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Exploring relationships between urban distances traveled and teleworking

Explorando relações entre distâncias urbanas percorridas e teletrabalho

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ABSTRACT
The advance of Information and Communication Technologies (ICTs) and the popularization of teleworking due to the COVID-19 pandemic have reshaped mobility dynamics in recent years. Concerning distances and teleworking, important causal relationships can be observed. The relationship investigated in this study is linked to the individual choice of teleworking due to the current distances to be traveled, especially in larger cities. Therefore, this article analyzed the relationships between urban distances traveled and teleworking and, secondarily, investigated the relationships between different work arrangements, trip frequencies, as well as the use of technologies. A three-step method was used, involving the sequential use of the following tools: (1) CART algorithm (Classification And Regression Tree); (2) Chi-square tests and (3) Multinomial Logit model. Data was collected through an online survey conducted with 247 respondents between April and June 2022. The participants were residents from various Brazilian cities. The results showed that part-time teleworkers travel longer distances for work-related trips (between 15.5 and 37.5 km), while full-time teleworkers travel less frequently for the same trip purposes. Additionally, face-to-face workers travel less frequently for other purposes. These findings are in line with the literature, showing a possible use of teleworking as a demand management tool, reducing travel frequencies. However, the possible negative impacts should be assessed as the influence of work arrangement in future household choices and, consequently, urban sprawl.

RESUMO
O avanço das Tecnologias da Informação e Comunicação (TICs) e a popularização do teletrabalho, com a pandemia de COVID-19, alteraram a dinâmica da mobilidade nos últimos anos. Em relação às distâncias e ao teletrabalho existem relações de causalidade importantes. A relação investigada no presente trabalho está atrelada à escolha de teletrabalho devido às distâncias atuais a serem percorridas, principalmente em cidades maiores. Assim, este artigo analisou relações entre distâncias urbanas percorridas e o teletrabalho e, de forma secundária, investigou relações entre os diferentes regimes, frequências de viagem e uso de tecnologias. Para isso, foi usado um método de três etapas, com uso sequencial das seguintes ferramentas: (1) Algoritmo CART (Classification And Regression Tree); (2) Testes qui-quadrado e (3) Modelo logit multinomial. Os dados foram obtidos por meio de uma pesquisa online, realizada entre abril e junho de 2022, com 247 respondentes, de diversas cidades brasileiras. Os resultados mostraram que teletrabalhadores parciais percorrem distâncias maiores para viagens com motivo trabalho (entre 15,5 e 37,5 km), enquanto teletrabalhadores integrais têm menor frequência de deslocamento para as mesmas viagens. Adicionalmente, trabalhadores presenciais se deslocam com menor frequência para viagens por outros motivos. Esses achados corroboram a literatura, mostrando um possível uso do teletrabalho como ferramenta de gestão de demanda, reduzindo as frequências de viagens. Contudo, é necessário avaliar os possíveis impactos negativos, visto que o regime pode influenciar escolhas domiciliares futuras mais distantes e, consequentemente, o espraiamento urbano.

1. INTRODUCTION

Teleworking gained widespread attention due to the COVID-19 pandemic, when it was adopted as a social distancing measure recommended by the World Health Organization (WHO) to help contain the spread of the virus (WHO, 2020). The effects of the COVID-19 pandemic on urban mobility, such as a reduction in travel frequency, a reduction in public transport use, and changes in travel patterns, have been observed (Soler, Christidis and Vassallo, 2023; Silva et al., 2023; Haas, Faber and Hamersma, 2020). Teleworking emerged as a strategic measure to ensure the continuity of economic activities despite travel restrictions during the period. Throughout this period, teleworking enabled certain economic activities to be carried out, albeit partially, by using Information and Communication Technologies (ICTs). This work arrangement resulted in a reduction in travel frequency and emerged as a potential tool for managing urban mobility demand.

Even after the end of the COVID-19 pandemic, teleworking has remained popular, albeit on a smaller scale, making it important to understand the implications of this phenomenon for mobility. As this work arrangement is likely to continue, especially in large urban centers, new perspectives are emerging for travel patterns and mobility management due to the potential influence of teleworking (Thulin, Vilhelmson and Brundin, 2023; Asmussen et al., 2024; Haas, Faber and Hamersma, 2020; Caldarola and Sorrell, 2022). Currently, individuals who already live further away from their workplace or in large centers may choose teleworking arrangements to reduce the time and inconvenience of physical travel. In the future, the possibility of teleworking may lead to new residential choices by teleworkers, generating possible urban sprawl (Lund and Mokhtarian, 1994; Wöhner, 2022; Pedreira Jr. and Pitombo, 2024; Ilham et al., 2024; Kappler and Silva, 2025). Thus, the topic of travel behavior and teleworking is currently relevant, considering the increased popularity of this work arrangement, driven by the disruptive event of the COVID-19 pandemic.

This article aims to investigate the relationships between different work arrangements and distances traveled. Secondarily, it analyzes the relationships between the work arrangements, variables such as trip frequencies for different purposes and travel modes, as well as the use of Information and Communication Technologies (ICTs).

Building on these considerations, the article contributes to studies examining the effectiveness of telework as a strategic tool for managing urban mobility demand in large centers, particularly in the post-COVID-19 pandemic era. It also initiates a discussion about its potential negative impacts, such as urban sprawl, new residential choices, and increased travel distances, which can overshadow the benefits and create new challenges for urban and transportation planning.

This article consists of six sections. Section 2 presents a theoretical framework that explores the topic of teleworking during the COVID-19 pandemic and its relationship to mobility, while Section 3 outlines the research questions and hypotheses. Section 4 describes the materials used and the proposed method. Section 5 presents the results obtained, and finally, Section 6 addresses the main conclusions of this study, the methodological limitations, and provides suggestions for future research.

2. THEORETICAL FRAMEWORK

2.1. Teleworking and the COVID-19 pandemic

Remote work has several nomenclatures, such as teleworking, distance working, home office, and virtual work (SOBRATT, 2020). Just as the term itself varies, teleworking can take on different work arrangements. It may be conducted full-time (covering total weekly hours) with the support of

Information and Communication Technologies (ICTs), or a part-time work arrangement, limited to certain days of the week or specific periods of the day. It can be done from different locations, outside the company's premises, usually at the worker's residence (Lavieri, Alves and Strambi, 2013; Olson and Primps, 1984). In this study, the term teleworking is defined as a work arrangement carried out outside the company's physical premises, occasionally supported by ICTs for remote monitoring, while also could enable a reduction or replacement of workers' travel.

The COVID-19 pandemic, as well as the various isolation measures to contain the spread of the virus, has brought numerous social changes, including in the ways people study, interact socially, and work (Shibayama et al., 2021). Although teleworking has been in practice for over 40 years (Nilles, 1975), it has long faced barriers such as infrastructure limitations and reluctance from both employers and employees. Consequently, usually it was typically used only as an occasional, informal arrangement within companies, becoming widespread as a formal work arrangement only during the COVID-19 pandemic in 2020 (Aguilera et al., 2016; Nguyen, 2021).

During this period, companies had to rapidly implement teleworking, while workers needed to adopt it, investing in and learning new technologies, adapting many activities to the virtual environment, and balancing work with family responsibilities (Caringal-Go et al., 2022; Fisher et al., 2020). Despite the challenges of quickly adapting to this work arrangement, both companies and workers experienced advantages and disadvantages, including reduced commuting costs for employees, lower infrastructure expenses for companies, as well as work-life conflicts and decreased motivation among workers (Buomprisco et al., 2021; Nguyen, 2021).

Since the end of the COVID-19 pandemic, teleworking levels have remained high compared to the pre-COVID-19 pandemic period, but not at the same levels reached during the COVID-19 pandemic (Wang, Kim and Mokhtarian, 2023; Costa et al., 2024). Some teleworkers and companies have maintained the regime, albeit with a different frequency and routine than during the COVID-19 pandemic (Green, Tappin and Bentley, 2020; Dias et al., 2022).

2.2. Impacts of teleworking on mobility

Even before the COVID-19 pandemic, the impact of teleworking on mobility had been a topic of research, as it was considered a potential tool for managing mobility. However, these studies yielded divergent results. Some suggested a possible reduction in travel demand and distances traveled (Choo, Mokhtarian and Salomon, 2005; Elldér, 2020), while others indicated an increase or minor reduction in travel frequency (Silva and Melo, 2018; He and Hu, 2015). Nevertheless, the limited adoption of teleworking prior to the COVID-19 pandemic hindered more accurate conclusions, further compounded by factors such as varying sample sizes, data structures, measurements, units of analysis, and modeling (Silva and Melo, 2018; Asmussen et al., 2024).

During the COVID-19 pandemic, travel restrictions led to a reduction in activities outside the home and an increase in teleactivities (Shamshiripour et al., 2020). Studies indicate that teleworking, boosted by the COVID-19 pandemic, contributed to a reduction in the frequency of trips to the workplace and altered commuting patterns (Haas, Faber and Hamersma, 2020; Silva et al., 2023). However, future concerns also arose, considering the potential for urban sprawl, whereby workers could choose to live further away from urban centers due to the flexibility provided by teleworking (Ramani, Alcedo and Bloom, 2024; Anik and Habib, 2023; Kappler and Silva, 2025).

After the end of the COVID-19 pandemic, studies analyzed the ongoing impacts of teleworking on mobility, showing indications that teleworking may continue to influence urban mobility patterns, with a possible continuation of remote working arrangements in large urban centers (Asmussen et al., 2024). In addition, changes in travel modes and increased travel distances are anticipated as a possible result of new residential choices enabled by teleworking (Caldarola and Sorrell, 2022; Gong, Liu and Zhang, 2024).

3. RESEARCH QUESTIONS AND HYPOTHESES

Remote work has the potential to reduce travel frequencies. However, there are concerns about a "rebound effect" and possible urban sprawl resulting from its use as a mobility demand management tool (Pedreira Jr. and Pitombo, 2024; Ilham et al., 2024). Studies on the advantages and disadvantages of teleworking for mobility have been practiced for nearly 50 years. O'Brien and Yazdani Aliabadi (2020) reviewed the evolution of this research, highlighting the variety of results and showing that, despite the extensive literature, controversies on the topic still remain.

Considering this, several questions could motivate the development of this important research topic. Does teleworking truly reduce travel distances, or is this arrangement chosen based on the actual distance from home to workplaces? Can this work arrangement affect future residential and travel mode choices? Could in-person work arrangements and longer travel distances be related to residential or workplace low accessibility?

These questions have gained increased attention nowadays. Studies indicate that teleworkers may travel longer distances than in-person workers, while also showing that the relationship between work arrangements and travel distances is more complex, involving factors such as the use of ICT, changes in travel modes, and trip purposes (Melo and Silva, 2017; Ravalet and Rérat, 2019; Asmussen, Mondal and Bhat, 2024). Additionally, from the perspective of developing countries, the following hypotheses related to traveled distances and work arrangements are proposed, as shown in Table 1.

Table 1: Associated and tested research hypotheses

Research questions	Hypotheses associated with the theme	References
Does teleworking truly reduce travel distances? Or is this arrangement chosen based on the actual distance from home to work?	**H1:** Longer travel distances are associated with the choice of teleworking when considering individual convenience.	(Ravalet and Rérat, 2019, Caldarola and Sorrell, 2024)
Could in-person work arrangements and longer travel distances be related to low local accessibility and spatial segregation?	**H2:** It is possible that some individuals who work in-person and commute long distances to their workplaces live in less accessible, spatially segregated locations.	(Ryan, Pereira and Andersson, 2023; Demoraes, Souris and Contreras Gatica; 2021)

Each possible relationship between travel distances and work arrangements should be examined, as the latter may run counter to the concept of sustainable mobility. Thus, this study has a testable hypothesis, which states that *"Longer travel distances are associated with the choice of teleworking when considering individual convenience*. In this case, the choice of teleworking (when possible) is made by individuals who reside at greater distances and/or in large capital cities. Thus, adopting teleworking in these cases can reduce the average traveled distances for work-related trips. Hypothesis 2 already addresses the low accessibility of spatially segregated locations and long distances to in-person work arrangements.

4. MATERIALS AND METHOD

4.1. Data

This study used data collected via an electronic form using the snowball sampling technique (Goodman, 1961). Due to the selection bias inherent in this procedure, it is important to highlight that the results cannot be extrapolated to the general population, and interpretations are limited to the sample in this study. It should also be emphasized that this methodological limitation, referring to sampling bias, is often observed in some studies in the literature that use online surveys (Baltar and Brunet, 2012; Voicu and Babonea, 2011; Campos et al., 2021). The questionnaire was divided into sections related to sociodemographic data, teleworking arrangements, commuting routines, and cognitive engagement, in addition to ICT proficiency.

4.2. Questionnaire design and adjustment

The questionnaire was first administered to a pilot sample to adjust the instrument and correct any inaccuracies. Four individuals were interviewed, with an average age of 37.8 years and an average response time of approximately 8 minutes and 34 seconds. Based on feedback from the pilot sample, further changes were made to the questionnaire to reduce potential respondent misunderstandings and improve data collection efficiency by restructuring certain questions. This questionnaire was intended for workers residing in Brazil, both teleworkers (part-time or full-time) and in-person workers.

The final structure consisted of four sections. The first section focused on sociodemographic characteristics, aiming to understand the workers' profiles. Data such as age, gender, place of residence, level of education, vehicle ownership, and work arrangement were collected. The second section, intended exclusively for teleworkers, included questions about the influence of the pandemic on adopting teleworking, the frequency of its use, and how the company monitors and supports teleworkers. The third section addressed commuting routines for all workers, such as frequency, duration, average distance traveled, average travel time, travel modes, and trip purposes. Finally, the last section examined workers' use of ICTs, aiming to relate technological proficiency to teleworking.

The descriptions of the variables collected and analyzed are shown in Table 2, with their respective measurement scales and response levels.

4.3. Data processing and analysis of distortions in self-reported data perceptions

In order to properly investigate the distances traveled, first, the relationship between distance and travel time self-reported by respondents had to be assessed. This step is justified by the fact that the individual's perception of distance is often inaccurate (Cools, Deuse and Reiter, 2024; Witlox, 2007; Soltani, Hoseini and Talebi, 2015). In contrast, travel time is usually reported more accurately, as it tends to be more easily memorized and estimated by individuals.

Thus, a correlation analysis was performed between the mean values of distance and time reported, aiming to verify the internal consistency of the data and identifying possible distortions. In addition, Wilcoxon non-parametric tests were applied to explore possible differences in mobility patterns according to the work arrangement (in-person, remote, or hybrid). This approach allows for the identification of statistically significant variations in the spatial and temporal behavior of commutes, according to the respondents' work arrangements.

Table 2: Description of the questionnaire variables

Group	Variable	Scale	Levels
Sociodemographics	Age	Numeric	-
	Gender	Nominal	Female; Male
	Educational level	Ordinal	High school diploma; Incomplete Bachelor's degree; Bachelor's degree; Master's degree; Doctoral degree
	Car ownership	Ordinal	0; 1; 2; 3 or more
	Residence location	Nominal	City and State
	Work arrangement	Nominal	In-person; Part-time telework; Full-time telework
Trips	Travel frequencies (by motive and mode)	Ordinal	None; Up to 3 times/month; Up to 3 times/week; Between 3 and 5 times/week; More than 5 times/week
	Travel distance (by motive, using main travel mode)	Ordinal	Less than 1 km; 1-5 km; 6-10 km; 11-15 km; More than 15 km
	Travel time (by motive, using main travel mode)	Ordinal	Less than 15 min; 15-30 min; 30-45 min; 45-60 min; 1-2 h; More than 2 h
	Travel distance to work	Numeric	-
	Travel time to work	Numeric	-
Work arrangement	Work arrangement	Nominal	In-person; Part-time telework; Full-time telework
ICTs	Confidence in handling computers (ICT 1)	Ordinal	Agreement scale (1: disagree completely to 5: agree completely)
	Ability to solve computer problems (ICT 2)	Ordinal	
	Ease to become acquainted with new computer programs (ICT 3)	Ordinal	
	Preference for computer jobs (ICT 4)	Ordinal	
	Interested in new computer technologies (ICT 5)	Ordinal	
	Proficiency in virtual meeting platforms (ICT 6)	Ordinal	
	Proficiency in activity management platforms (ICT 7)	Ordinal	

Source: Adapted from Dias et al. (2022).

4.4. Three-step procedure

After the questionnaire was developed and adjusted, and the data were processed, several steps were carried out to implement the three-step procedure. Initially, chi-square tests were used to identify independent variables significantly associated with work arrangements (variable of interest). Then, with these selected variables, multicollinearity tests were applied to remove independent variables that were highly correlated with each other. The three-step procedure began with the sequential application of a Decision Tree (DT) algorithm to determine the limit ranges of distances associated with the work arrangement, a chi-square test to statistically corroborate the limits determined by the DT algorithm, and the calibration of a multinomial logit model with three alternatives (1, 2, and 3—the work arrangements) to quantify and find statistical significance relationships. All steps are shown in Figure 1.

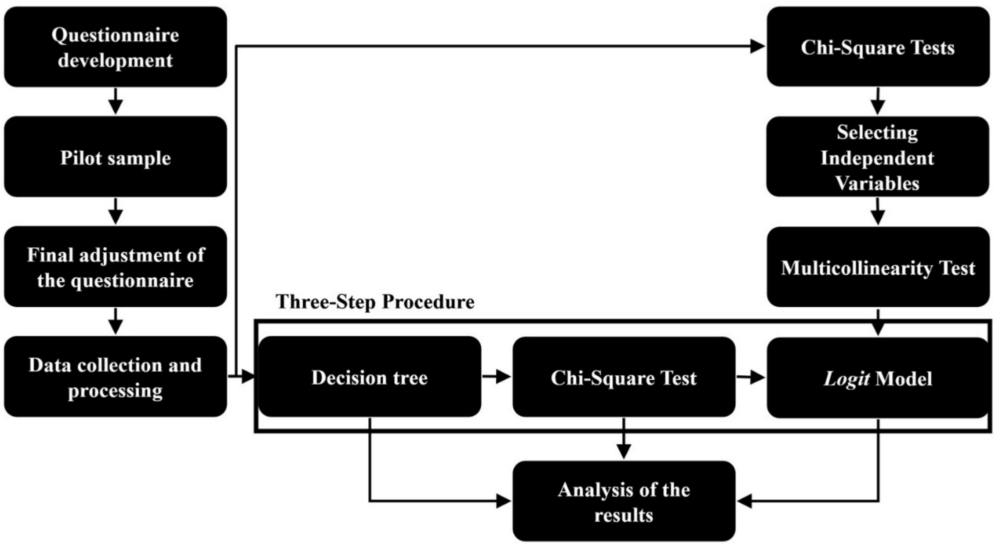

Figure 1. Flowchart of the methodological procedure.

The Classification And Regression Tree (CART) decision tree algorithm is based on binary trees, using induced rules associated with estimated values of the dependent variable. This algorithm divides the data into subgroups according to the values of the independent variables, establishing "If... then..." rules to obtain maximum internal homogeneity of the nodes obtained according to the values of the dependent variable. For categorical dependent variables, homogeneity is measured using the Gini index (Breiman et al., 1984). These segmentations present a tree-like structure, consisting of the root node, which contains all the data; the child nodes, which represent the subgroups established by hierarchical statements; and the leaf or terminal nodes, which cannot be further subdivided according to the stopping rules (Kass, 1980; Breiman et al. 1984; Quinlan, 1993).

The CART algorithm was initially used to determine the limits of distances traveled for commuting trips and their influence regarding choices of work arrangements. Using the numerical variable of distances to work as an independent variable and the work arrangement variable as a dependent variable, the relationships between distance and choice of work arrangement, as well as limit distances, were established.

Based on the distance ranges associated with the choice of teleworking and in-person work arrangements, a chi-square test was conducted to assess the significance of the relationship between these distances traveled and the work arrangements, thereby corroborating the associations identified in the decision tree. In this case, the null hypothesis states that there is no association between the work arrangements and the identified distance ranges, whereas the alternative hypothesis indicates the existence of an association between the variables. In a step prior to calibrating the logit model, chi-square tests of association between each of the variables and work arrangement were conducted to select independent variables. From the set of variables selected through the association test, a multicollinearity analysis is performed, calculating the Variance Inflation Factor (VIF), to select the independent variables.

Subsequently, a multinomial logit model is calibrated, which is based on random utility functions consisting of variables related to individuals and alternatives (Ben-Akiva and Lerman, 1985; McFadden, 1974). The model considered sociodemographic variables, mobility, distances, and engagement with ICTs, with the "In-person", "Part-time Telework" and "Full-time Telework" work arrangements as the set of three alternatives. For the calibration of the model, only coefficients significantly different from zero were considered, considering a significance level of 10%.

5. RESULTS AND DISCUSSION

5.1. Sample obtained

The data was collected between April 12 and June 30, 2022. A total of 247 responses were obtained from 63 cities in 18 states in Brazil. The sample has an average age of 31 years, with 56.7% female participants, 60.3% holding a college degree, 50.2% owning a car, and the majority residing in the Southeast region (74.5%). In addition, most participants are in-person workers (51.4%), followed by full-time teleworkers (27.5%) and part-time teleworkers (21.1%). In terms of commuting, the longest average commutes to work are those of part-time teleworkers, who travel around 21.1 km, while in-person workers commute an average of 10.3 km and full-time teleworkers only 6 km.

5.2. Data consistency: distortions in perceptions of self-reported data

Correlation analysis was applied between the "Commuting distance" and "Commuting time" variables. The Pearson's correlation coefficient and its p-value were evaluated, as shown in Table 3.

Table 3: Correlation results between average distance and average travel time for work purposes

Index	Value
R Coefficient	0.692
P-value	0.000

The value of the R coefficient indicates that there is a strong positive correlation between the data, while its p-value indicates that this correlation is significant, adopting a significance level of 5% (p-value < 0.05). Therefore, a strong correlation between these two variables is an indicator of consistency, suggesting that the self-reported distance data is plausible and follows a pattern consistent with the reported times. This also corroborates that travel time tends to be more accurately recalled by respondents than distance, but distances for repetitive trips, such as work, are more accurately reported (Witlox, 2007).

In addition to the correlation analysis, differences between average distances and average travel times for work between pairs of work arrangements were also evaluated. The test results are shown in Table 4.

Table 4: Wilcoxon p-value results for mean distance and mean time between pairs of work arrangements

	In-person vs Full-time	In-person vs Part-time	Full-time vs Part-time
Average distance	0.000	0.316	0.000
Average time	0.000	0.019	0.000

According to the obtained values, adopting a significance level of 5% (p-value < 0.05), it can be observed that there are differences in the average distance variable between the in-person and full teleworking arrangements and between full-time and part-time teleworking. It should also be noted that there are differences in the average time between the same work arrangements. Based on these results, the variable "Commuting Distance" can be used in subsequent analyses. Its association with the variable "Commuting Time" confirms that distortions in distance perception, commonly found in self-reported data, were mitigated in the database used.

5.3. Decision tree for determining distances

Using the "Work arrangement" (dependent variable) and "Commuting distance" (independent variable) variables, the decision tree was obtained containing commuting distance limits for the different work arrangements, shown in Figure 2. Using the CART algorithm, it was observed that teleworkers travel, on average, between 15.5 km (node 2) and 37.5 km (node 5). Meanwhile, in-person workers travel distances less than 15.5 km (node 1) or greater than 37.5 km (node 6). This difference in distances between teleworkers and in-person workers has been studied in the literature, which also indicates greater distances for teleworkers and similar ranges of values (Melo and Silva, 2017; Ravalet and Rérat, 2019). Node 6 possibly characterizes the group of in-person workers who live in less accessible locations, known as spatial segregation, which is related to Hypothesis 2 (H2).

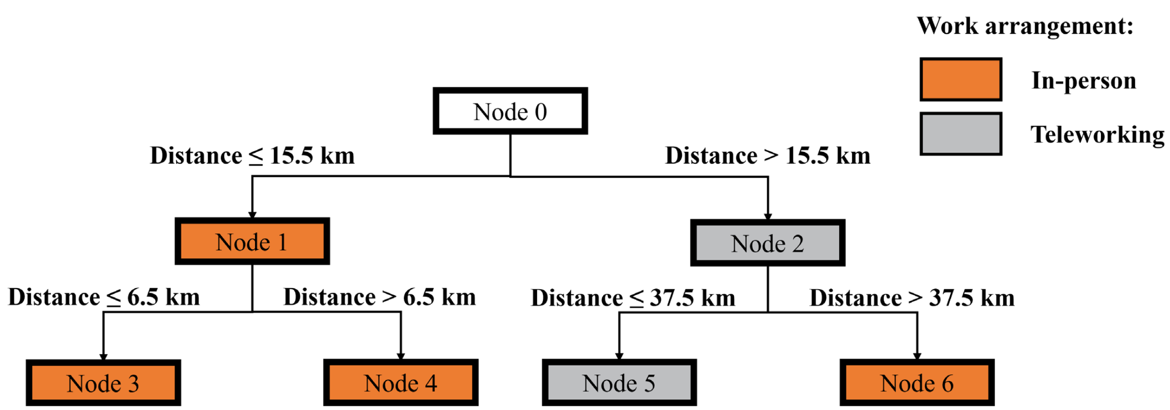

Figure 2. Decision tree diagram for distances.
Source: Adapted from Dias, Ribeiro and Pitombo (2023).

Subsequently, individuals' profiles related to each terminal node were evaluated. Node 3 consists of individuals who work predominantly in-person, have an average age of 31.5 years, mostly have completed higher education (62.07%), own one car (47.13%), use a car/motorcycle as a driver (50.57%), and travel 3.3 km to work. For nodes 4 and 5, the profiles are similar, differing only in their choice of work arrangement. They have an average age of 33.3 and 30.9 years, respectively, have completed their higher education (66.07% and 47.83%, respectively), own 1 car (60.71%), and use a car/motorcycle as a driver (50% and 52.17%, respectively). The average commute distance is 10.3 km (node 4 – in-person work arrangement) and 23.6 km (node 5 – teleworking work arrangement), respectively. The results for nodes 4 and 5 show the longest distances for teleworkers, associated with Research Hypothesis 1. Finally, node 6 consists of in-person workers with an average age of 31.7 years. This node has the highest number of individuals with complete higher education (86.67%), also 66.67% of individuals owning 1 car, however, most commute using public transportation (bus or subway) to commute trip (46.67%) and travel an average distance of 91.3 km.

5.4. Chi-square test for determining distance ranges

To test the significance of the relationships found in the decision tree between work arrangements and distances traveled, the chi-square test was applied. To this end, the distance ranges obtained were categorized. For the analysis of the first level of the tree, distances shorter than 15.5 km were defined as category 0, while longer distances were defined as category 1. In the second test, distances shorter than 15.5 km were again classified as 0, while values between 15.5 and 37.5 km were designated as 1 and distances longer than 37.5 km as class 2. Finally, for the third analysis, distances shorter than 6.5 km were assigned category 0, distances between 6.5 and 15.5 km were assigned category 1, and distances longer than 15.5 km were assigned category 2. The test results are shown in Table 5. By adopting a significance level of 5%, it can be seen that all p-values were significant, which confirms the hypothesis of a relationship between the limits of distances traveled to work and the choice of work arrangements (H1).

Table 5: Results of chi-square tests for distances traveled according to work arrangements

Categories	Variables	Chi-square	p-value	Degrees of freedom
(0: dist ≤ 15.5km; 1: dist > 15.5 km)	Work arrangement (0: In-person; 1: Teleworking)	581.775	0.01587	1
(0: dist ≤ 15.5km; 1: 15.5 km < dist ≤ 37.5 km; 2: dist > 37.5 km)	Work arrangement (0: In-person; 1: Teleworking)	932.182	0.00946	2
(0: dist ≤ 6.5 km; 1: 6.5 km < dist ≤ 15.5 km; 2: dist > 15.5 km)	Work arrangement (0: In-person; 1: Teleworking)	11.489	0.00320	2

H_0: there is no association between distance ranges and work arrangements. H_1: there is an association between distance ranges and work arrangements.
Source: Adapted from Dias, Ribeiro and Pitombo (2023).

As the test only indicates whether there is an association between distance ranges and work arrangements, graphs were created (Figure 3 (a), (b) and (c)) showing the quantities of each work arrangement category within each distance range to obtain the direction of the effect studied or the direction of the association.

Regarding the direction of the effect, it can be seen in Figures 3 (a) and (c) that for shorter distances, the presence of teleworkers is greater. Analyzing Figure 3 (b), for distances of 6.5 to 15.5 km, the presence of face-to-face work increases. Finally, as distances increase, the presence of telework also increases again, as shown in Figures 3 (a) and (c).

5.5. Calibration of multinomial logit model

The multinomial logit model was calibrated to investigate the relationships between sociodemographic variables, displacements, distances traveled, ICTs use and proficiency, and work arrangements (primary and secondary objectives). Prior to calibration, independent variables associated with the type of work arrangement were selected using a chi-square test. The results of the tests to select potential independent variables are shown in Table 6.

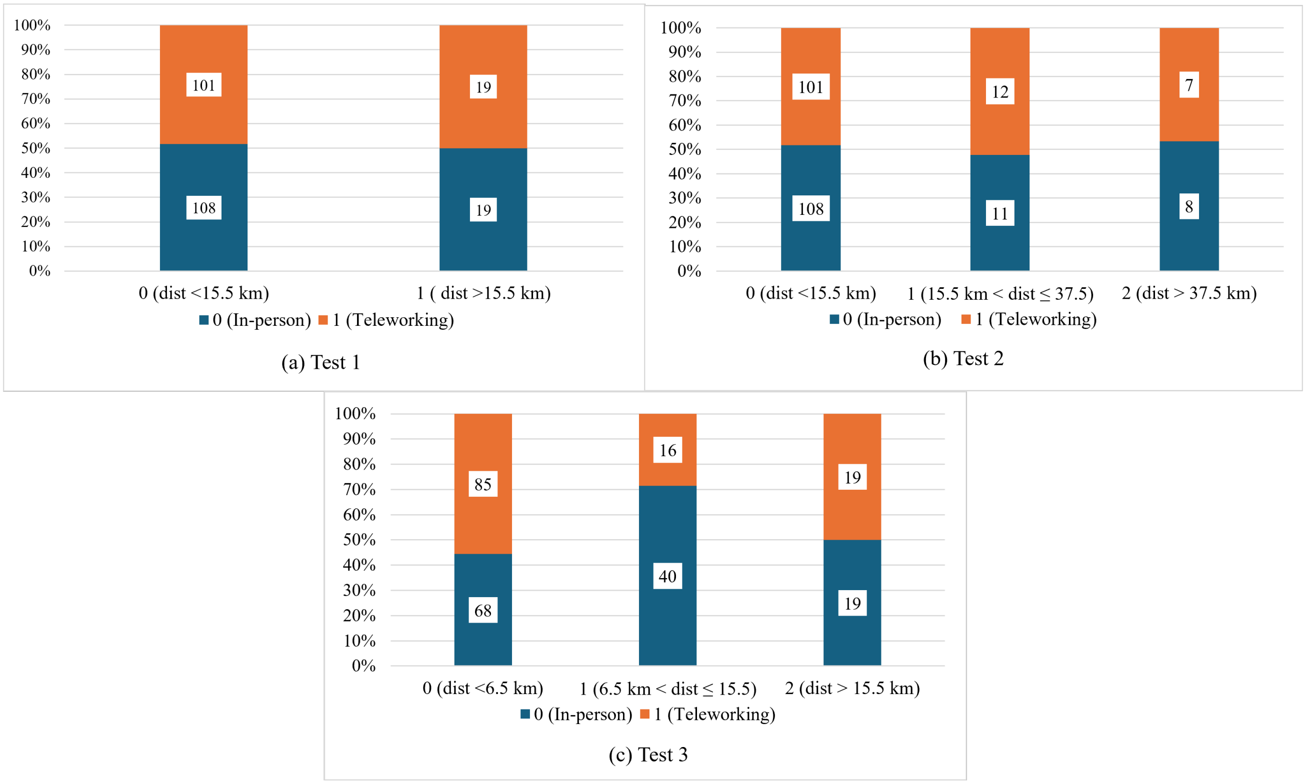

Figure 3. Work arrangement category within each distance range (a) Test 1; (b) Test 2; (c) Test 3.

Regarding sociodemographic variables, there is a significant association between educational level and work arrangements, as well as between region and work arrangements. These associations were expected, given that teleworking is associated with a higher level of education among teleworkers (Góes, Martins and Nascimento, 2021) and with regions of greater economic development and a higher concentration of professions that can be performed remotely (Góes, Nascimento and Martins, 2020).

Based on the results of the chi-square tests for comparisons between commuting variables and work arrangements, there are significant differences between work arrangements across several variables of trip frequency, travel time, and travel distance.

For work-related trips, both general and by car (as a driver or passenger), public transportation, and mobility apps, the p-values indicate significant differences between all work arrangements. This indicates that the work arrangement significantly influences the frequency with which individuals travel to work, either in general terms or using these specific travel modes.

Similarly, the work arrangement also influences the frequency of trips for shopping, health, and leisure purposes, that is, the way work is performed affects the need or frequency of travel for these purposes.

On the other hand, for trips using bicycles, taxis, and public transportation regarding other trip purposes, no statistically significant differences were observed between the work arrangements. This suggests that the work arrangement does not substantially influence the use of these travel modes for other purposes.

Travel times for work and leisure also seem to be influenced by the type of work arrangement, as do the traveled distances for work, shopping, and leisure.

Table 6: Results of chi-square tests to select potential independent variables for calibration of the multinomial logit model

Group	Variable	p-value
Sociodemographics	Gender	0.186
	Age	0.653
	Educational level	0.007
	Region	0.002
	Car ownership	0.112
Trips	TF (work) general	0.000
	TF (work) on foot	0.069
	TF (work) bicycle	0.956
	TF (work) ride	0.000
	TF (work) driver	0.000
	TF (work) public	0.001
	TF (work) app	0.012
	TF (work) taxi	0.416
	TF (shopping) general	0.014
	TF (leisure) general	0.006
	TF (health) general	0.013
	TF (O) on foot	0.037
	TF (O) bicycle	0.273
	TF (O) ride	0.032
	TF (O) driver	0.046
	TF (O) public	0.760
	TF (O) app	0.715
	TF (O) taxi	0.260
	TT (work)	0.000
	TT (shopping)	0.325
	TT (leisure)	0.033
	TT (health)	0.540
	TD (work)	0.000
	TD (shopping)	0.032
	TD (leisure)	0.033
	TD (health)	0.307
ICTs	ICT 1	0.087
	ICT 2	0.176
	ICT 3	0.213
	ICT 4	0.005
	ICT 5	0.224
	ICT 6	0.000
	ICT 7	0.003

H_0: there is no association between the variables and work arrangements.
H_1: there is an association between the variables and work. arrangements.
TF = trip frequency; O = other trip purposes besides work; TT = travel time; TD = travel distance; ICT 1: Confidence in handling computers; ICT 2: Ability to solve computer problems; ICT 3: Ease to become acquainted with new computer programs; ICT 4: Preference for computer jobs; ICT 5: Interested in new computer technologies; ICT 6: Proficiency in virtual meeting platforms ; ICT 7: Proficiency in activity management platforms.
Source: Adapted from Suzuki Goshima et al. (2023).

Regarding the use of Information and Communication Technologies, an association between the preference for computer-based work (Technology 4) and the work arrangement can be observed, as well as proficiency in the use of virtual meeting platforms (Technology 6) and activity management platforms (Technology 7). This higher familiarity with such technologies may be related to the greater use of these tools in teleworking for monitoring and performing activities.

In addition, for the variable “distance traveled”, this was categorized considering the limits determined by the CART algorithm, with distances less than 15.5 km defined as category 0, and longer distances as category 1. After selecting the initial variables using chi-square tests, multicollinearity tests were also performed and VIF was calculated to remove variables that could cause problems in calibrating the multinomial logit model (Table 7).

Table 7: VIF values of the independent variables

Variable	VIF
Educational level	1.233
Region	1.352
TF (work) general	1.875
TF (work) ride	1.739
TF (work) driver	2.736
TF (work) public	1.592
TF (work) app	1.171
TF (shopping) general	1.565
TF (leisure) general	1.561
TF (health) general	1.364
TF (O) on foot	1.398
TF (O) ride	1.505
TF (O) driver	1.802
TV (work)	3.008
TV (leisure)	1.516
TD (work)	2.914
TD (shopping)	1.419
TD (leisure)	1.790
ICT 4	1.472
ICT 6	2.115
ICT 7	1.720
Average distance	1.591

According to Table 7, all VIF values were below 5, indicating low/moderate multicollinearity (Hair et al., 2010; Kyriazos and Poga, 2023; James et al., 2013). Therefore, all independent variables previously selected by the chi-square tests were retained, as there were no multicollinearity problems. After calibration, the independent variables associated with insignificant coefficients were removed.

Finally, the three utility functions of the logit model were stipulated according to Equations 1, 2, and 3. The independent variables and alternative sets of the model are listed in Table 8.

$$V_{1j} = ASC_1 + \beta_{1TF\_O\_DRIVER} \times TF\_O\_DRIVER_j + \beta_{1TF\_W\_PUBLIC} \times TF\_W\_PUBLIC_j$$
$$+\beta_{1TF\_W\_GENERAL} \times TF\_W\_GENERAL_j + \beta_{1TF\_W\_DRIVER} \times TF\_W\_DRIVER_j + \beta_{1ICT6} \times ICT6_j \quad (1)$$

$$V_{2j} = \beta_{2TF\_W\_APP} \times TF\_W\_APP_j + \beta_{2TF\_W\_RIDE} \times TF\_W\_RIDE_j$$
$$+\beta_{2TF\_W\_GENERAL} \times TF\_W\_GENERAL_j + \beta_{2TF\_W\_DRIVER} \times TF\_W\_DRIVER_j + \beta_{2ICT7} \times ICT7_j \quad (2)$$

$$V_{3j} = ASC_3 + \beta_{3AVERAGE\_DIST} \times AVERAGE\_DIST_j + \beta_{1TF\_W\_GENERAL} \times TF\_W\_GENERAL_j \quad (3)$$

Table 8: Description of the independent variables of the model and the set of alternatives

Variable	Description
Set of alternatives	(1) In-person workers
	(2) Full-time teleworkers
	(3) Part-time teleworkers
TF_O_DRIVER	Trip frequency for other purposes by car (driver)
TF_W_PUBLIC	Frequency of work-related travel by public transport
TF_W_GENERAL	Frequency of work-related travel
TF_W_DRIVER	Frequency of work-related travel by car (driver)
TF_W_APP	Frequency of work-related travel by app (ex: Uber, 99)
TF_W_RIDE	Frequency of work-related travel by car (ride)
ICT6	ICT 6: Proficiency in virtual meeting platforms
ICT7	ICT 7: Proficiency in activity management platforms
AVERAGE_DIST	Average distance to work longer than 15.5 km. (0) No; (1) Yes

Source: Adapted from Dias, Goshima and Pitombo (2024).

Only variables related to parameters significantly different from zero were included in the final model, adopting a confidence level of 90% (α = 0.1). The main results of the model calibration are shown in Table 9.

The results show that in-person workers are less likely to make frequent trips as drivers for purposes unrelated to work (TF_O_DRIVER), as seen by the negative coefficient associated with this variable. On the other hand, they are more likely to use public transportation for work-related travel (TF_W_PUBLIC), suggesting a dependence on or preference for this travel mode for work. The choice of public transportation is possibly related to lower income classes (Bokhari and Sharifi, 2024; Pereira et al., 2021). This assumption may be consistent with Hypothesis 2 of this study, related to the spatial segregation of the lower-income population, greater dependence on public transportation, and the in-person work arrangement.

Furthermore, in-person workers travel for work more often ($TF\_W\_GENERAL$) and are more likely to use a car as a driver for work-related trips (TF_W_DRIVER), as shown by the positive coefficients.

For full-time teleworkers, the negative coefficients associated with the variables of work-related trips as a driver (TF_W_DRIVER), ride (TF_W_RIDE), and by app (TF_W_APP) suggest a lower frequency of trips in these categories. This behavior is consistent with the nature of full-time telework, where the need to commute to work is reduced.

Table 9: Estimated parameters of the multinomial logit model

Work arrangement		Independent variable	β	Odds Reasons (OR)	p-value
1	In-person	(Intercept)	4.376		0.002 ***
		TF_O_DRIVER	-0.35	0.704	0.026 **
		TF_W_PUBLIC	0.704	2.022	0.001 ***
		TF_W_GENERAL	0.418	1.52	0.000 ***
		TF_W_DRIVER	0.69	1.994	0.000 ***
		ICT6	-1.175	0.309	0.000 ***
2	Full-time teleworking	TF_W_APP	-0.884	0.413	0.037 **
		TF_W_RIDE	-1.039	0.354	0.004 ***
		TF_W_GENERAL	-0.642	0.526	0.000 ***
		TF_W_DRIVER	-0.924	0.397	0.000 ***
		ICT7	0.377	1.458	0.095 *
3	Part-time teleworking	(Intercept)	-0.858		0.359
		AVERAGE_DIST	1.021	2.777	0.021 **
		TF_W_GENERAL	0.223	1.25	0.041 **

* p-value < 0.10; ** p-value < 0.05; *** p-value < 0.01.
Source: Adapted from Dias, Goshima and Pitombo (2024).

Regarding ICTs, for in-person workers, the negative coefficient of the ICT6 variable indicates that high skills in using virtual meeting platforms are associated with a lower inclination toward in-person work. For full-time teleworkers, proficiency in using activity management platforms (ICT7) has a positive coefficient, indicating that these workers tend to increasingly value these tools and are more inclined to adopt full-time teleworking.

Finally, the dummy variable for average distance to work greater than 15.5 km (AVERAGE_DIST) has a positive coefficient in the part-time teleworking arrangement. This suggests that partial teleworkers travel longer distances to arrive at their workplace, which corroborates the findings of De Vos, Van Ham and Meijers (2019) and Dias, Goshima and Pitombo (2024).

5.6. Public policies and practical applications related to the phenomenon

Based on the results found, it was observed that teleworking influences urban travel patterns, which requires the formulation of specific public policies to mitigate its negative effects and maximize its benefits. For in-person workers, who continue to make work-related trips, it is essential to invest in increasing the frequency, quality, and price regulation of public transportation (Silva et al., 2023; Hu and Chen, 2021). According to the results obtained in the study sample, in-person workers use cars as their main travel mode, which can lead to an increased demand for road infrastructure in several cities. Using private transportation can be discouraged by expanding and improving public transportation and implementing shared mobility strategies, for example (Silva et al., 2023; Costa, Pitombo and Souza, 2022).

Furthermore, teleworking not only affects commuting, but also influences other daily activities, such as leisure and shopping, which require policies that promote the decentralization of working hours. This flexibility can be used as an effective demand management tool, reducing peaks in transportation systems (Wöhner, 2022; Nilles, 1991; Motte-Baumvol and Schwanen, 2024).

Finally, it is essential to consider the situation of part-time teleworkers who live further away from urban centers, for whom public transportation must be adjusted and accessibility to these regions improved, promoting integration with other travel modes, such as bicycles and on-demand transportation services (Silva et al., 2023; Costa, Pitombo and Souza, 2022).

Public policies that consider the different contexts of various workers contribute to a more efficient adaptation of urban mobility in response to the transformations brought about by teleworking.

6. CONCLUSIONS, LIMITATIONS AND FUTURE STUDIES

The main objective of this study was to investigate the relationships between different work arrangements (in-person, part-time teleworking, and full-time teleworking) and the distances traveled by workers. Secondarily, it investigated the relationship between work arrangements and trip frequency, travel modes, and the use of Information and Communication Technologies (ICTs). This analysis was motivated by changes in urban mobility behavior induced by the COVID-19 pandemic, which drove the adoption of teleworking and brought new perspectives to urban and transportation planning.

To achieve these objectives, data was collected using an electronic questionnaire, applying the snowball sampling technique. The procedure adopted included correlation analyses, nonparametric statistical tests, the use of decision tree algorithms (CART), chi-square tests, and, finally, calibration of a multinomial logit model to quantify the associations between work arrangements and the independent variables of interest.

The main findings of this study indicate that the work arrangement is associated with distances, as well as several sociodemographic, behavioral, and technological variables. It was observed that the level of education and the region of the country significantly influence the type of work arrangement adopted, with a higher prevalence of telework in more developed regions and among individuals with higher levels of education. In addition, characteristics related to trips, such as the frequency of commuting trips and the distances traveled, also vary according to the work arrangement. Finally, the study showed that factors related to engagement and proficiency in the use of Information and Communication Technologies (ICTs) – such as a preference for computer-based work, familiarity with virtual meeting platforms and activity management tools – are directly related to adopting teleworking arrangements, whether part-time or full-time.

Regarding the hypotheses on distances traveled and work arrangements, Hypothesis 1, which was fully tested, was explored, showing that longer distances are likely linked to teleworking arrangements, where teleworking (part-time or full-time) was an individual convenience for those who already live far from their workplaces or in larger cities/capitals. Hypothesis 2, partially tested, may be linked to findings related to individuals who work in person and travel long distances to work, in addition to using public transportation by the in-person category. The more frequent use of public transportation may be related to lower income levels and, consequently, to the population residing in places with low accessibility. However, further investigation is necessary, as this study does not have data of this nature for a more thorough investigation.

The causal relationships between work arrangements and distances can split into two different directions. It is reasonable to assume that, given the possibility of teleworking offered by companies, individuals who already face long commutes opt for this work arrangement, even if only part-time, as a way to mitigate the temporal and physical costs of travel. On the other hand, moving to more remote areas, made possible by the flexibility of teleworking, represents a future decision with the potential to contribute to urban sprawl. Such relationships are relevant and have considerable potential for future research with different methodological approaches.

Regarding limitations, the study uses snowball sampling, which does not allow for the extrapolation of results to the entire population. For future data collection, it is suggested that social media boosting be used to preserve the characteristics of interest and increase the representativeness of the sample. In addition, the absence of questions related to the accessibility of individuals' places of residence did not allow for a detailed exploration of Hypothesis 2. The absence of socioeconomic variables such as income or some robust proxy variable was also noted, which diminishes the impact of findings related to lower income groups (Hypothesis 2).

For future research, it is recommended that variables be included to assess the residential choices of teleworkers and in-person workers, as well as variables to measure the accessibility of places of residence. Additionally, the inclusion of variables capable of measuring workers' income is proposed.

This study contributes to the understanding of work arrangements and their impacts on mobility patterns, especially concerning distances traveled, travel modes used, and travel frequencies for different trip purposes. The reduction in travel frequency among teleworkers points to a positive impact on urban mobility, suggesting that teleworking can be an efficient tool for managing transportation demand. On the other hand, the increase in distances traveled raises concerns about negative effects, such as urban sprawl, highlighting the need for future studies that deepen the relationship between the choice of work arrangement and urban sprawl.

AUTHORS' CONTRIBUTIONS

VCD: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; CYSG: Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Writing – original draft; CSP: Conceptualization, Formal analysis, Funding acquisition, Project administration, Resources, Supervision, Supervision, Validation, Writing – review & editing.

CONFLICTS OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence tools were used in the research reported here or in the preparation of this article.

Data Availability Statement

The data supporting the results of this study are not publicly available due to the privacy of the research participants.

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