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Analysis of the German Commuter Network

Period 2013 - 2021

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Abstract Understanding the behavior of commuters is crucial as the number of commuters steadily rises, causing significant traffic congestion in many cities. Indeed, commuter behavior is vital in city and transport planning and policy-making. Previous studies have investigated various factors that may impact commuting decisions. Still, these studies are often limited by the scale of data examined, including time duration, space, and the number of commuters. To address this gap, we gathered large-scale inter-city commuting data in Germany and analyzed the weighted commuting network from 2013 to 2021. This work relies on publicly available data so that the results can be reproduced.

Keywords Commuter · Complex Network Analysis · Spatial Data

1 Introduction

The ongoing work presented here aims to analyze the Commuter flows in Germany from 2013 to 2021 from a network science perspective [1–8]. Using all years of the period makes it possible to consider the short-term effects due to the COVID-19

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pandemic. The network consists of the German districts (nodes) and the commuter flows (Einpender) (edges) and incorporates weights based on the overall number of commuters. We exclude Commuter flows from outside German districts. The Federal Employment Agency, BA (Bundesagentur für Arbeit) (Dataset "Arbeitsmarkt in Zahlen, Sozialversicherungspflichtig Beschäftigte - Pendlernach Kreisen") provided us with the data representing the Commuter flows. One may notice different annotations in the dataset regarding the data quality of the years 2013/14, 2016/2017, and 2019 due to technical issues or local government reorganization. Coordinates were added to the dataset using the dataset Geographische Namen 1:250 000 (GN250), State geometries are added using the dataset Verwaltungsgebiete 1 : 250 000 (VG250-EW) (© GeoBasis-DE / BKG 2021) provided by the Federal Agency for Cartography and Geodesy (BKG).

2 Results

Preliminary results of the analysis confirm the findings of the BBSR regarding the increase in commuting activity. Indeed, the number of commuters in Germany has continuously increased in recent years. According to the Federal Office for Building and Regional Planning - BBSR, commuters rose by 6.6 percent in five years, from 18.4 million employees in 2016 to 19.6 million in 2021. This corresponds to 59.5% of all those subject to social security contributions. The group of commuters with a one-way commute of more than 50 kilometers experienced a sharp increase of 7.4%. It rose from 3.3 million in 2016 to 3.6 million in 2021. Among the major cities, Munich continues to lead the list with the most commuters [9].

The analysis of the minimum Degree through time show that commuting increases. For example, the min degree increases from 30 in 2013 to over 40 in 2021. The median Degree rose from 115 in 2013 to more than 130 in 2021. The degree distribution shows that most districts have a low degree while a few districts have a high Degree.

Figure 1 shows the evolution throughout the global topological properties of the network. The diameter decreased from 3 in 2013 to 2 in 2014. Since then, it did not change. So, in terms of commuter routes, the German districts are pretty close. Taking into account the overall commuter counts as the weight adds a bit more dynamics to the diameter development as it decreases from 39 (2013) to 36 (2017/18) and increases again to 40 (2021). The density increases throughout the period (from 0.33 in 2013 to 0.37 in 2021) except for one drop from 2019 to 2020. It shows that commuting in Germany is increasing in numbers and connections between the districts. Although far from a complete graph, 0.37 seems pretty dense concerning the topic and the geographical extent of Germany. The development of transitivity follows the same trend, with the same drop between 2019 and 2020. It suggests that the increase also occurs between transitively connected nodes, for example, districts related to the same urban district. The Degree Correlation Coefficient shows a negative increase from -0.179 in 2013 to -0.188 in 2021. So, the network becomes more disassortative over time. It suggests that the rural-urban commuter relationships increased in the given period. The Federal Institute for Population Research (Bundesinstitut für Bevölkerungsforschung) reports that migration to urban municipalities has been steadily decreasing since 2012 and since 2014. They have even recorded migration losses. In contrast, rural districts have

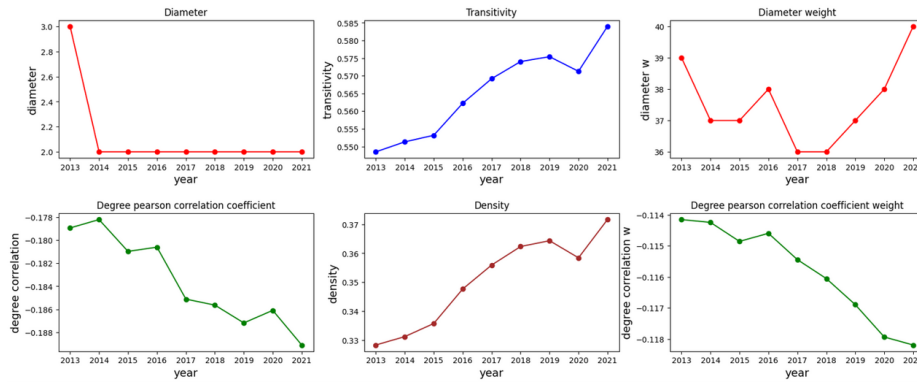


Fig. 1 Global topological properties evolution from 2013 to 2021

gained population for some years, indicating a renewed suburbanization phase in Germany [10]. One can assume that these people don't migrate to the rural areas because of a new job offer in these districts but due to other reasons, e.g., lower housing prices. Considering the weights, we observe the same trend but on a less disassortative level. The analysis of the community structure of the network also reveals interesting insights. Figure 2 shows the evolution of the community structure over the period uncovered by the Louvain Community Detection Algorithm. The communities fit the geographical areas quite well except for some large cities such as Berlin and Hamburg, which are in the southeastern cluster. We can also see that the community in central Germany disappeared in 2014, 2019, and 2021. The modularity exhibits low values around 0.2, characteristic of a weak community structure with many links between the communities. We observe a slightly decreasing trend except for a short increase between 2018 and 2020.

Using the overall commuter flows as weight. We can see that the community structure of the weighted network divides into smaller communities. The high modularity (0.7) shows that the communities are more cohesive. Their evolution in time follows the same trend as the unweighted community structure. The weighted community structure does not fit the state's borders well, except for some communities surrounding more prominent cities such as the Karlsruhe or the Mainz region. Furthermore, the number of communities varies between 10 and 13 (Fig.3). Some clusters disappear, e.g., in Lower Saxony / Eastern North Rhine-Westphalia, where the number of communities evolves between 1 and 3. It could be a result of the structure of the area consisting of rural areas and a few urban areas like Bremen, Hannover, Braunschweig, and Bielefeld.

We plan to extend the current analysis of static networks to include temporal networks, which can capture how the network structure and dynamics change over time[11]. It could involve investigating how different types of temporal dependencies affect the behavior of the network and the properties of its microscopic and mesoscopic structure. Additionally, incorporating information about the timing and duration of interactions between nodes could provide a more nuanced understanding of commuting patterns and dynamics.

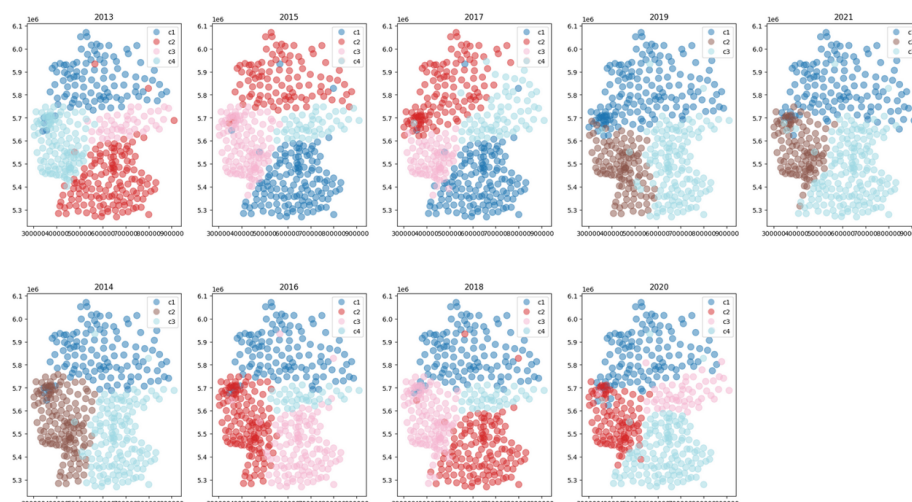


Fig. 2 Community structure evolution of the unweighed network uncovered by Louvain from 2013 to 2021

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