Proceeding Series of the Brazilian Society of Computational and Applied Mathematics, v. 11, n. 1, 2025.

Trabalho apresentado no XLIII CNMAC, Centro de Convenções do Armação Resort - Porto de Galinhas - PE, 2024



# Correspondences Between Topological Properties of Mobility Networks and the Spread of COVID-19 in Brazil

Rômulo J. V. Rocha[1], Suleimane Ducure[2],
DECOM/UFOP, Ouro Preto, MG

Leonardo B. L. Santos[3]
CEMADEN, São José dos Campos, SP

Elbert E. N. Macau[4]
UNIFESP, São José dos Campos, SP

Fernanda S. H. Souza[5], Vander L. S. Freitas[6]
DECOM/UFOP, Ouro Preto, MG

The COVID-19 pandemic, driven by the SARS-CoV-2 virus, has emerged as a global crisis, deeply impacting nations and communities worldwide. Originating in Wuhan, China, in late 2019, the disease quickly transcended national borders, challenging healthcare systems, economies, and daily life. It has brought to light the intersection between public health and urban mobility. The virus spread intrinsically links to human movement and urban connectivity [1]. Investigating the complex mobility network in urban areas, between cities, and at a global level is essential to understand how people are infected and subsequently transmit the virus. In this context, graph analysis emerges as a robust methodology for examining mobility, providing a systematic approach to model and comprehend the intricate dynamics of disease spread [2]. Several studies have delved into the nuanced relationship between urban mobility patterns and the transmission of COVID-19 [1, 3, 4].

We explore the correspondences between the onset of COVID-19 cases and urban mobility in Brazilian cities, showing that network metrics such as degree, strength, and betweenness can sort cities that first presented notifications. The present study is an adaptation of [3], which investigates the correspondence between the structure of the terrestrial mobility network and the emergence of the virus in Brazil. We have expanded our analysis to include additional transport modes and modified the methodology to incorporate a filtering step, as well as refine the way we calculate the correspondences between COVID-19 and mobility data.

Our methodology consists of calculating the intersection between two datasets: i) mobility data - terrestrial, fluvial[7], and aerial[8]; ii) COVID-19 case notification data[9]. We first merge the three transport modes into a single network containing the flows of vehicles between Brazilian cities and compute metrics such as degree, betweenness, closeness, and their weighted counterparts. Cities

[1]romulo.rocha@aluno.ufop.edu.br
[2]suleimane.ducure@aluno.ufop.edu.br
[3]leonardo.santos@cemaden.gov.br
[4]elbert.macau@unifesp.br
[5]fsumika@ufop.edu.br
[6]vander.freitas@ufop.edu.br
[7]`https://www.ibge.gov.br/geociencias/organizacao-do-territorio/redes-e-fluxos-geograficos/15797-ligacoes-aereas.html`
[8]`https://www.ibge.gov.br/geociencias/organizacao-do-territorio/redes-e-fluxos-geograficos/15797-ligacoes-aereas.html`
[9]`https://covid19br.wcota.me/en/`

 

are sorted according to the metrics in descending order as they assign importance to nodes based on certain topological properties. This list of cities is confronted with the list of cities that first notified COVID-19 cases. We hypothesize that there is a direct correspondence between such lists, and that mobility is related to the trajectory of the disease.

We compute the intersection between the two lists (network nodes sorted according to a metric and cities that first notified cases). For each notification date, we progressively include all cities that notified their first case until then and compare the intersections between those cities and the first $n$ cities sorted by metric, considering that $n$ is the number of cities in the first set. Additionally, we vary the number of cases a city needs to report to be included in the first set to filter noisy data. As can be seen in the example of Table 1, cities are ordered by the emergence of the first COVID-19 case notification, by degree and betweenness. When comparing the sets, for the first date, 2020/02/25, there is a 100% correspondence in all metrics, since São Paulo is the city with the highest metrics and also the first to notify cases. However, for the second date, 2020/03/06, there is a 33% percent correspondence (São Paulo, Feira de Santana, and Rio de Janeiro belong to the first set, but only São Paulo appears in the others).

Table 1: Cities ordered by date, degree, and betweenness.

| Order | Dates | Emergence of cases | Degree | Betweenness |
|---|---|---|---|---|
| 1 | 2020/02/25 | São Paulo | São Paulo | São Paulo |
| 2 | 2020/03/06 | Feira de Santana | Belo Horizonte | Recife |
| 3 | 2020/03/06 | Rio de Janeiro | Brasilia | Belo Horizonte |
| 4 | 2020/03/07 | Brasília | Recife | Brasília |

The results demonstrate that the correspondence for most network metrics surpassed random expectation, confirming that mobility is a reliable predictor of COVID-19 onset. Closeness and its weighted counterpart stood out as the least effective in matching the disease's onset, while degree and strength were shown to be the best. When varying the minimum number of cases to include a city in the notification list, strength, and weighted betweenness compete for the second position of best correspondences.

## References

[1] A. Arenas, W. Cota, J. Gómez-Gardeñes, S. Gómez, C. Granell, J. T. Matamalas, D. Soriano-Paños, and B. Steinegger. "Modeling the spatiotemporal epidemic spreading of COVID-19 and the impact of mobility and social distancing interventions". In: **Physical Review X** 10.4 (2020). Published, p. 041055. DOI: 10.1103/PhysRevX.10.041055.

[2] A.-L. Barabási and M. Pósfai. **Network science**. Cambridge Series in Statistical and Probabilistic Mathematics. Cambridge University Press, 2016. ISBN: 9781107076266.

[3] V. L. S. Freitas, T. C. R. O. Konstantyner, J. F. Mendes, C. S. N. Sepetauskas, and L. B. L. Santos. "The correspondence between the structure of the terrestrial mobility network and the spreading of COVID-19 in Brazil". In: **Cadernos de Saúde Pública** 36 (2020), pp. 1–12. DOI: https://doi.org/10.1590/0102-311X00184820.

[4] M. U. G. Kraemer, C.-H. Yang, B. Gutierrez, C.-H. Wu, B. Klein, D. M. Pigott, Open COVID-19 Data Working Group, L. Du Plessis, N. R. Faria, R. Li, et al. "The effect of human mobility and control measures on the COVID-19 epidemic in China". In: **Science** 368.6490 (2020). Published, pp. 493–497. DOI: 10.1126/science.abb4218.