) from both the Kralovéhradecký and Pardubický regions. There are twice as many municipalities in the HKR as in the OVR, documenting much smaller municipalities around Hradec Králové (HK) than around Ostrava (OV). Hradec Králové (population 100,000) is a typical old central European city, surrounded by agricultural country with small settlements. More important settlements are situated close to the perimeter of this region. Pardubice, another regional capital with a similar population, is situated just 15 km to the south. The region is also well connected to Prague and its agglomeration.

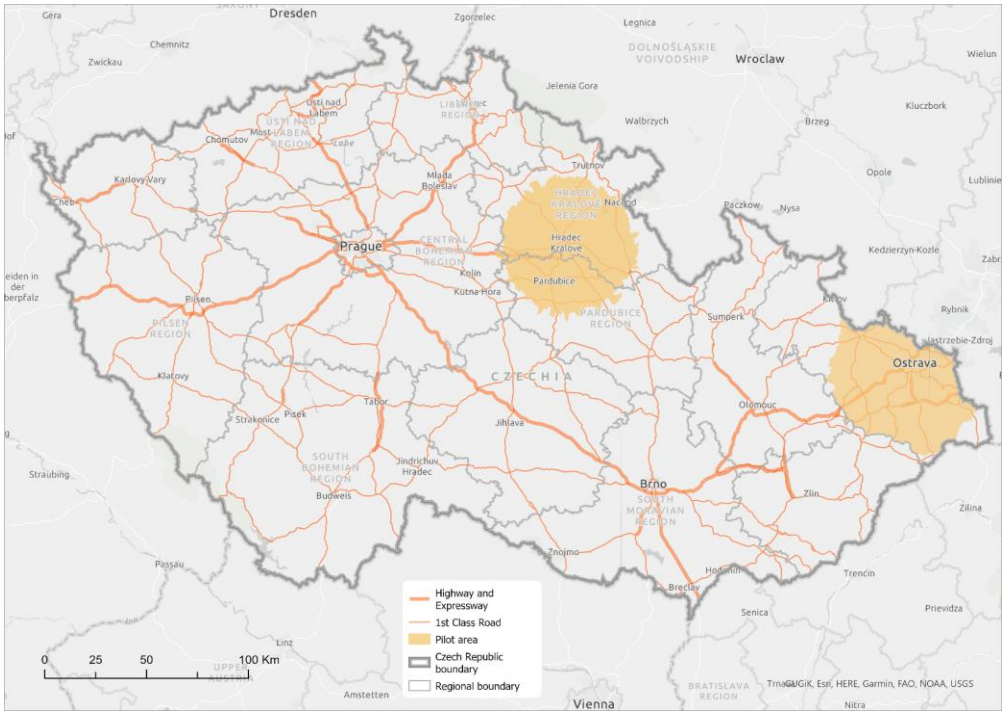


***Fig. 1.*** *Pilot areas – the Ostrava region and the Hradec Králové region*

Municipalities are represented by a significant reference points specified by Czech Statistical Office (CZSO 2023) for each municipality in an urban centre.

Our study is focused only on the transport component because we are interested in changes to PT transport services in the pandemic period and no substantial changes of land use components are assumed in these two-years, it being a relatively short time period.

Accessibility of each municipality is assessed by an evaluation of PT trips to all other municipalities. Due to the intention to analyse only the transport component, no specific destinations, such as supermarkets, doctors, etc., were set up. Using a specific destination may be more

representative of the real needs of seniors, however, such settings bring additional uncertainty to the evaluation.

GTFS data was bought from CHAPS Brno Ltd. which administers electronic timetables in Czechia. Working days are represented by 8. 10. 2019 and 5. 10. 2021 (Tuesdays), and weekends by 12. 10. 2019, and 9. 10. 2021 (Saturdays). The first date corresponds to usual regular pre-COVID-19 schedules, the second date is intended to capture changes following the one and a half year duration of pandemic restrictions. Data covers both regions and contains schedules of all providers integrated in regional PT coordinators (ODIS, IREDO: trains and buses) as well as all urban transport providers in the region, i.e., cities and towns:

- For the Hradec Králové region: Hradec Králové, Chrudim, Kostelec nad Orlicí, Náchod, Pardubice, Přelouč, Rychnov nad Kněžnou, Týniště nad Orlicí.
- For the Ostrava region: Ostrava, Český Těšín, Frýdek-Místek, Havířov, Karviná, Nový Jičín, Opava, Orlová, Studénka, Třinec.

Searching of PT connections was conducted using OTP server version 1.5.0. OTP is an open-source platform written in Java for multimodal and multi-agency trip planning (Project Leadership Committee 2022). The tool is designed to use OpenStreetMap and GTFS, released by transit agencies. The tool is based on two main modules – the Graph Builder module and the Routing module (Young 2021). The Graph Builder uses the OpenStreetMap data to generate the street networks for modelling pedestrian, bicycle, and automobile routes, and the GTFS data to generate the transit networks. It then combines the two types of networks into one multimodal transport network, stored in the so-called graph.obj file (Yin et al. 2015). The Routing module uses the built Graph as an input and, together with user specified parameters, performs analysis such as shortest path or travel time isochrones. The graph.obj data model is configured using three main JSON configuration files: otp-config.json, build-config.json, and router-config.json (Project Leadership Committee 2022). The parameter *maxTransferDistance* was set to 1000 m in order to eliminate longer walking distances between transfers. The parameter *platformEntriesLinking* was set to true in order to link unconnected entries to public transport platforms.

Both public transit and walking modes are included. The gait speed was set to 2.52 km/h according to recommendations for the over 65 population (Studenski 2011, Weber 2016, Gaglione et al. 2019). The search was repeated for two times per day – departures at 8 AM and 2 PM. These settings reflect the needs and preferences of the elderly where early departures are often unsuitable, walking speed is limited, and walking distance for transfers should be minimal (Webber et al. 2010, Vidovićová et al. 2013). After 8 AM is a usual time for shopping, doctor's visits etc., while 2 PM reflects some after lunch activities such as visits, shopping, etc. From the traffic point of view, 8 AM represents a peak hour, while 2 PM represents an off-peak hour, similar to Kar et al. (2022).

The number of searched trips for one time slot is 39,402 for the Ostrava region, and 163,620 for the Hradec Králové region.

The parameters of the proposed transit connection between the origin and the destination are recorded, namely, transit time, waiting time, and walking time for each trip segment. Next, secondary parameters are calculated, i.e., number of transfers, the net walking time (*WalkTimeT*) and net travel duration (*Duration*, eq. 1), and a binary indicator of inaccessibility.

*WalkTimeT* refers to the total walking time for transfers. This excludes walking time from the origin to the transit stop and walking time from a stop to destination. Thus, walking time

from the centroid of the municipality to a transit stop is omitted due to large differences depending on addresses within the municipality.

$$Duration = Route\_Total\_TransitTime + Route\_Total\_WaitingTime + WalkTimeT \quad (1)$$

Inaccessible municipalities are those where no transit connection is found, or the travel duration is longer than two hours. The duration limit was set up according to data analysis and previous experiences with searching PT connections for the Ministry of Labour and Social Affairs. The calculation of other characteristics is not constrained by threshold values. The share of inaccessible municipalities from all municipalities in the region is calculated as a ratio of the number of inaccessible municipalities to the total number of municipalities -1.

Further, parameters for each municipality are aggregated providing average travel time (*avgTime*, eq. 2), weighted average travel time which includes weighting by population (census 2011) (*WavgTime*, eq. 3), and average transfers which represents, fittingly, the average number of transfers (*avgTransfer*, eq. 4).

The following indicators were enumerated and discussed: share of non-accessible municipalities (%), average transport time, average number of transfers, and weighted average transport time.

$$avgTime = \frac{\sum_i duration_i}{N} \quad (2)$$

$$WavgTime = \frac{\sum_i (duration_i * pop_i)}{\sum_i pop_i} \quad (3)$$

$$avgTransfer = \frac{\sum_i transfers_i}{N} \quad (4)$$

where $N$ is the number of available destinations (municipalities), $pop_i$ is the population in the municipality $i$, and $transfers_i$ is the number of transfers on the route to the municipality $i$.

Temporal differences are evaluated by an index of change (e.g., Květoň et al. 2012).

## Results

### Accessibility status in 2019

Accessibility in the regions is evaluated using four selected indicators: share of inaccessible municipalities, average transport time, average number of transfers, and weighted average transport time for each departure time. To illustrate the explored accessibility status, results representing the best accessibility conditions (Tue, 2 PM, 2019) follow.

The average share of inaccessible municipalities in HKR (fig. 2 left) is 46%. The best accessibility (less than 15% of inaccessible municipalities) can be found close to HK and good accessibility extends radially towards the north-west, north, east and south due to good train and bus connections. A similar low share of inaccessible municipalities can be found in some isolated areas (e.g., around Chlumec which is well served by train connections to HK).

The average share of inaccessible municipalities in the OVR (fig. 2 right) is 36%. The relatively well accessible area is much larger than in the HKR and covers the majority of the region. The pattern of accessibility is not apparently shaped by railway networks or transport corridors. In the southern area (Nový Jičín – Frýdek-Místek districts), bus transport plays a more important role than regional railways. Contrary to the HKR, even small municipalities are well served by bus not only towards the regional capital, but also directly to other important towns, usually district capitals.

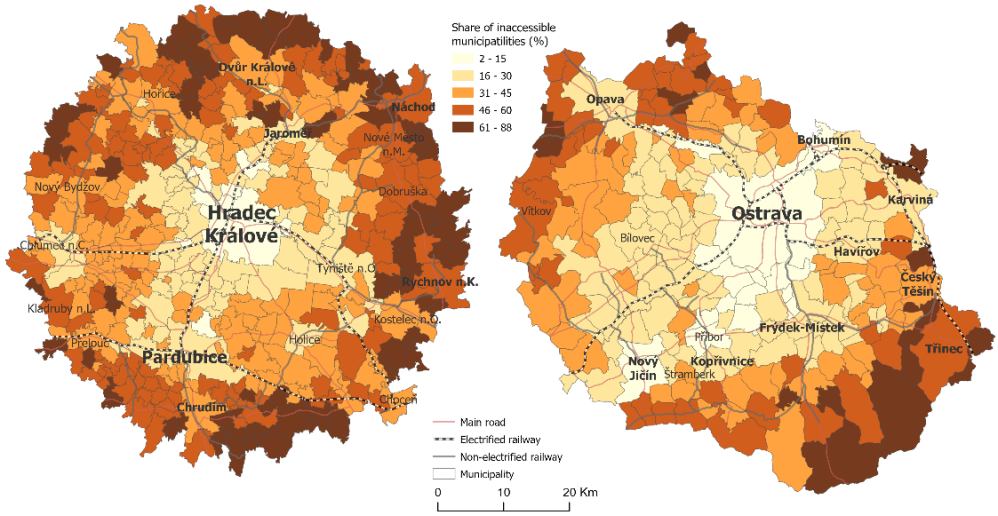


***Fig. 2.*** *Share of inaccessible municipalities % (Tue 8. 10. 2019 14:00, HKR left, OVR right)*

The influence of three electrified train corridors (to Týniště, Pardubice and Jaroměř) is well recognizable in a pattern of *average travel time* in the HKR (fig. 3 left). Interestingly, the municipalities along the main railway corridor to Chlumec and Prague (westward from HK) do not show a lower average time, which indicates a predominance of express trains operating in this corridor and poor connectivity from Chlumec and HK to other areas within the region. Oppositely, in the OVR (fig. 3 right) the best conditions are found only in Ostrava and almost no relation with railways is observed due to the increased role of bus connections.

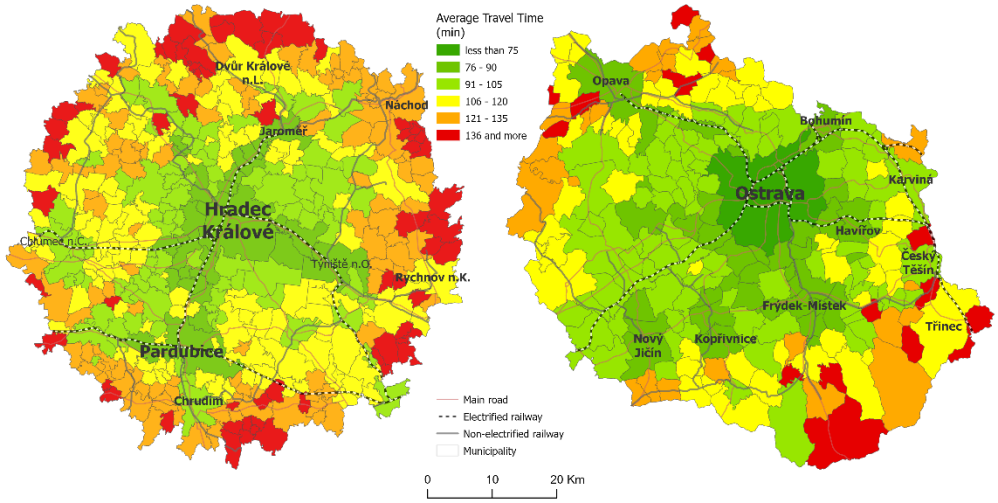


***Fig. 3.*** *Average travel time to all municipalities*
*(Tue 8. 10. 2019 14:00; HKR left, OVR right)*

The *weighted average travel time* in both the HKR and the OVR (fig. 4) confirms a central role of regional capitals for their regions. The observed pattern demonstrates the population dominance of the central city over its surroundings and is further emphasized by the method of circular selection of the surrounding villages.

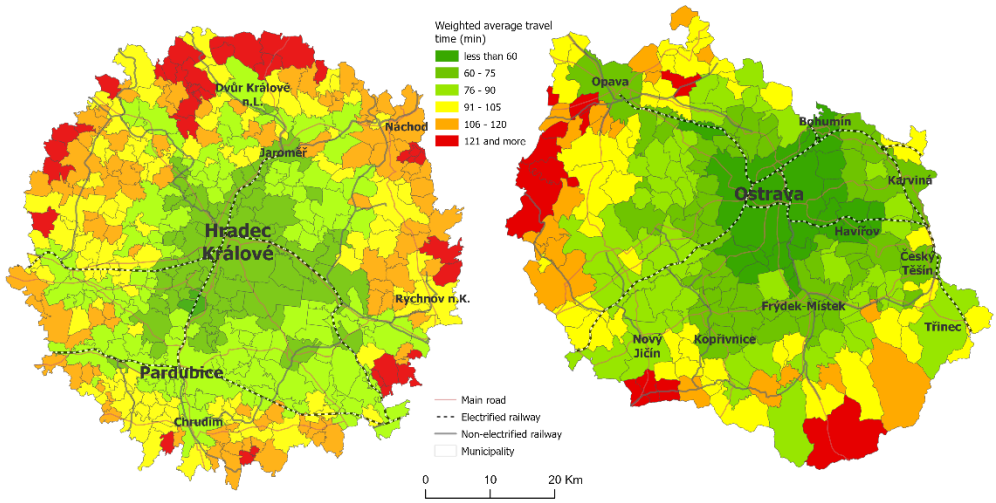


***Fig. 4.*** *Weighted average travel time to all municipalities (Tue 8.10.2019 14:00; HKR left, OVR right)*

Using the *average number of transfers***,** more useful outputs were obtained.

In the HKR (fig. 5 left), besides the three previously identified main corridors, new corridors with fewer transfers are indicated. They are linked with long-distance bus connections (i.e., Hořice-Jičín-Liberec, the Giant Mts. through Dvůr Králové, and the Orlické Mts. through Dobruška). The lower number of transfers also shows important transport hubs close to the perimeter of the region (Náchod, Rychnov etc.).

A different pattern can be seen in the OVR (fig. 5 right). Corridors are almost absent. Instead, in the eastern and south-eastern parts we can see an oscillation of transfer values due to a link of smaller municipalities to larger neighbours which indicates a hierarchy in the transport network.

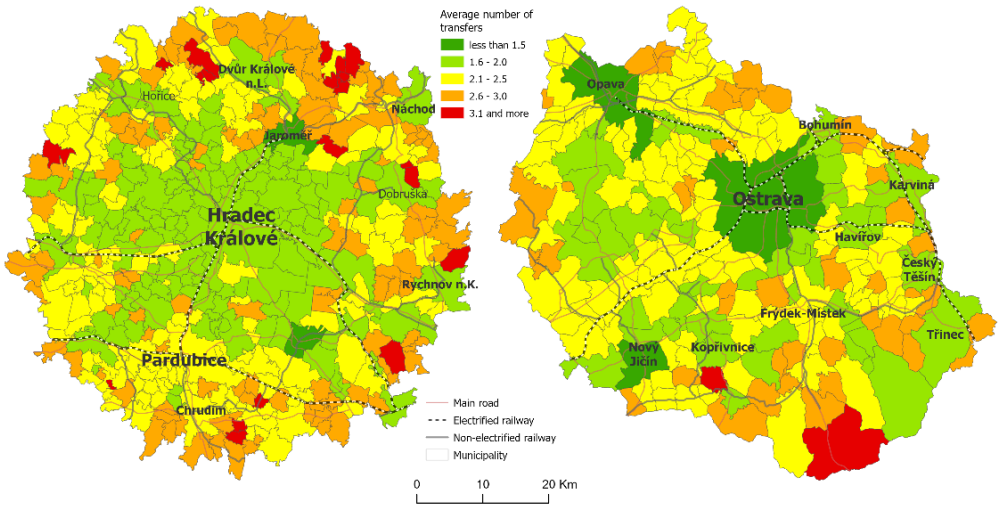


***Fig. 5.*** *Average number of transfers in 2019 (Tue 8. 10. 2019 14:00; HKR left, OVR right)*

All four indicators provide useful results, therefore we used them to evaluate changes in accessibility. The most promising indicators for vulnerable groups of passengers (such as seniors) are the average share of inaccessible municipalities (NARATE) and the average number of transfers (AVGTRANSFERS).

**Changes in accessibility between 2019 and 2021**

Accessibility changes are evaluated with bivariate maps where the middle part represents unimportant changes of the index value in the range of 90-110%; the low class contains values below 90% and the high class for values above 110%. The horizontal axis is dedicated to departures at 2 PM, and the vertical axis to departures at 8 AM. The schema was set up the way to create a positive corner (both important positive changes or a combination of one important positive and one unimportant change) (green tones), and a negative corner, correspondingly.

The bivariate maps show how many municipalities experience important changes in accessibility between 2019 and 2021 on typical workdays (Tue). Differences on weekends (Sat) are similar (tab. 1) however due to limited space, they are not present in this paper.

***Tab. 1.*** *Average changes (in %) of indicators of accessibility for HKR and OVR 2019-2021*

| | HKR | | | | OVR | | | |
|---|---|---|---|---|---|---|---|---|
| | Tue 2 PM | Tue 8 AM | Sat 2 PM | Sat 8 AM | Tue 2 PM | Tue 8 AM | Sat 2 PM | Sat 8 AM |
| NARATE | 99.47 | 98.19 | 98.33 | 98.61 | 112.80 | 100.69 | 104.98 | 102.43 |
| AVGTIME | 99.05 | 98.23 | 98.63 | 97.05 | 102.84 | 100.40 | 100.98 | 102.43 |
| AVGTRANSFER | 99.98 | 100.08 | 101.20 | 100.00 | 100.14 | 100.88 | 104.41 | 104.17 |
| WAVGTIME | 99.02 | 98.54 | 97.47 | 97.36 | 101.65 | 101.04 | 103.53 | 103.39 |

The major differences appear in *the number or share of inaccessible municipalities.* Important changes at both times are found in 5% and 10% of municipalities in the HKR and the OVR, respectively. However, important changes in at least one time are recognised in 53% and 79% of municipalities in the HKR and the OVR, respectively, showing that the majority of municipalities face some important change.

In HKR, more positive changes in inaccessibility can be seen (fig. 6 left). Decreasing of accessibility is usually faced by individual municipalities, while improvements are observed in larger areas mainly in the south-east direction from HK (towards Holice and surroundings), north-east (e.g., Nové Město and Dobruška) and villages around Chlumec.

Contrarily, the share of inaccessible municipalities mainly increased over the two years in the OVR. The increase for 2 PM departures is more considerable than for 8 AM departures. Higher inaccessibility at both times is found in Ostrava, Frýdek-Místek (160%), villages south of Frýdek-Místek (some more than 200%), Novojičínsko (Nový Jičín 170%), and villages south or south-east from Opava. Many municipalities which show important changes of accessibility for only one departure time are often located outside main transport corridors and served by local buses. Improved accessibility conditions are more sparsely distributed across the whole region. Among other municipalities, an improvement in Mošnov reflects the support of the regional government in adding further airport transport connections.

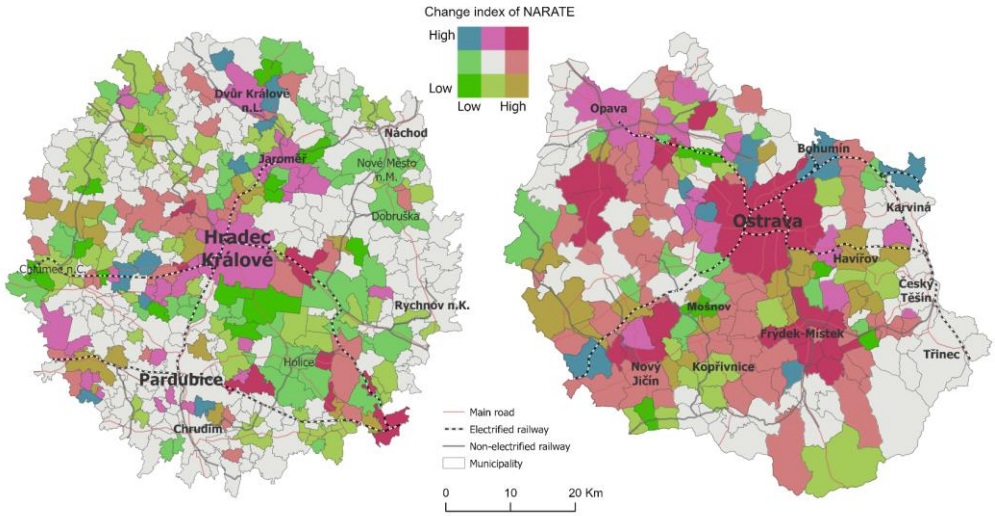


***Fig. 6.*** *Change index of inaccessible municipalities for HKR (left) and OVR (right) (Tue, X: 2 PM, Y: 8 AM, 2021/2019)*

The differences in inaccessibility between regions are confirmed by histograms (fig. 7). Distribution of index values in HKR is almost symmetrical and a majority of values are within ±25%. The distribution of changes in the OVR is shifted toward higher values (18 municipalities show an index of change higher than 150%).

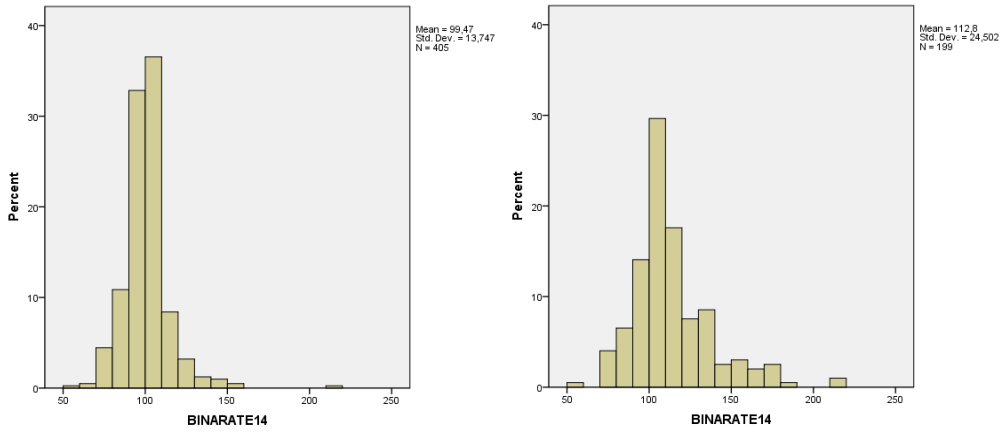


***Fig. 7.*** *Change indices of inaccessible municipalities (Tue, 2 PM, 2021/2019) for HKR (left) and OVR (right)*

Much fewer changes are portrayed in the *average travel time* (fig. 8). With one exception, no municipality faces important changes for both departure times, and only 16% and 17% see substantial changes in the HKR and the OVR (resp.) at one time.

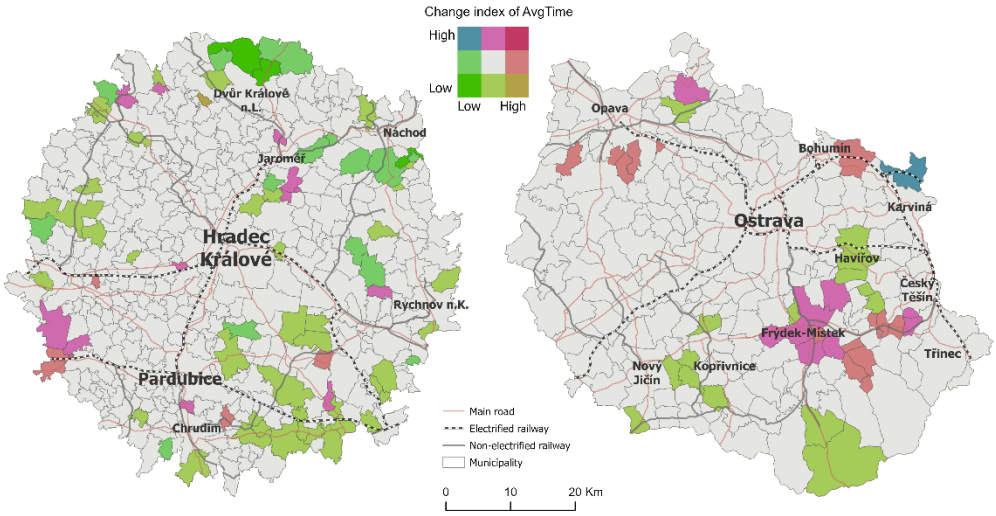


***Fig. 8.*** *Change index of AvgTime for HKR (left) and OVR (right) (Tue, X: 2 PM, Y: 8 AM, 2021/2019)*

Similar results with small changes were found for *weighted average travel time*.

Changes in the number of *transfers* are more recognizable. Only 1-2% municipalities face the same sizable changes in the average number of transfers for both departure times, but a meaningful change is seen at one departure time in approximately one third of municipalities (27% in the HKR and 31% in the OVR).

In the HKR (fig. 9 left), the change of transfer conditions is more diverse, driven mainly by changes in local transport connections. E.g., in one village (Studnice, 111%) the only nearby train stop was taken out of service and bus connections cause an increase of transfers. Worsened conditions are found in several villages in northern, western and and central locations. A decreasing number of transfers is discovered mainly close to the western and southern borders of the study area.

In the OVR (fig. 9 right), positive changes to a number of transfers are in balance with those with negative changes. The geographical distribution in the OVR shows an improved core, while the periphery declined. While Ostrava and municipalities toward Havířov improve, an increased number of transfers are found in Opava and its surroundings, Karviná, Český Těšín, and Bohumín. Cancelled buses to Frýdek-Místek are reflected in the increased number of transfers in Janovice at 8 AM.

Altogether, the PT accessibility situation in the HKR in 2021 is almost the same or better in the majority of municipalities, contrary to the OVR where negative changes are frequent and decrease the originally superior PT conditions in this region. This is confirmed by the share of inaccessible municipalities as well as by the number of transfers. Both these indicators address sensitive transport features for seniors. Some settlements especially (and surprisingly even large towns) in the OVR felt a significant drop in services. Of course, it is unclear if this is the result of the pandemic or if this change corresponds to anticipated temporal changes towards reduced public transport services. Contrarily, average travel time is practically unchanged.

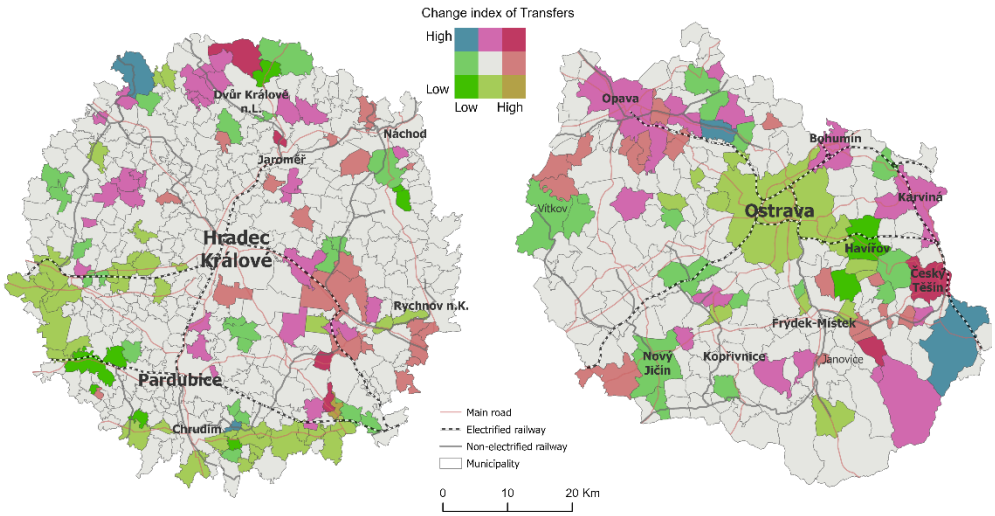


***Fig. 9.*** *Change index of transfers for HKR (left) and OVR (right) (Tue, X: 2 PM, Y: 8 AM, 2021/2019)*

## Discussion

Simple indicators such as number of connections/departures are easy to use due to their transparency and ease of collection, but they do not provide any details about the journey or comfort of travel (transfers, waiting times, etc.). Application of PT timetables enables the building of realistic trips and the assessment of many parameters. However, searching of possible transit connections and selection of the optimal one for reading required parameters (travel time, waiting time, walking distance, barriers, etc.) is demanding for several reasons: computational demandingness (Benenson et al. 2017), dependency of the result on the parameter settings, and individual preferences. This study also faced a large volume of calculations (1,624,176 searched trips) and testing of appropriate settings for optimal route searching. These obstacles limit the study assessment of only two times of day on four days total, and accessibility calculation for only an urban reference point, similar to the centroids used, e.g., by Rosik et al. (2021).

The combined search for walking and public transport was implemented according to the recommendation of Benenson et al. (2017) who underline that disregarding the walk time as well as the exact location of the transit stop may result in over- or underestimation of accessibility.

Accessibility assessment of Czechia often detects better accessibility in the Moravian and Silesian municipalities than in the Czech municipalities (Ivan 2013, Bernard 2022). Our finding confirms a higher level of accessibility in the Ostrava region than in the Hradec Králové region. Over the two years, the difference becomes smaller due to accessibility improvement in the HKR, but the difference is still considerable. The reason for this advantage in the OVR lies primarily in the larger average size of the municipality linked with a higher population and, thus, it exhibits better public transport services. The share of municipalities with less than 3,000 inhabitants is 77% in the OVR and 94% in the HKR.

Scholars also often discuss the role of transport corridors in improvement of local accessibility. Marada and Květoň (2010) stated that the population size, overall character of urbanisation, and situation of the settlement in the transport network influences the number of transport connections. This idea has been previously proven, e.g., in the region of Jesenicko (Květoň 2006). The role of transport corridors in accessibility is discussed also in other countries, e.g., Martínez Sánchez-Mateos (2014) document their contribution to build a polycentric structure

for the Madrid region. The important role of public transport corridors (related to long-distance bus connections and express trains) was confirmed in the HKR. It seems the electrified railway corridors to Pardubice, Týniště and Jaroměř positively influence all the investigated accessibility indicators. The one exception is the railway corridor to Chlumec and Prague, likely due to a lower frequency of passenger trains. The influence of rapid long-distance bus connections is visible only in a reduction of average number of transfers in municipalities situated along these routes. Contrarily, in the OVR, the role of corridors is less imprinted into spatial accessibility patterns. This can be explained by the weaker role of transit through the OVR and the multi-nodal character of the transport network.

Changes of accessibility between 2019 and 2021 in the examined regions are assessed differentlyaccording to the indicator employed and to the departure time. Using strict conditions (travel time max. 2 hours), the ratio of inaccessible municipalities at one of the departure times changed in the majority of municipalities between these two years (OVR in almost 80% of municipalities, and HKR in 53%). The number of municipalities with considerable changes for both times is not high (5-10%). However, in the case of the OVR, it includes not only small municipalities but also important towns where changes are quite high. Ostrava shows a notable increase of inaccessible municipalities of 150% at 2 PM and 138% at 8 AM, but it is calculated from the low base value (increasing from 2% to 3%). A different situation is found in Frýdek-Místek which experienced an actual high increase 172% and 144%, respectively (e.g., from 18% to 31% of inaccessible municipalities at 2 PM). Contrarily, Hradec Králové reached only 100% and 112%, and Pardubice 95% and 92%, respectively. The positive and negative changes compensate for one another and, therefore, the mean calculation for the whole region does not show any significant differences. The average indices of changes vary between only 97% and 101% for all indicators in the HKR, and between 100% and 113% in the OVR. Differences in other indicators are much smaller and without substantial differences between regions. Substantial changes in the average travel time are about 16% in the HKR and the OVR for one departure time, and in the average number of transfers for about one third of municipalities.

The change of average number of transfers provides challenging results. Some of the important changes are directly influenced by changes of PT services such as cancellation of all urban transport connections between Frýdek-Místek and Janovice or closure of a train stop. However, major changes are related to the reduction of some connections.

A clear spatial reasoning for all discovered changes was not found. The majority of the notable changes are pronounced only at one time of departure. In the HKR, important positive changes reflected in more indicators were found in Nové Město and Chlumec, and negative ones in Přelouč. In the OVR, the most negative changes are found in Frýdek-Místek and its surroundings.

The study also confirms the important role of setting time of departure/arrival for searching PT connections on the final accessibility assessment (e.g., Martin et al. 2008, Horák et al. 2015).

Several limitations of this study can be seen. Usage of PT timetables for evaluation of transit offers leads to overly optimistic results. Existing literature on transit accessibility is based on oversimplified assumptions that transit services operate at deterministic speeds using predetermined timetables (Cheng et al. 2018).

In the case of PT, a more detailed analysis than that at the level of municipalities should be used due to discontinuous estimates when evaluating two adjacent zones and the essential influence of walking on the first/last mile (to and from transit stops) on the accessibility assessment (Benenson et al. 2017). Our study is focused on the regional level and changes of public transport offers during the COVID-19 pandemic period. A more detailed study would require setting concrete destinations, include walking, and may overshadow changes in timetables.

Another limitation is that no return trip was considered. Such evaluation needs the setting of appropriate scenarios, and the settings might impact the results of the accessibility study in unexpected ways and complicate the assessment of the transit-only component.

## Conclusions

The study employed four indicators of accessibility: share of inaccessible municipalities, average transport time, weighted average transport time and average number of transfers. The results show that the most sensitive indicator is the share of inaccessible municipalities limited by maximal accepted travel time (for seniors, two hours), the maximal walking distance to PT stops (for seniors, 1 km) and maximal number of transfers. This indicator usually provides the biggest differences between daily departure times, as well as between working/non-working days. In this study, we used a departure after 8 AM and after 2 PM according to the elderly's preferences. The indicator is the most variable at 2 PM; 8 AM provides more stable results. The other indicators were not limited by the maximal duration to obtain comparable results across the regions. They are less sensitive, and differences are much smaller. The average number of transfers is not recommended as the main indicator, but as a complement to other indicators because it is highly influenced by changes in routes.

Changes of accessibility between 2019 and 2021 were found mainly in the ratio of inaccessible municipalities under conditions suitable for seniors. The mean accessibility for the whole region was slightly improved in 2021 in the HKR, and slightly worsened in the OVR. In several major towns, the worsening is quite high, such as in Frýdek-Místek (about 160%) and Nový Jičín (170%). However, the most significant differences in the accessibility of municipalities are visible only for one of the selected departure times. Only a few municipalities show differences for both departure times, indicating variable effects on accessibility depending on the time of day-situation.

We cannot confirm the anticipated general deterioration of PT accessibility during the pandemic period. Documented changes of accessibility, especially the local negative changes for some important towns such as Frýdek-Místek, indicates the local cutting of services. Still, it is difficult to prove if these recognised changes are caused by the pandemic or if they reflect more common trends or even temporal variation in services. Nevertheless, the character of these changes has a potential to negatively influence the local spatial mobility of seniors.

The study confirms the important role of setting time of departure/arrival when searching PT connections to the resulting accessibility assessment.

The pattern of accessibility in the HKR is influenced by railway networks and bus transport corridors. In the OVR, such influence is not visible. Electrified railway corridors with fast and frequent transport especially improve the local accessibility. The proximity of train corridors is imprinted in the results of all indicators; however, bus corridors only influence the number of transfers.

An increase of average travel time is often connected with a decrease in transfers. Longer connections with more stops but fewer transfers are more suitable for seniors.

The findings contribute to improving the understanding of accessibility measures and their behaviour, as well as the discovery of locations where the level of public transport services is not satisfactory.

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