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Urban transportation resilience in response to COVID-19: case of Polish cities

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Abstract. COVID-19 was a unique event that globally influenced socio-economic systems in many dimensions. One of them was transportation and mobility patterns, especially during lockdown introduced for the sake of public health. Although restrictions were rather universal within each country, cities were characterized by different mobility patterns. The aim of this study was to analyse changes in mobility patterns in response to COVID-19 and define similarities in urban transportation resilience. For this purpose COVID-19 – Community Mobility Reports were used. Results show that work-related mobility was the most influenced in the long term. Bigger cities needed more time to revert to pre-pandemic level. During the first month of lockdown mobility associated with workplaces as well as grocery and pharmacy presented similar decrease. The biggest decrease characterises mobility connected with retail and recreation. Although it met pre-pandemic patterns around the summer 2020, it required almost one more year to reduce fluctuations.

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1. Introduction

The predictability of urban systems is related to its resilience to external factors that may disturb its typical functioning. From a psychological perspective, resilience is defined as the ability to adapt positively to life conditions, but it covers also the ability to recover from adversity and trauma and the process of successfully adjusting to adversity, trauma, tragedy, threats, or even large sources of threat (Barthélemy et al., 2021). In case of cities, researchers define urban resilience as the ability to maintain or quickly return to desired functions in the face of a disturbance, to adapt to change, and to rapidly transform systems that limit current or future adaptive capacity (Kapucu et al., 2021). One of urban systems which can be more or less resilient to disturbing factors is a transportation system. It is one of the basic elements of the proper functioning of the city and according to the concept of urban metabolism it works like a bloodstream (Musango et al., 2017). Therefore, proper functioning of the city is strictly related to the operating transport system.

There are many factors that can affect urban systems disorders. However, since the turn of 2019 and 2020, one of the main variables observed globally was COVID-19 pandemic. It was related to the change in the functioning of societies in many aspects of everyday life. It was due to the restrictions on the functioning of communities, which sometimes also took the form of a lockdown (Gafter et al., 2022). As a results it influenced many urban systems connected with water (Kazak et al., 2021) and energy demand (Wen et al., 2022), clothing supply chains (Milewska, 2022), food security (Ouoba & Sawadogo, 2022), real estate market (Bełej, 2021; Trojanek et al., 2021) and many others. It was no different in the case of the transport systems in cities. During the COVID-19 peak, transportation authorities around the world reported a 95% drop in number of users (Naveen & Gurtoo, 2022). As Krusche et al. highlighted the inability to travel freely leads to a variety of negative consequences, including social isolation and poor physical and mental health (Krusche et al., 2022). Therefore, a need to adapt urban transport planning to COVID-19 is commonly raised by the scientific community (Simić et al., 2022). Bagdatli and Ipek noticed that it is critical to study the shifting user needs in all segments of society as a result of COVID-19 and to identify successful post-pandemic transportation policy (Bagdatli & Ipek, 2022). At the same time, Shortall et al. stress that it is very difficult to provide ready-made policy recommendations on which measures should be implemented, considering characteristics of a city, region or country as well as external factors like state of virus (this or any other in the future) spread (Shortall et al., 2022). However, Guo et al. presented on the analysed examples how combination of COVID-19 and policies influence spatial and temporal distribution characteristics of traffic (Guo et al., 2022). That is why understanding the dynamics of urban transportation resilience is needed to understand how quickly which transportation needs will have to be fulfilled.

There are different aspects of transportation systems that were analysed by researchers. One of the main topics carried out by research teams worldwide is connected with public transport. That is associated mostly to the fact that public transport as a collective mode is a potential place of transmission of the disease. Fridrisek and Janos analysed in their study safe distances between passengers for public transport planning in order to understand how many and how big vehicles should operate on each route to offer safe conditions to passengers (Fridrisek & Janos, 2022). The attitude of public authorities in that aspect is very important because, as Chen et al. analysed, there is an impact of the COVID-19 remedial measures on passenger decisions (Chen et al., 2022). Maintaining transportation systems which can be insecure from the perspective of passengers may lead to shifting from public transport modes to individual, as Mogaji observed in his research (Mogaji, 2022). Therefore, many researchers focused on concerns (Beck et al., 2021), sense of safety (Kłos-Adamkiewicz & Gutowski, 2022), perception of risk (Zavareh et al., 2022), preferences (Javid et al., 2021) and change of behaviour of passengers (Aydin et al., 2022) when it comes to public transport. Less common were studies on other modes of transport where vehicles are shared, like public bikes (Bouhouras et al., 2022), car sharing (Alonso-Almeida, 2022), trains or aircrafts (Yang & Chen, 2022). The most rare are studies which analyse urban mobility as a whole, without distinguishing into specific modes of transport (Rahman et al., 2021; Tarkowski et al., 2020). Despite many studies on changes in transport due to COVID-19, most of them analyse individual urban case studies (Javid et al., 2021; Przybylowski et al., 2021; Turek et al., 2021; Aydin et al., 2022; Bagdatli & Ipek, 2022; Simić et al., 2022), which due to different methodological approaches does not allow easy comparisons of situation between different cities. Comparisons between cities or regions are less common (Jaekel & Muley, 2022).

On the basis of the literature review, it can be concluded that the gap in the state of knowledge lies in the lack of comparative research looking for similar behavioural reactions to COVID-19 in different cities. Therefore, the aim of this research was to analyse changes in mobility patterns in response to COVID-19 and define similarities in urban transportation resilience between different cities. The study investigated socio-economic and geographical relations between types of cities and the way their transportation systems returned to previous or stabilized on a new level after facing a disturbance caused by COVID-19. This paper has five sections. Section 1 introduces the field of the study. The data used in the research and methods are described in section 2. Section 3 presents results of changes in mobility patterns divided by purposes of mobility for 65 analysed cities in Central European conditions (all located in Poland). Finally, discussion of the obtained results is presented in section 4 and concluding remarks on the types of urban transport resilience are presented in section 5.

2. Research materials and methods

The dataset used in this research comes from COVID-19 Community Mobility Reports (CMR) supported by Google (*COVID-19 Community Mobility Report*, n.d.). This dataset was verified as a reliable data source and used in other studies (Tarkowski et al., 2020; Rahman et al., 2021; Fridrisek & Janos, 2022). The CMR distinguishes six types of mobility. These categories are: retail and recreation (mobility trends for places such as restaurants, cafés, shopping centres, theme parks, museums, libraries and cinemas), grocery and pharmacy (mobility trends for places such as supermarkets, food warehouses, farmers markets, specialty food shops and pharmacies), parks (mobility trends for places like national parks, public beaches, marinas, dog parks, plazas and public gardens), public transport (mobility trends for places that are public transport hubs, such as underground, bus and train stations), workplaces (mobility trends for places of work) and residential (mobility trends for places of residence). For the purpose of this study two categories were excluded, namely parks and public transport. Due to implemented restrictions, mobility covered by these two categories was strongly influenced by central decisions, not by individual patterns of mobility, therefore, it does not present behaviour of citizens properly. Mobility monitored by four other categories was more related to basic needs, therefore, they reflect mobility patterns of society more precisely.

Mobility data was compared with social, economic and spatial characteristics of cities in order to search for relations between urban transportation resilience and types of cities. Based on databases of the national statistical office (Statistics Poland) following variables were obtained to describe cities: area, population, distance from regional city, total income, total expenses, share of a rural sector in local economy, share of an industrial sector in local economy, share of a service sector in local economy.

In order to analyse urban transportation resilience for each variable, the percentage change in mobility relative to the baseline period before the introduction of Covid-related restrictions (15.02 - 14.03.2020) was analysed. Then a time to return to normality was analysed, defined as the return to baseline (zero percent change in mobility rate) after the fluctuation caused by the restrictions. Weekly averages were determined for each variable. When the weekly average during the pandemic returned to zero, a return to normality was considered to have occurred. The duration of the return to normality in weeks was determined and further analysed. All cities were classified based on the time of return to a baseline in four purposes of mobility. Based on dendrogram for hierarchised clustering (Euclidean distance and Ward joining method) and analysis of variance a number of clusters were determined. Final classification was conducted by k-means clustering method.

3. Research results

3.1. Categories of urban transportation resilience

Urban mobility patterns varied significantly between different purposes of mobility. Compared to the baseline before COVID-19, the period necessary to stabilize mobility again was noticeably shorter in case of grocery and pharmacy (between 7 and 26 weeks) as well as retail and recreation (between 9 and 77 weeks) purposes. The most significant differences were observed in case of mobility caused by workplaces which varied from 11 to over 113 weeks. Clustering of analysed cities distinguished three types of urban transportation resilience (Fig. 1, Tab. 1, Tab. 2).

The first group includes cities that have the longest period of irregularities in mobility related

Table 1. Cities assigned to subsequent clusters in order of increasing distance from the cluster center

1	2	3
Bydgoszcz	Rybnik	Włocławek
Łódź	Nowy Sącz	Elbląg
Katowice	Zielona Góra	Opole
Poznań	Lublin	Chorzów
Konin	Toruń	Świnoujście
Dąbrowa Górnicza	Gorzów	Koszalin
Gdynia	Wałbrzych	Przemyśl
Jelenia Góra	Kielce	Ostrołęka
Bielsko-Biała	Biała Podlaska	Szczecin
Chełm	Grudziądz	Słupsk
Gdańsk	Piotrków Tryb.	Płock
Olsztyn	Leszno	Radom
Białystok	Piekary Śląskie	Mysłowice
Rzeszów	Łomża	Jaworzno
Tarnów	Żory	Ruda Śląska
Suwałki	Siemianowice Śląskie	Legnica
Zamość	Jastrzębie Zdrój	Krosno
Bytom		Tarnobrzeg
Zabrze		Sopot
Sosnowiec		Siedlce
Tychy		
Świętochłowice		
Częstochowa		
Gliwice		
Kraków		
Kalisz		
Wrocław		
Warszawa		

Source: own study

to workplaces and exceeds 102 weeks. These cities were also impacted stronger when it comes to retail and recreation (on average almost 27 weeks). Residential-related mobility was interrupted for approximately 15 weeks, similarly to grocery and pharmacy – 14 weeks. The second group was characterized with a middle level of disruptions in work-related mobility (on average 60 weeks) but the highest irregularity in grocery and pharmacy category (almost 18 weeks). The third group is characterized with the shortest periods necessary to stabilize their mobility patterns in three out of four categories (workplaces – 30 weeks, residential – 14 weeks, grocery and pharmacy – 12 weeks) and only slightly higher value in one category (retail and recreation – 17 weeks).

The obtained results prove that work-related mobility was the most significantly influenced by COVID-19. At the same time that is the only category which presents noticeable changes between three clusters both in relative data (Fig. 1) and absolute data (Fig. 2). Therefore, mobility associated with workplaces was chosen as a measure of urban transportation resilience. The first group of cities presents the lowest resilience of urban transportation to shock caused by COVID-19 pandemic. The second group of cities characterizes the middle level of urban transportation resilience. The most resilient cities in terms of urban transportation are clustered within the third group.

3.2. Urban transportation resilience vs. socio-economic characteristic of cities

In order to verify if there are any patterns between urban transportation resilience and other factors, eight variables were tested. A share of a rural, industrial or service sector in the local economy aimed to distinguish the character of a city. Area

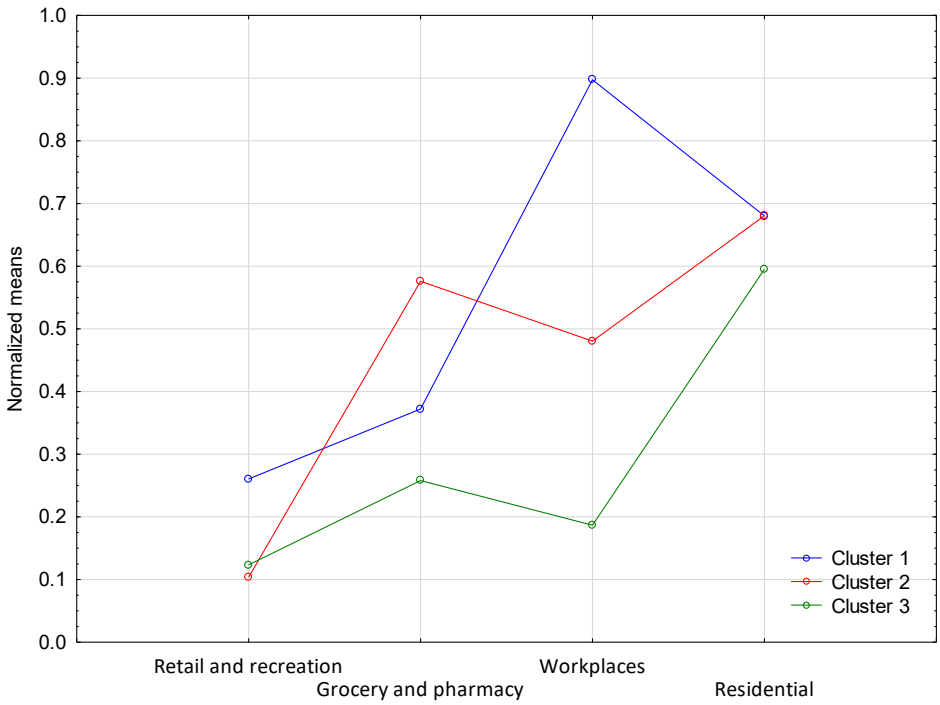

Fig. 1. Results of clustering of cities by their mobility patterns
Source: own study

Table 2. Mean values for clustering of cities by their mobility patterns

No. of cluster	Retail and recreation	Grocery and pharmacy	Workplaces	Residential	No. of cases	Percent (%)
1	26,7 (±21.2)	14,1 (±3.8)	102,5 (±8.3)	15,3 (±1.8)	28	43,0
2	16,1 (±2.6)	17,9 (±4.0)	60,0 (±12.0)	15,3 (±1.9)	17	26,2
3	17,4(±12.0)	11,9 (±3.0)	30,1 (±20.4)	13,5 (±5.3)	20	30,8

Source: own study

and population were considered as factors reflecting the size of a city. Distance from a regional city aimed to verify how peripherally each city is located. Total income and total expenses in the municipal budget were analysed to assess wealth of a city. Each variable has been presented in box plots for each cluster (Fig. 3). For the purpose of visualisation Warsaw (capital city) was excluded as extreme values in case of many variables stretched the scale and made other objects not clearly visible.

Analysing differences between clusters it can be observed that the first cluster differs from the second and third. The first cluster contains cities with a lower share of the agriculture sector in their economy. These cities are noticeably bigger both in terms of area as well as population. This cluster includes both regional cities and cities which are closer to regional centres. The budgets of these cities are also bigger in terms of income as well as expenses. When it comes to differences in characteristics between cities in the second and third cluster, differences are not that visible. The only exception is a distance to a regional city which on average is higher in case of cities in the third cluster.

All the variables were also tested by t-test in order to verify statistical importance of observed differences. The results showed that peripheral location of a city, its' wealth, nor type of economy do not present statistically important influence on resilience of urban transportation. The only two variables which were statistically important from that perspective were the area of a city and its population.

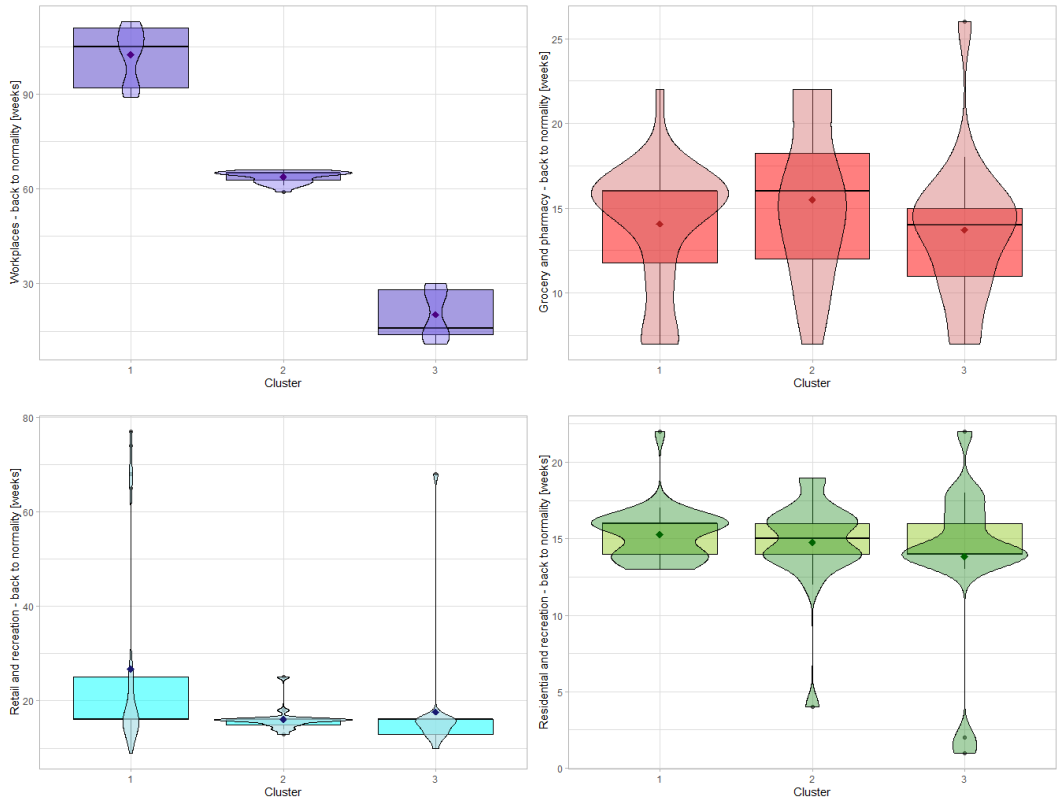

Fig. 2. Violin plot for different types of mobility in three cluster groups of cities
Source: own study

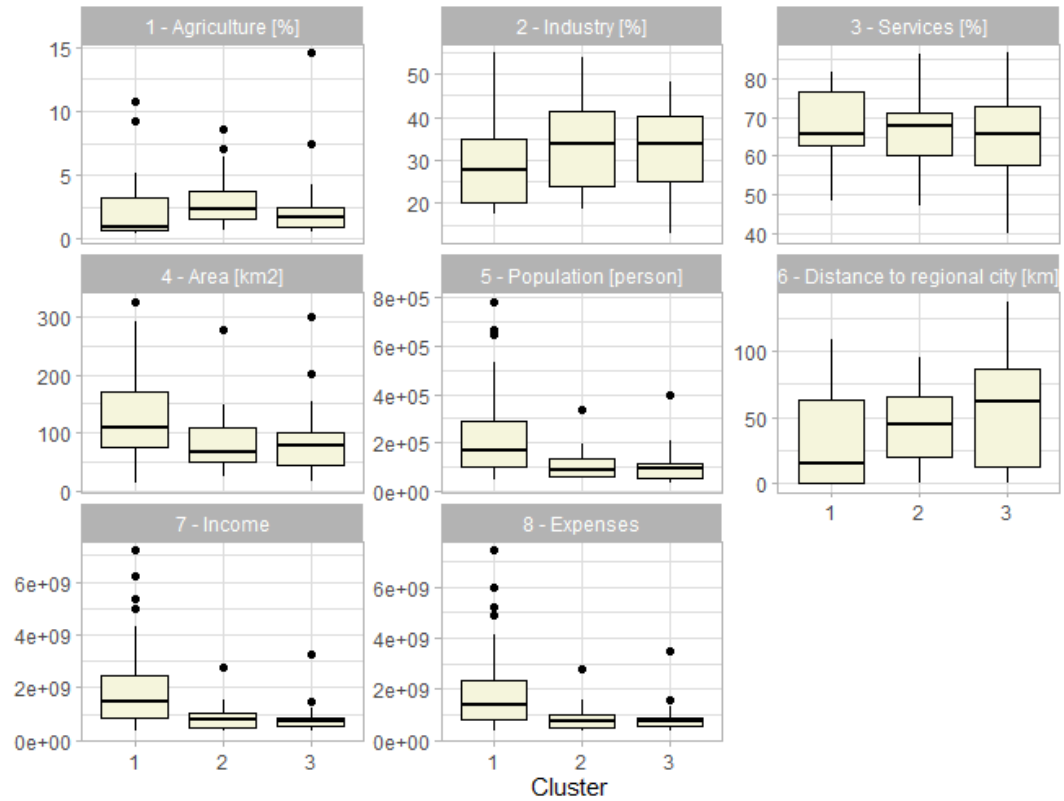

Fig. 3. Box plots for the different characteristics of the cities with a breakdown by cluster.
Source: own study

3.3. Case studies of urban mobility in selected cities

More precise characteristics of resilience of urban mobility was carried out by detailed analysis of representatives of each clustered group. Based on the minimum distance from the centre of each cluster one city was selected. Representatives are as follows: cluster 1 - Łódź (Fig. 4), cluster 2 - Rybnik (Fig. 5), cluster 3 - Włocławek (Fig. 6). For better visibility of charts, visualisation was prepared for 2-week means.

In the case of Łódź the mobility for purposes associated with grocery and pharmacy dropped by 43% during the lockdown period and reached a baseline as a first type of mobility after 11 weeks. The most significant decrease in mobility during lockdown was observed in case of mobility connected with retail and recreation (–62%) and was the second type reaching pre-pandemic period after 20 weeks. Łódź reached a pre-pandemic baseline for workplaces mobility after the longest period of 87 weeks, after a minimum extreme of –44%.

Rybnik noted a decrease of grocery and pharmacy mobility by 41% in the lockdown period and reached a baseline after 12 weeks. Retail and recreation mobility dropped by 66% and reached a baseline after 25 weeks. Work-related mobility decreased by 40% and met pre-pandemic mobility level after 61 weeks.

In the case of Włocławek the first type of mobility that reached a baseline was the one associated with grocery and pharmacy which met pre-pandemic level after 7 weeks (–40% during lockdown). Second was a mobility connected with retail and recreation which came back to normality after 11 weeks, noting at first a drop by 62%. Work-related mobility reached a baseline after 22 weeks, after decreasing by 36% during lockdown.

In the case of all the analysed cities three similarities were observed. First of all in all cases mobility associated with residential purposes increased in the first phase of the analysed period (lockdown introduced in mid-March 2020) by around 18% and gradually dropped back to the pre-pandemic baseline during summer period (July-August 2020). It is also a purpose of mobility that is characterised by the lowest deviation during the whole analysed period. Secondly, the decrease of mobility in the first lockdown period was very similar in case of workplaces as well as grocery and pharmacy (purple and red lines on charts). In following weeks they started to differ more significantly, however, for the first month they are almost overlapping for Łódź, Rybnik and Włocławek. The third universal observation is that although a mobility connected with retail and recreation reached at a certain point a pre-pandemic baseline earlier (June-September 2020), it was noticeably below a baseline until the late May/early June 2021, and only after that moment it was oscillating around a baseline.

4. Discussion

The results obtained in the research suggest few patterns which characterise mobility in analysed cities. First of all, mobility of citizens which was associated with grocery, pharmacy, retail and recreation decreased during lockdown and met the pre-pandemic patterns of mobility earlier and did not present significant differences between all 65 cities. On the other hand, work-related mobility also decreased, however, it needed a longer period to reach a baseline. Relatively slower stabilisation of work-related mobility patterns was possible due to popularisation of remote work in many companies (Atahan & Alhelo, 2022; Roberto et al., 2023; Rodrigues da Silva et al., 2023), however, similar changes can be observed also in shopping and development of e-commerce (Campisi et al., 2021; Xi et al., 2023). Although, in terms of shopping, the study conducted for Lon Angeles stressed that economic status is a factor differentiating how commonly people changed in-person shopping to online shopping (Lu & Giuliano, 2023).

Secondly, cities which occurred to be the least resilient to COVID-19 in terms of their transportation patterns in that field were the biggest cities with average area of 148 km2 and average population of 297700. Smaller cities were statistically more resilient, while differences in type of local economy, peripheral local from regional cities or size of a budget were not statistically significant. That stands in line with conclusions of other studies which highlighted that smaller cities and socio-economic systems in these cities may be more resistant to COVID-related global pressures. It was presented for example in a case of a bike-sharing system (Qin & Karimi, 2023) or a real estate market (Kazak et al., 2023).

Moreover, residence-related mobility increased in the initial phase of lockdown in all analysed cases, while it came close to the baseline around the summer of 2020. Restrictions introduced during that time significantly limited commuting for longer distances and many activities had to be

Fig. 4. Variability of four types of mobility in Łódź with indication of the moment of return to the base level (triangles)
Source: own study

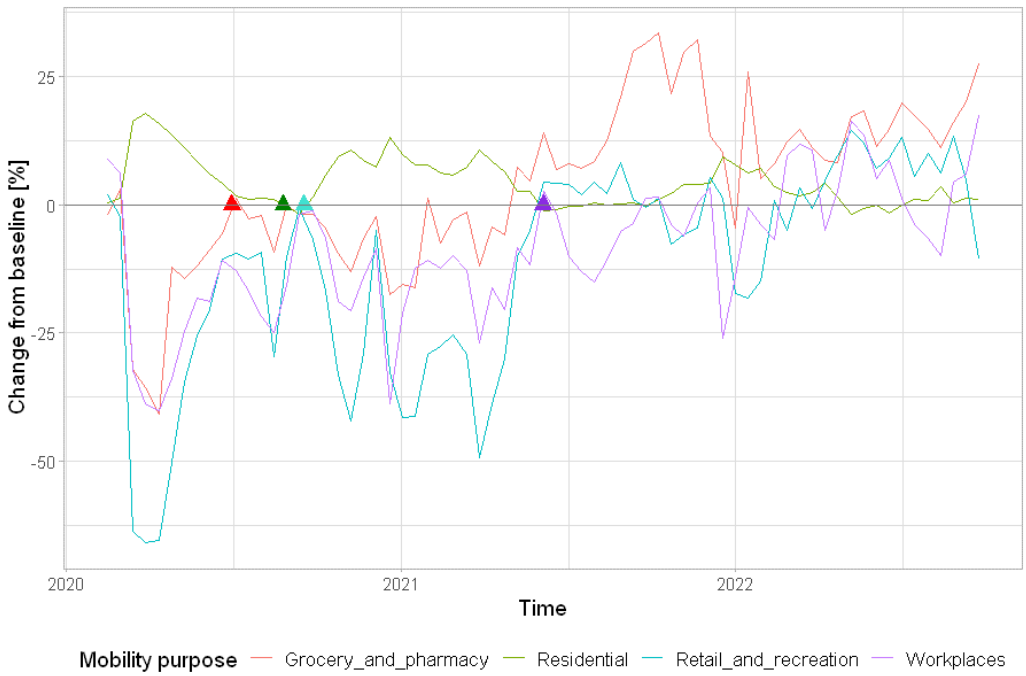

Fig. 5. Variability of four types of mobility in Rybnik with indication of the moment of return to the base level (triangles)
Source: own study

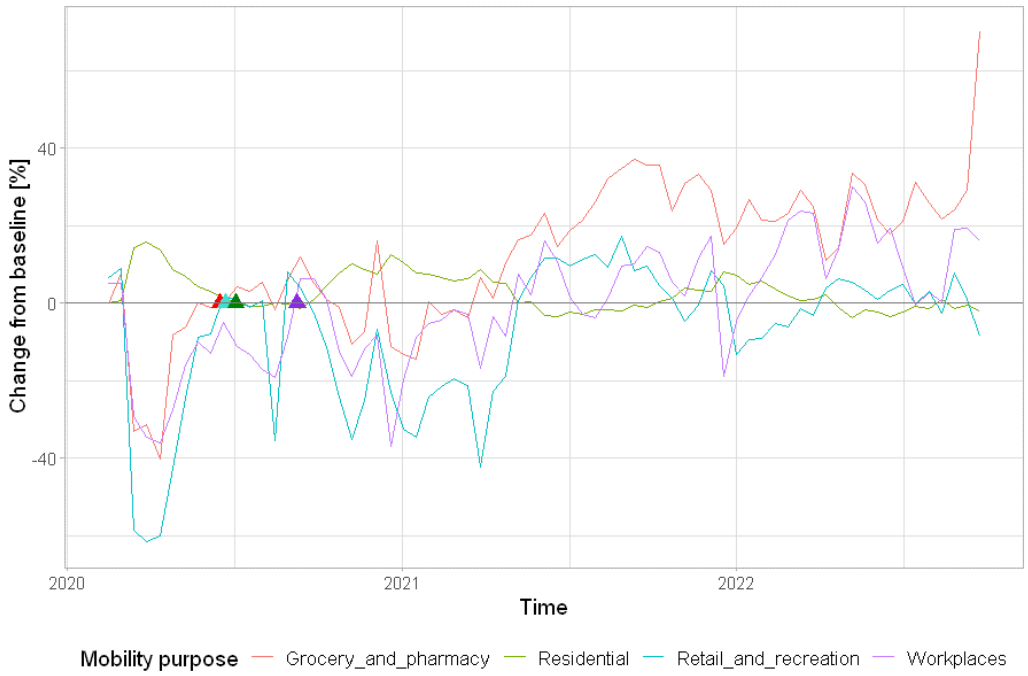

Fig. 6. Variability of four types of mobility in Włocławek with indication of the moment of return to the base level (triangles)
Source: own study

realised more locally. Therefore, considering the approach of data collection all mobilities realised in the closest neighbourhood of homes could be possibly categorised as mobility connected with residential purposes. That could be confirmed by opinion that "new normality" in mobility was based on revamping car-based behaviours and enhancing micromobility (Corazza et al., 2021).

Additionally, the result confirms that the decrease in mobility associated with workplaces as well as grocery and pharmacy presented a similar pattern in the beginning of lockdown. The open question is if that could be explained by the fact that many of these activities were previously realised together, for example by doing groceries or visiting pharmacies on the way to or from work. That could potentially explain similarities in charts for all three representatives of each cluster.

Finally, mobility connected with retail and recreation reached a pre-pandemic baseline around summer 2020, however, real stabilisation around the baseline can be observed from around late May/early June 2021 onwards. The merged category of retail and recreation does not allow to distinguish the share of each element in total value of indicator, however, it can be noticed that their stabilisation overlapped with summer periods and only after over a year it can be assessed as similar to pre-pandemic period.

5. Conclusions

The research proves that mobility patterns in cities were significantly influenced during the COVID pandemic period. The most clear impact was observed in case of work-related mobility. Bigger cities were less resilient to this shock, while smaller cities returned to stability in shorter periods. Considering changes in ways how some parts of local economies operate, it is assumed that a new level of stability of a system does not have to meet pre-pandemic patterns. It refers especially to these aspects of activity where development of remote solutions may replace previous ways of fulfilling needs.

The conducted research is characterised by two main limitations. First, the generalisations of the database used in the research treat some categories together, which are potentially interesting from a scientific perspective. However, this is still one of the most detailed datasets available and the same approach for data collection allows comparative studies between different cities. Secondly, due to a different way of describing administrative units which not in all cases overlaps with national statistics, only 65 Polish cities were possible to be analysed. Although this limitation, this study compares a sufficient number of cities which allow

analysis on a higher scale that just a case study approach.

Future studies on urban transportation resilience in response to systematic changes in socio-economic systems should also cover international context as different lifestyles connected with socio-cultural background may deliver new findings in that regard. With better understanding of the resilience of our cities we can define which domains of urban activity requires more support or a new idea how it can be reorganised to maintain an efficient system fulfilling the needs of citizens. Finally, that would help to build a more sustainable and predictable urban system. Understanding disruptions of mobility patterns may be a crucial element for local decision-makers to improve or redesign mobility planning in cities.

References

Alonso-Almeida, M. del M. (2022). To Use or Not Use Car Sharing Mobility in the Ongoing COVID-19 Pandemic? Identifying Sharing Mobility Behaviour in Times of Crisis. *International Journal of Environmental Research and Public Health*, 19(5): 3127. DOI: https://doi.org/10.3390/ijerph19053127.

Atahan, A. & Alhelo, L. (2022). The Impact of the COVID-19 Pandemic on Mobility Behavior in Istanbul After One Year of Pandemic. W A. Akhnoukh, K. Kaloush, M. Elabyad, B. Halleman, N. Erian, S. Enmon II, & C. Henry (Eds.)., Advances in Road Infrastructure and Mobility. Springer International Publishing. DOI: https://doi.org/10.1007/978-3-030-79801-7_65.

Aydin, N., Kuşakcı, A.O. & Deveci, M. (2022). The impacts of COVID-19 on travel behavior and initial perception of public transport measures in Istanbul. *Decision Analytics Journal*, 2: 100029. DOI: https://doi.org/10.1016/j.dajour.2022.100029.

Bagdatli, M.E.C. & Ipek, F. (2022). Transport mode preferences of university students in post-COVID-19 pandemic. *Transport Policy*, 118: 20–32. DOI: https://doi.org/10.1016/j.tranpol.2022.01.017.

Barthélemy, E.J., Thango, N.S., Höhne, J., Lippa, L., Kolias, A. & Germano, I.M. (2021). Resilience in the Face of the COVID-19 Pandemic: How to Bend and not Break. *World Neurosurgery*, 146: 280–284. DOI: https://doi.org/10.1016/j.wneu.2020.11.105.

Beck, M.J., Hensher, D.A. & Nelson, J.D. (2021). Public transport trends in Australia during the COVID-19 pandemic: An investigation of the influence of bio-security concerns on trip behaviour. *Journal of Transport Geography*, 96: 103167. DOI: https://doi.org/10.1016/j.jtrangeo.2021.103167.

Bełej, M. (2021). Housing Price Forecasting in Selected Polish Cities During the COVID-19 Pandemic. *Geomatics and Environmental Engineering*, 15(4): 4. DOI: https://doi.org/10.7494/geom.2021.15.4.59.

Bouhouras, E., Basbas, S., Ftergioti, S., Paschalidis, E. & Siakantaris, H. (2022). COVID-19's pandemic effects on bike sharing systems: A new reality for urban mobility? *Applied Sciences*, 12(3): 1230. DOI: https://doi.org/10.3390/app12031230.

Campisi, T., Russo, A., Tesoriere, G., Bouhouras, E. & Basbas, S. (2021). COVID-19's Effects over E-commerce: A Preliminary Statistical Assessment for Some European Countries. IN: WO. Gervasi, B. Murgante, S. Misra, C. Garau, I. Blečić, D. Taniar, B.O. Apduhan, A.M.A. C. Rocha, E. Tarantino, & C.M. Torre (Eds.)., Computational Science and Its Applications – ICCSA. Springer International Publishing. DOI: https://doi.org/10.1007/978-3-030-86979-3_27.

Chen, C., Feng, T., Gu, X. & Yao, B. (2022). Investigating the effectiveness of COVID-19 pandemic countermeasures on the use of public transport: A case study of The Netherlands. *Transport Policy*, 117: 98–107. DOI: https://doi.org/10.1016/j.tranpol.2022.01.005.

Corazza, M. V., Moretti, L., Forestieri, G. & Galiano, G. (2021). Chronicles from the new normal: Urban planning, mobility and land-use management in the face of the COVID-19 crisis. *Transportation Research Interdisciplinary Perspectives*, 12: 100503. DOI: https://doi.org/10.1016/j.trip.2021.100503.

COVID-19 Community Mobility Report. (2022). COVID-19 Community Mobility Report. Available at: https://www.google.com/covid19/mobility?hl=pl (Accessed: 17 July 2023).

Fridrisek, P. & Janos, V. (2022). COVID-19 and suburban public transport in the conditions of the Czech Republic. *Transportation Research Interdisciplinary Perspectives*, 13: 100523. DOI: https://doi.org/10.1016/j.trip.2021.100523.

Gafter, L., Tchetchik, A. & Shilo, S. (2022). Urban resilience as a mitigating factor against economically driven out-migration during COVID-19: The case of Eilat, a tourism-based city. *Cities*, 125: 103636. DOI: https://doi.org/10.1016/j.cities.2022.103636.

Guo, W., Feng, Y., Luo, W., Ren, Y., Tan, J., Jiang, X. & Xue, Q. (2022). The Impacts of COVID-19 and Policies on Spatial and Temporal Distribution Characteristics of Traffic: Two Examples in Beijing. *Sustainability*, 14(3): 1733. DOI: https://doi.org/10.3390/su14031733.

Jaekel, B. & Muley, D. (2022). Transport impacts in Germany and State of Qatar: An assessment during the first wave of COVID-19. *Transportation Research Interdisciplinary Perspectives*, 13: 100540. DOI: https://doi.org/10.1016/j.trip.2022.100540.

Javid, M.A., Abdullah, M., Ali, N. & Dias, C. (2021). Structural equation modeling of public transport use with COVID-19 precautions: An extension of the norm activation model. *Transportation Research Interdisciplinary Perspectives*, 12: 100474. DOI: https://doi.org/10.1016/j.trip.2021.100474.

Kapucu, N., Ge, Y. 'Gurt', Martín, Y. & Williamson, Z. (2021). Urban resilience for building a sustainable and safe environment. *Urban Governance*, 1(1): 10–16. DOI: https://doi.org/10.1016/j.ugj.2021.09.001.

Kazak, J.K., Kłysz, N.A. & Kamińska, J.A. (2023). Housing Market in Central European City during the COVID-19 Pandemic. *Critical Housing Analysis*, 10(1): 27–38.

Kazak, J.K., Szewrański, S., Pilawka, T., Tokarczyk-Dorociak, K., Janiak, K. & Świąder, M. (2021). Changes in water demand patterns in a European city due to restrictions caused by the COVID-19 pandemic. *Desalination and water treatment*, 222: 1-15. DOI: https://doi.org/10.5004/dwt.2021.27242.

Kłos-Adamkiewicz, Z. & Gutowski, P. (2022). The Outbreak of COVID-19 Pandemic in Relation to Sense of Safety and Mobility Changes in Public Transport Using the Example of Warsaw. *Sustainability*, 14(3): 1780. DOI: https://doi.org/10.3390/su14031780.

Krusche, A., Wilde, L., Ghio, D., Morrissey, C., Froom, A. & Chick, D. (2022). Developing public transport messaging to provide crowding information during COVID-19: Application of the COM-B model and behaviour change wheel. *Transportation Research Interdisciplinary Perspectives*, 13: 100564. DOI: https://doi.org/10.1016/j.trip.2022.100564.

Lu, Y. & Giuliano, G. (2023). Understanding mobility change in response to COVID-19: A Los Angeles case study. *Travel Behaviour and Society*, 31: 189–201. DOI: https://doi.org/10.1016/j.tbs.2022.11.011.

Milewska, B. (2022). The Impact of the COVID-19 Pandemic on Supply Chains in the Example of Polish Clothing Companies in the Context of Sustainable Development. *Sustainability*, 14(3): 1899.

Mogaji, E. (2022). Wishful thinking? Addressing the long-term implications of COVID-19 for transport in Nigeria. *Transportation Research Part D: Transport and Environment*, 105: 103206. DOI: https://doi.org/10.1016/j.trd.2022.103206.

Musango, J. K., Currie, P., & Robinson, B. (2017). Urban metabolism for resource efficient cities: from theory to implementation. UN Environment: Paris, France.

Naveen, B.R. & Gurtoo, A. (2022). Public transport strategy and epidemic prevention framework in the Context of Covid-19. *Transport Policy*, 116: 165–174. DOI: https://doi.org/10.1016/j.tranpol.2021.12.005.

Ouoba, Y. & Sawadogo, N. (2022). Food security, poverty and household resilience to COVID-19 in Burkina Faso: Evidence from urban small traders' households. *World Development Perspectives*, 25: 100387. DOI: https://doi.org/10.1016/j.wdp.2021.100387.

Przybylowski, A., Stelmak, S. & Suchanek, M. (2021). Mobility Behaviour in View of the Impact of the COVID-19 Pandemic—Public Transport Users in Gdansk Case Study. *Sustainability*, 13(1): 364.

Qin, Y. & Karimi, H.A. (2023). Evolvement patterns of usage in a medium-sized bike-sharing system during the COVID-19 pandemic. *Sustainable Cities and Society*, 96: 104669. DOI: https://doi.org/10.1016/j.scs.2023.104669.

Rahman, S.M., Ratrout, N., Assi, K., Al-Sghan, I., Gazder, U., Reza, I. & Reshi, O. (2021). Transformation of urban mobility during COVID-19 pandemic – Lessons for transportation planning. *Journal of Transport & Health*, 23: 101257. DOI: https://doi.org/10.1016/j.jth.2021.101257.

Roberto, R., Zini, A., Felici, B., Rao, M. & Noussan, M. (2023). Potential Benefits of Remote Working on Urban Mobility and Related Environmental Impacts: Results from a Case Study in Italy. *Applied Sciences*, 13(1): 607. DOI: https://doi.org/10.3390/app13010607.

Rodrigues da Silva, A.N., Pitombo, C.S., Pedreira Junior, J.U., Ciriaco, T.G.M. & Costa, C.S. (2023). Chapter 8—Changes in mobility and challenges to the transport sector in Brazil due to COVID-19. In: WJ. Zhang & Y. Hayashi (Eds.)., *Transportation Amid Pandemics*. Elsevier. DOI: https://doi.org/10.1016/B978-0-323-99770-6.00010-7.

Shortall, R., Mouter, N. & van Wee, B. (2022). Full article: COVID-19 passenger transport measures and their impacts. *Transport Reviews*, 4(42): 441–466. DOI: https://doi.org/10.1080/01441647.2021.1976307.

Simić, V., Ivanović, I., Đorić, V. & Torkayesh, A.E. (2022). Adapting Urban Transport Planning to the COVID-19 Pandemic: An Integrated Fermatean Fuzzy Model. *Sustainable Cities and Society*, 79: 103669. DOI: https://doi.org/10.1016/j.scs.2022.103669.

Tarkowski, M., Puzdrakiewicz, K., Jaczewska, J. & Połom, M. (2020). COVID-19 lockdown in Poland–changes in regional and local mobility patterns based on Google Maps data. *Prace Komisji Geografii Komunikacji PTG*, 23(2): 46-55.

Trojanek, R., Głuszak, M., Hebdzynski, M. & Tanas, J. (2021). The COVID-19 Pandemic, Airbnb and Housing Market Dynamics in Warsaw. *Critical Housing Analysis*, 8(1): 72–84. DOI: https://doi.org/10.13060/23362839.2021.8.1.524.

Turek, T., Diakowska, E. & Kamińska, J.A. (2021). Has COVID-19 Lockdown Affected on Air Quality?—Different Time Scale Case Study in Wrocław, Poland. *Atmosphere*, 12(12): 1549. DOI: https://doi.org/10.3390/atmos12121549.

Wen, L., Sharp, B., Suomalainen, K., Sheng, M.S. & Guang, F. (2022). The impact of COVID-19 containment measures on changes in electricity demand. *Sustainable Energy, Grids and Networks*, 29: 100571. DOI: https://doi.org/10.1016/j.segan.2021.100571.

Xi, H., Li, Q., Hensher, D.A., Nelson, J.D. & Ho, C. (2023). Quantifying the impact of COVID-19 on travel behavior in different socio-economic segments. *Transport Policy*, 136: 98–112. DOI: https://doi.org/10.1016/j.tranpol.2023.03.014.

Yang, S. & Chen, Z. (2022). The Impact of COVID-19 on High-Speed Rail and Aviation Operations. *Sustainability*, 14(3): 1683. DOI: https://doi.org/10.3390/su14031683.

Zavareh, M.F., Mehdizadeh, M. & Nordfjærn, T. (2022). Demand for mitigating the risk of COVID-19 infection in public transport: The role of social trust and fatalistic beliefs. *Transportation Research Part F: Traffic Psychology and Behaviour*, 84: 348-362. DOI: https://doi.org/10.1016/j.trf.2021.12.010.