

Article

Study into the Impact of the Pandemic on Travel Patterns within the Metropolitan Area of Rio de Janeiro

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Abstract: Despite the ending of social distancing and post-pandemic return to normal activities, the impacts of COVID-19 on urban mobility persist, particularly with regard to public transport. Consequently, this study looks into the post-pandemic changes in travel patterns, seeking to comprehend the effects on the municipalities and suggest helpful measures geared to achieving more sustainable patterns following the lockdown isolation. The chosen case study is the Metropolitan Area of Rio de Janeiro, Brazil. The study was divided into four distinct phases, namely understanding the problems, choosing the study area, field research and making recommendations based not only on the literature but on consultation with operators and experts. The methodological process involves the analysis of data from the field research, to assess any changes in patterns that may have been identified. The results show the changes in the means of travel, with emphasis on a preference for app-based transport services, to the detriment of sustainable transport. The study also shows the challenges facing public transport and the relationship between the choice of travel means and the socioeconomic profile of the passenger.

Keywords: post-pandemic effects; sustainable mobility; travel patterns; urban transport; transport systems



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1. Introduction

Due to the social distancing imposed during the pandemic, it was expected that there would be a reduction in travel demand. Among the leading causes were the growing adoption of remote work and the convenience of making purchases online, which significantly affected the population's participation in leisure and work activities [1] and, consequently, had an impact on public transport, involving both diminished travel and changed in travel patterns [2]; 2023 data from the FGV (Getúlio Vargas Foundation) corroborates this scenario, showing that a substantial proportion of companies claimed to have adopted the remote working regime, either partially or fully [3]. This study is particularly interested in analyzing the changes in travel distribution within the Rio de Janeiro Metropolitan Area (RJMA), to provide a new understanding of the urban environment.

The passenger and freight transportation system of the RJMA offers a complex network covering a variety of means [4]. Travel is predominantly conducted by road, due to the nature of the land use, as well as complex socioeconomic and institutional influences in the region. However, this variety of options faces frequent challenges, such as persistent

congestion, structural limitations, and coverage deficiencies. The high-capacity networks, like the main highways, follow radial patterns in relation to the city of Rio de Janeiro, the state capital. The city's neighborhoods are thus interconnected by express and arterial routes, with few alternative options. This is because the development of the RJMA is closely related to the growth of the city of Rio de Janeiro, directly affecting the occupancy pattern of the mesoregion [5].

To counteract the external influences on traffic, it is necessary to adopt strategies that will alleviate the pressure on urban roads [6], such as encouraging the use of public transport. However, a 2023 survey carried out by SEMOVE (Federation of Companies Dealing with Mobility in the State of Rio de Janeiro), showed that, since 2014, part of the public transport system had already seen falling demand, in the case of municipal and intercity buses, ferries and trains, and that this was accentuated during the pandemic period [7]. Weighed against this, there was considerable growth in the use of vans, indicating a change in individual travel patterns, as people started using lower-capacity transport. Furthermore, the NTU (National Association of Urban Transport Companies) monitored the demand for buses in Brazil, from the beginning of the pandemic period (March 2020) to February 2023, noting that the demand was still 17.2% below that observed in February 2020 [8]. It is that new travel profile that we sought to investigate.

This study aims to perform a comprehensive and in-depth description of the transport system within the Rio de Janeiro Metropolitan Area. Our objective is to fully understand the complexities and dynamics that permeate this system, encompassing factors such as road infrastructure, available means of transport, connectivity between different transport means and the impact of these factors on urban mobility, taking into consideration the impact of the pandemic on the travel patterns within the mesoregion.

This study will mainly contribute towards:

- identifying a possible new post-pandemic travel profile;
- a better understanding of the correlations between geographic and socioeconomic features and the means of transport utilized;
- estimating the effects of the pandemic on public transport;
- knowledge of and estimating the growth trend of app-based transport services;
- selecting measures to be adopted by public policies focusing on sustainable mobility.

Furthermore, it is hoped that this study will help to further understand the new transport dynamics observed in numerous cities around the world and provide support for its assessment and possible changes. It is important to note that this paper does not address issues related to COVID-19 transmission. Instead, our research is dedicated to investigating the subsequent effects of travel patterns post-pandemic.

In addition to this Section 1, this work is organized as follows. Section 2 looks at the impact of the pandemic on public transport, putting what motivated this study into context. The methodological procedure used in this study is the subject of the following section. Section 4 provides an overview of the RJMA, with a description and interpretation of the data obtained from the interviews conducted. Section 5 offers recommendations based on critical reading of the literature and the opinions of the experts consulted. Finally, Section 6 draws conclusions and makes recommendations for future research.

2. Impact of the Pandemic on Public Transport

In exploring the importance of public transport and understanding the effects of diminishing demand, this review focuses on the motivations behind the study, emphasizing its objectives and reasons.

The pandemic period emphasized the vital importance of public transport in the functioning of municipalities, by enabling the economic activities deemed essential by the public authorities and, particularly, by ensuring the provision of health, public safety, urban cleaning, and the services of other strategic sectors during the period. However, both in Brazil and around the world, it was strongly affected by the health control requirements.

This section will describe some of the problems that arose during that period, such as the drop in demand, the financial impact of that decline and operational alternatives that were employed during the period.

The sharp fall in demand and consequent reduction in revenue had a negative impact on the financial position of both public and private operators. In contrast to Brazil, Western European economies had already heavily subsidized public transport services before the pandemic, as reported by the European Metropolitan Transport Authorities [9], allowing them to maintain high service standards despite reduced demand.

In this context, the Netherlands and Sweden provided monetary compensation to transport operators, ensuring the continued operation of their systems [10]. Similarly, Chile, where the services have been privatized since the '90s, also allocated financial resources.

In Latin American cities, studies have shown substantial changes in urban mobility patterns during the COVID-19 pandemic, characterized by a notable decrease in public transport usage and an uptick in active transportation modes such as walking and cycling [11]. Initiatives to expand cycling infrastructure in cities such as Bogotá and São Paulo were accelerated to accommodate this shift in preferences [12]. Moreover, research highlights the socio-economic disparities exacerbated by the pandemic, affecting the accessibility to transportation options for lower-income populations [13].

In the state of Rio de Janeiro, passenger transportation by bus, which had already seen a 26% reduction in paying demand (2014–2019), the situation deteriorated. In the RJMA, for example, there was a 73% drop in demand in April 2020, according to SEMOVE [7]. However, it was not possible to reduce the supply by the same proportion, for two reasons: (a) in order to guarantee a minimum plausible supply and (b) the need to reduce vehicle occupancy, avoiding internal crowding so as to mitigate the potential spread of the illness.

A simplified representation of the situation of the urban transport system in the RJMA, covering low, medium and high-capacity means, is shown in Figure 1. Light Rail Vehicles and Bus Rapid Transit represent medium capacity means. Ferries can range from medium to high capacity. Trains and the subway are high-capacity means of transport, with high passenger demands. Finally, buses can range from low to medium capacity, covering urban and suburban routes.

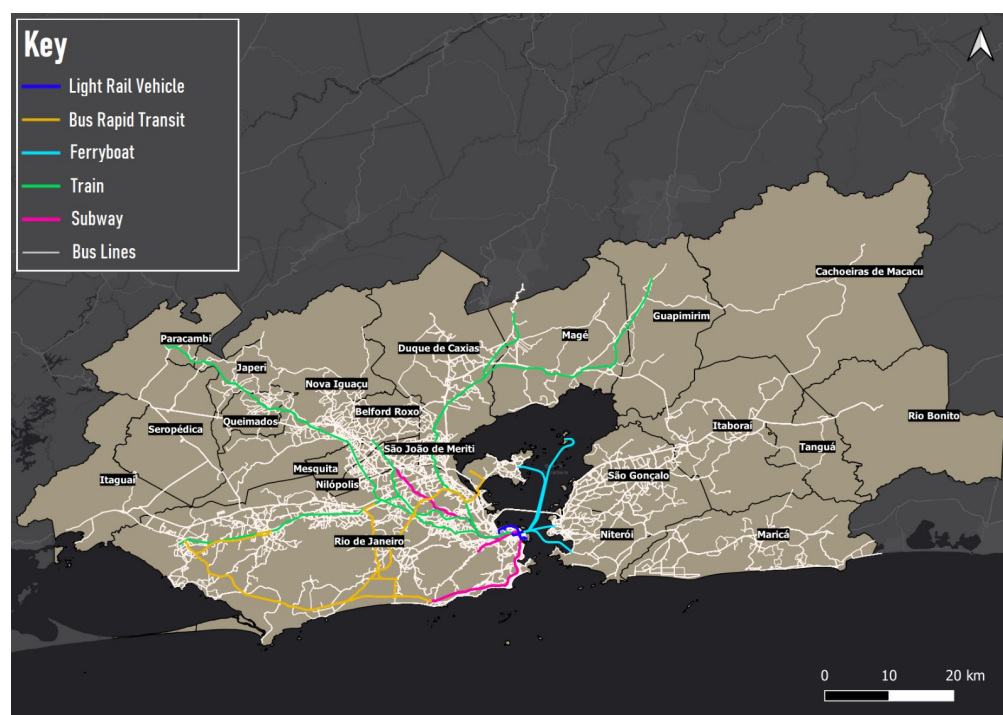


Figure 1. Low, medium and high-capacity public transport systems in the RJMA.

For a better understanding of the transport network within the mesoregion, we briefly describe some of the systems that it comprises: (i) Light Rail Vehicle (LRV), which operates in a network that is integrated with ferries, trains and subways within the state capital's central; (ii) Bus Rapid Transit (BRT), which connects different points within the state capital; (iii) Subway, which comprises three main operational lines; (iv) Train, which is responsible for connecting various municipalities, embracing urban and suburban areas; (v) Ferryboat, devoted to public transport operations by waterway, connecting the eastern region and the state capital; (vi) municipal and intercity buses, including low-capacity transportation with more extensive reach, which connect with the state capital and other municipalities.

Since the model of financial support for public transport in Brazil is highly dependent on the fares paid by the passengers, with very few examples to date of government subsidies or other sources of revenue that could reasonably cover the operating costs, the main challenge for the sector during the pandemic was the discrepancy between revenue and fixed operating costs.

The crisis generated by the COVID-19 pandemic brought existing problems to the fore, as well as creating new ones. That is why it is so important not only to provide quality service but also to adapt to new requirements, ideally making use of new technology.

In this respect, user information systems, to know the moment the vehicle has arrived, and applications that indicate vehicle occupancy, are some of the new allies of the public transport system. An initiative that is also gaining ground is on-demand public bus transport systems. This can be beneficial in situations where there is not enough demand to justify a conventional service and can be used to offer a quality service in response to a specific demand, a demand that conventional public transport has been losing in recent years.

The system works as an alternative to public transport and allows the control of passenger boarding, as well as providing users with predictable vehicle arrival times at the waiting point. In this way, the operators are able to control the number of people inside the buses and distribute the flow of users, avoiding overcrowding. This has happened in a number of cities around the world, such as Shenzhen, in China, where the operating company itself encourages greater use of on-demand bus services, which started to be offered for the first time in 2017. Passengers can reserve seats and the supply of vehicles is adjusted according to the demand. Various special "Resumption of Work" services were also introduced to transport workers from nearby cities and provinces back to Shenzhen after the pandemic lockdown ended [14].

That was a measure that converges with the technical paper published by COPPE [15], which indicates the need to reorganize the fleet for the post-pandemic period, by conducting a quantitative survey of the passengers, based on ticketing records, thus enabling a redistribution aimed at avoiding overcrowding in excess of the limit imposed by the health authorities. Furthermore, according to the paper, NACTO, an association of 81 major North American cities and public transport agencies, considers it necessary to prioritize routes whose origin and destination are in areas that greatly depend on public transport and to identify intermediate areas, where passengers are unable to board, due to the bus being full, so as to make empty vehicles available and use those areas as new starting points, thereby alleviating the pressure on certain routes.

Most of the measures recommended in this document by experts were not implemented, leading to a decline in the quality of the services and problems being highlighted. Travel experiences on crowded buses, due to changes in supply and aggravated by the resumption of economic activities, had a negative effect on the passengers' perception of comfort and safety. Consequently, many people failed to notice the diminishing demand, but only the decline in the quality of the services provided. According to Ref. [16], based on qualitative research among passengers, it was possible to perceive that the pandemic drew attention to old problems in the bus system, involving aspects of planning, operation, communication, and regulation, among others.

The pandemic changed people's expectations regarding the travel conditions on public transport (e.g., in terms of distance, comfort, health standards, etc.). What is more, new mobility practices were observed. Increased levels of walking and cycling on local and shorter journeys were noted, reflecting a change in lifestyles and habits. On the other hand, trends emerged in working from home, hybrid work and flexible working hours [17].

Despite it being an essential service for the population, a number of factors affect people's decisions regarding the use of public transport. The fare price, the user's social class, the characteristics of the journey, the quality of the service, the cost of similar alternative services and weather conditions are examples of factors that affect this demand [18].

When it comes to service quality, this aspect is even more complex since customer satisfaction is related to the perceived quality of the service, which is a factor of the relationship between the expectation one has for the service and the perceived performance of the service [16]. In the context of public transport, passengers consider themselves satisfied when the experience meets or exceeds their expectations, and it is precisely that factor that allows them to choose the same service in the future. The attributes of choice are key factors when thinking about changing the means of transport and understanding people's real needs and expectations helps when designing a system to serve the population.

Making transport systems compatible with the city's spatial structure offers great potential for organizing the territory in order to promote non-motorized and collective means of transport and rationalize the use of automobiles, creating a relationship in which everyone benefits [19]. In this context, it is important to be aware of the new core factors that emerged with the advent of the hybrid and remote work model during the pandemic, as people avoided long commutes and took the opportunity to perform various activities close to their homes, during their work breaks.

3. Materials and Methods

This study focuses on analyzing the post-pandemic travel patterns in municipalities within the Rio de Janeiro Metropolitan Area, examining the dynamics that influence the transport system. To that end, the research opens into four phases: knowledge of the problem, considering a global view of the problem; selecting the study area; field research; recommendations based on a review of the literature and expert opinion. The process is illustrated in Figure 2. The green and red circles represent, respectively, the start and the end of the research process.

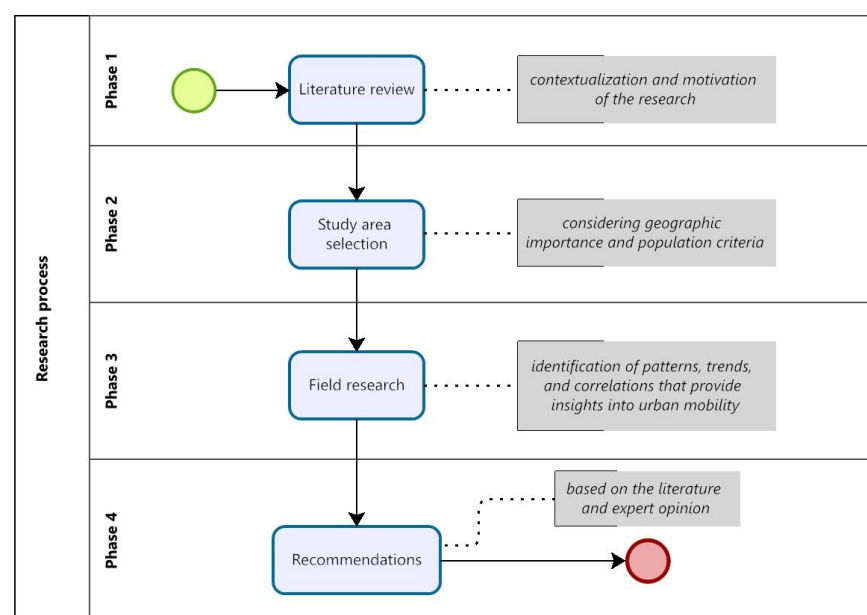


Figure 2. The research process. Created using Bizagi Modeler.

Each of these steps, with the exception of contextualization of the research problem, which was already presented in the previous section, will be detailed below.

3.1. Selecting the Study Area

A city that is considered healthy is comprised of several hubs or subcenters, of different sizes, which bring together diverse and complementary activities. Planned core features create opportunities for people to carry out their activities in nearby locations—working, residing, and studying—which can help to avoid long daily commutes between outlying neighborhoods and the center that are presently common in most major cities [20].

To understand the behavior of passengers in the transport system, and especially those who have stopped using it, it was decided to conduct research in locations that represented a variety of socioeconomic profiles. This was due to the fact that the RJMA is heterogeneous, presenting significant differences, both in terms of scale and spatial location, in addition to aspects related to gender, age, and above all, destination.

So, considering the significant context of the Rio de Janeiro Metropolitan Area, with the volume of intra- and inter-city travel and the availability of data, the approach focused on the municipalities shown in Figure 1. Rio de Janeiro is the city that has the greatest number of jobs and the greatest number of available transport means. The Eastern Region, comprising the municipalities of Niterói, São Gonçalo, Maricá and Itaboraí, does not have available medium and high-capacity transport means and the main connections with the state capital are by ferryboat and across the Rio-Niterói Bridge, for those who use buses and private vehicles, with the municipality of Niterói as their origin. In the Baixada Fluminense (Duque de Caxias, Nova Iguaçu, Belford Roxo, São João de Meriti, Magé, Mesquita, Nilópolis and Japeri), in addition to municipal and intercity buses, some municipalities have a train that connects to the state capital. This region has the lowest GDP (Gross Domestic Product) and average wages in the study area.

The strategic allocation of interviews in each municipality was guided not only by its geographical importance but also by population and operational criteria, as shown in Table 1.

Table 1. Municipalities included in the study, with their respective populations.

Municipality	Population (2022)	Fleet (2024)	Monthly Demand (2024)
Rio de Janeiro	6,211,223	4116	57,398,062
São Gonçalo	896,744	481	3,524,353
Duque de Caxias	808,161	329	2,320,831
Nova Iguaçu	785,867	330	2,450,874
Belford Roxo	483,087	5	31,763
Niterói	481,749	624	5,108,971
São João de Meriti	440,962	56	400,922
Magé	228,127	47	245,745
Itaboraí	224,267	38	6320
Maricá	197,277	93	3,317,236
Mesquita *	167,127	-	-
Nilópolis	146,774	43	296,317
Japeri	96,289	8	15,804
Total	11,167,654		

Source: [21,22]. * There are no municipal bus lines.

The choice of research points for the application of face-to-face interviews involved identifying central features in each region, with priority given to places with travel-generating hubs, sidewalks, or squares with a significant number of commercial establishments and heavy circulation of pedestrians. What is more, a questionnaire was made available online, in order to extend the scope of the research and the number of participants, including those who adopted remote work or were unemployed.

3.2. Field Research

3.2.1. Determining the Sampling

The ensuring of statistical robustness was based on the sample definition. First, the calculation of the minimum sample (n) was performed, with a confidence level of 95% and a maximum sampling error (E) of 2%. The critical value $z_{\alpha/2}^2$ associated with the 95% confidence level was determined at 1.96, using Equation (1). This definition ensures the representativeness of the sample, necessary to address the migration of demand in different circumstances and social groups.

$$n = \frac{z_{\alpha/2}^2 0.25}{E^2} \quad (1)$$

The result of this calculation indicated a minimum sample of 2400 interviews to meet statistical standards. However, to increase the robustness of the study, a larger number of interviews was conducted. Between the months of August and October 2023, 4323 interviews were conducted in person (92%) and online (8%), thereby guaranteeing additional breadth and depth in the data collection and a degree of confidence of 99%, with a 2% margin of error.

3.2.2. Collection and Analysis of the Data

The data collection process was organized with a view to making a comprehensive analysis. The emphasis was first directed at understanding the profile of the interviewees, exploring variables such as gender and income, in order to obtain a representative demographic overview. The aim is to identify the profiles of frequent and occasional passengers, taking into consideration that those who use transport regularly have distinctive perceptions. For the same reason, individuals who make transfers or opt for direct journeys may have different experiences.

Next, the questionnaire sought to elucidate pre-pandemic travel patterns, investigating routes, preferred means of transport and travel frequency. Due to the significant proportion of buses in the total number of journeys [23], special attention was devoted to that means of transport. In the case of the RJMA, the bus system accounts for 67% of the paying passengers within the transport network [22]. The questionnaire explored whether the bus was the main means of travel, the frequency of use of that service and whether there was any need to make transfers or integration with other means of transport. Furthermore, the reasons why some people did not use the buses were investigated, when applicable, with a view to assisting proposals for improvements. Similarly, when considering the reasons behind changes in travel patterns, reflections were guided by the characteristics that were identified.

Finally, attention was directed at the post-pandemic travel patterns, highlighting adaptations brought about by the COVID-19 pandemic. In the case of those who reported changes in their travel behavior, an in-depth approach was adopted, to understand the nuances of those changes. That detailed analysis sought not only to identify the changes but to also comprehend the underlying reasons that drove them. It is understood that, due to the diversity of the RJMA, the choice of means of transport may be influenced not only by each individual's preference but also by a lack of options.

In data analysis, questionnaires, the primary sources of data, are subjected to a procedure of processing and interpretation, performed by experts in the field. For this purpose, software was used to analyze the collected responses.

In order to enable better visualization of the results, charts were drawn up to illustrate the research findings, and to facilitate a better understanding of the results, a comparative analysis was performed, to identify patterns, trends and correlations that could provide insights into the transport situation within the RJMA.

3.3. Recommendations

In the final stage of the research, a review of the literature was carried out and experts in the field were consulted to elucidate suggestions and propose measures for the improvement of urban mobility within the RJMA.

The review of the literature was divided into four stages, covering: defining the review protocol; determining the reference base for the research and obtaining the final base; analyzing the final base; exploratory analysis to determine strategies for increasing the use of public transport and improving its quality.

In the first stage, the review protocol was defined, including the research objective, inclusion and qualification criteria, and search method. Studies from 2013 onwards were considered, and documents were limited to those aligned with the study's aims. The search was conducted using the Web of Science and Scopus databases, recognized for their reliability [24].

In the second stage, the articles were filtered, and the reference base was determined. To that end, the results obtained from the two databases were compiled, repeated articles were removed and then a full analysis of the articles found was carried out. This analysis took into account the application of the inclusion and qualification criteria for the final screening of the studies. At the end of this stage, the studies that would form the final basis of the analysis were obtained and used in the development of this paper.

In the third stage, an analysis of the final database was performed, noting the year of publication, leading periodicals, the words most repeated in the titles, and the places they were published. In the fourth and final stage, an exploratory analysis was performed to determine the policies that encourage the use of public transport, so as to attain the pertinent sustainable development goals.

The experts were consulted, in turn, during the 20th Rio Transport Congress, held in December 2023 in Rio de Janeiro, Brazil. The gathering was attended by academics and professionals from the region's main transport systems.

The meeting strategy comprised two phases: first, planning and organizing the session to discuss the research results on urban transport in the study area; second, inviting operators from all regional transport systems. The event commenced with the moderator's opening remarks and contextualization of the meeting's purpose. Academics then presented the field research results, followed by operators sharing major challenges within their areas based on the study data.

4. Overview of the Changes in the RJMA

This section shows the presentation of the results, with cross-analysis, seeking to relate the profiles to any eventual migration in the means of transport. Section 4.1 presents the profile of the interviewees, detailing it according to parameters such as age group, level of education, and municipality of residence. Next, in Section 4.2, the main changes in travel patterns are presented by municipality and means of transportation. Finally, Sections 4.3 and 4.4 are dedicated, respectively, to identifying the reasons for changes in travel patterns and the choice of transport means.

4.1. Profiles of the Interviewees

A brief description of the interviewees is presented below, in terms of gender, income, age group and education, followed by some considerations regarding those characteristics, relating them to the travel patterns and the reasons for the changes.

Looking at the profile of the interviewees, it was seen that the female gender represents the majority of the participants (54.08%), while the male gender represents 45.52%. Another 0.39% chose not to state their gender. As for gross monthly income, 77.73% of the respondents have a family income of up to two minimum wages, 19.54% have an income of between two and five minimum wages and only 2.73% receive more than five minimum wages. A study carried out by ARSEC [25] in the municipality of Cuiabá (MT), revealed that 73.10% of public transport users have completed their secondary education, while only

20.69% of the users have completed their higher education. So, the profile of the population interviewed seems to converge with the national profile of public transport users.

With regard to age group, the greatest representation was of those between 25 and 54 years of age (75.32%), which covers the economically active population who most use public transport (80% of journeys in Brazilian cities are for work and/or study purposes, according to the World Resources Institute [26]). As for the education level, around 38.61% have completed high school. Individuals with higher education, whether undergraduate or postgraduate, completed or not, account for just 17.47% of the responses.

Regarding the place of residence, 46.91% reported living in the city of Rio de Janeiro and 10.78% in São Gonçalo. It was noted that the observed percentages are directly related to the size of the population in each municipality.

4.2. Changes in the Travel Patterns

When asked about any changes in travel patterns, 85.47% reported that they maintained the same pattern as in the pre-pandemic period. In other words, their traveling remained the same in 2023, with no change. Of the participants who reported changes in their pattern (14.53%), it was noted that this behavior mainly occurred among the population with an income of more than three minimum wages and a higher level of education—see Figure 3.

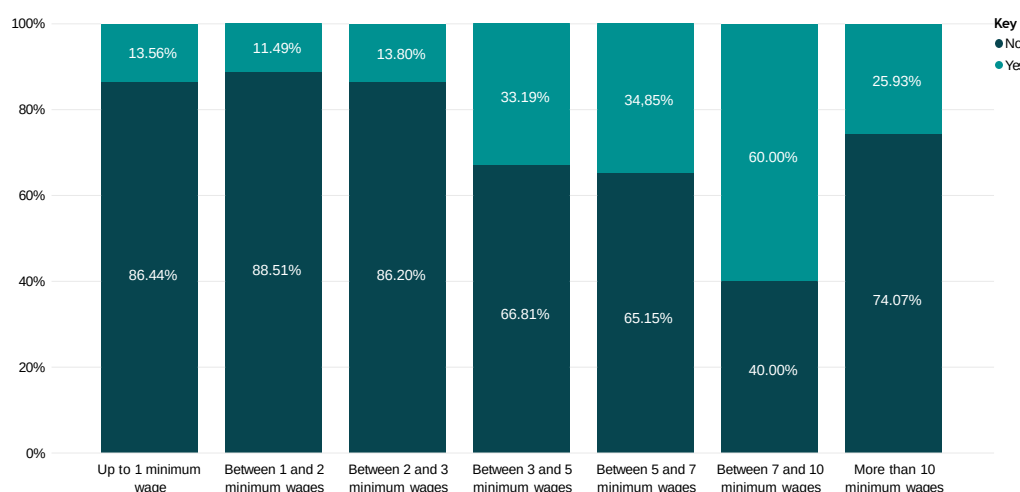


Figure 3. Differences in travel patterns per gross monthly income.

In an analysis by municipality, it was observed that the biggest changes in travel patterns related to the municipalities of São João de Meriti (37.88%), Mesquita (37.50%), Nilópolis (24.65%) and Belford Roxo (23.81%). The lowest percentage change was in Nova Iguaçu (9.6%), followed by Rio de Janeiro (10.5%). It should be noted that, of the 13 municipalities surveyed (Table 1), the four reporting the greatest change in travel patterns are among the seven with the lowest average wages [27].

In general, considering all the participants (whether or not they changed their travel patterns), it was found that, during the pre-pandemic period, around 79.57% of those interviewed used only buses, 12.47% used a bus and another means (integration), 5.16% used buses or another means (sometimes one, sometimes another) and just 2.80% chose not to use buses, preferring another means of transport.

Of those who changed their travel patterns, 67.68% used only buses, 13.38% used integrated means, 12.74% alternated using a bus with another means and 6.21% did not travel by bus. In the post-pandemic period, there was a reduction of approximately 4.94% in the use of buses, whether exclusively or integrated with other means of transport. There was also an increase in the use of other means of transport, as shown in Figure 4.

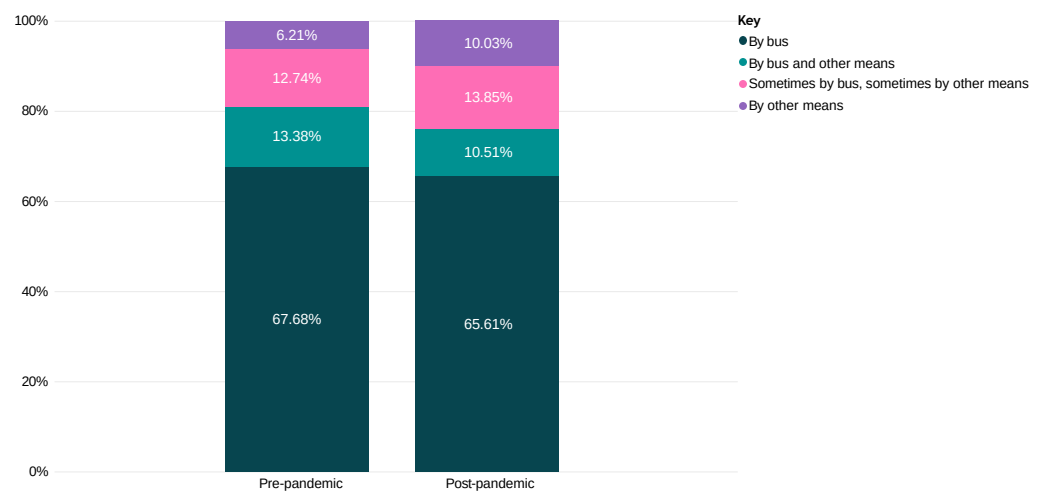
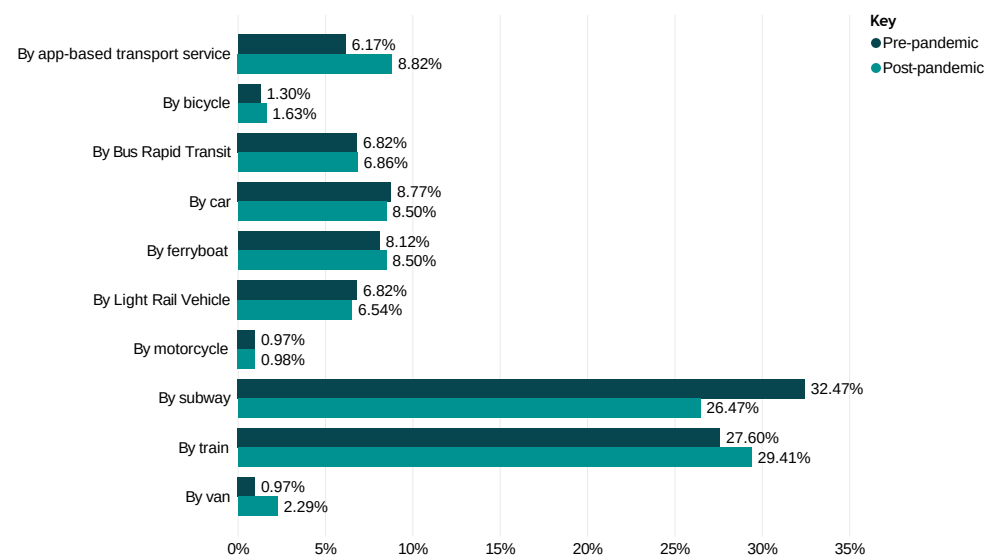


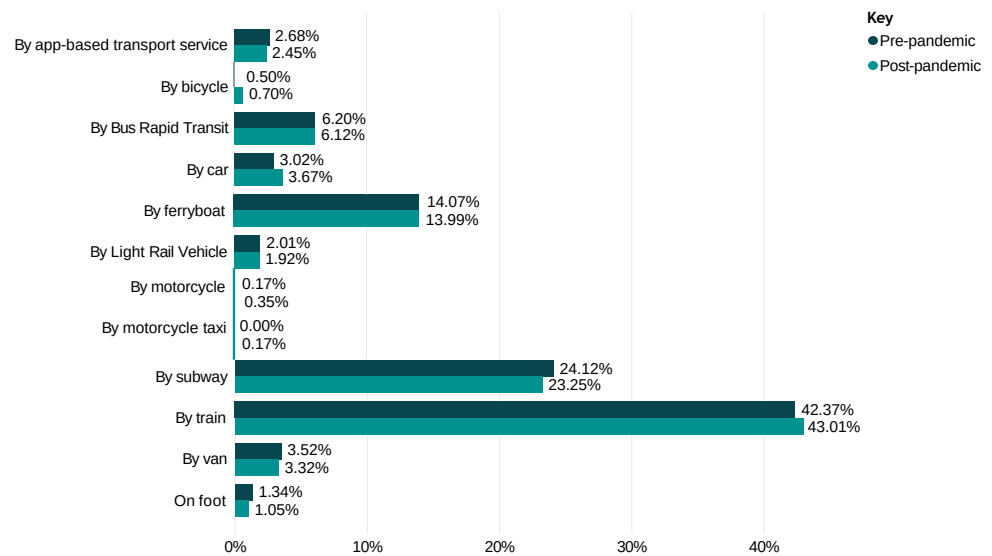
Figure 4. Principal movement during the pre- and post-pandemic periods.

As the proportion of individuals who use buses is quite significant (79.92%), the decision was made to assess the alternative means by removing the bus statistics from the analysis. Consequently, this indicates that there was no significant change among those who claim to use buses and other means of transport (Figure 5b). However, among those who sometimes choose to use a bus (Figure 5a), there was an increase in journeys by train (1.81%) and using app-based transport (2.65%) and a reduction in the subway market share (−6.00%). Among those who said they only use other means of transport (not buses) (Figure 5c), there was a reduction in the use of trains (4.19%) and walking (9.53%). However, for this profile of the interviewee, there was an increase in app-based transport (5.83%) and subway use (8.31%). The car continued to be among the three leading means of travel.

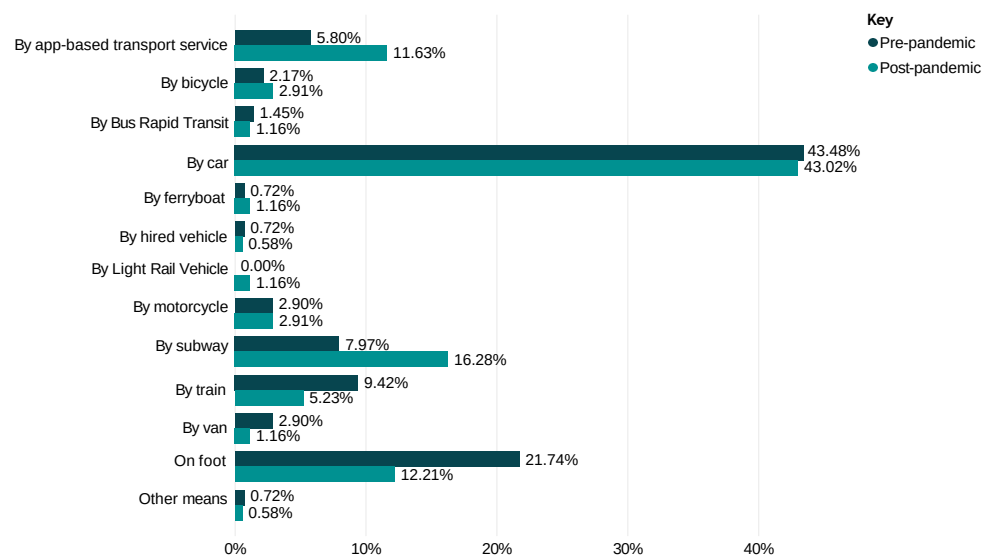


(a) travel, sometimes by bus, sometimes by other means.

Figure 5. Cont.



(b) travel by bus and other means.



(c) travel by other means.

Figure 5. Principal movement during the pre- and post-pandemic periods, excluding buses.

Therefore, it is possible to infer that the pandemic did not cause significant changes in the use of private transport, but it did bring about a significant increase in travel using app-based transport. Table 2 shows the main changes observed in the municipalities of Duque de Caxias, Niterói, Rio de Janeiro and São Gonçalo.

Table 2. Changes in means of travel in some of the municipalities studied.

Municipality	Means Showing an Increase	Means Showing a Reduction
Duque de Caxias	Car	Subway integration
Niterói	Car, Ferryboat, Bicycle	Other means of transport
Rio de Janeiro	App-based transport services	Subway
São Gonçalo	App-based transport services	Bus

4.3. Reasons for Changes in the Travel Patterns

When assessing the main reasons underlying the changes in travel patterns (Figure 6), unemployment appears as the justification with the highest percentage of responses (23.61%), followed by change in destination (19.61%) and adoption of the remote work regime (19.35%), in full or in part (hybrid). Increased waiting time, health reasons and/or reduced mobility and higher fuel costs account for just 1.81% of the total responses. Issues in relation to the lack of transport lines and services that people used prior to the pandemic accounted for 11.87% of the reasons cited.

Looking at the reasons for changing travel patterns per municipality, unemployment was the principal reason cited in Mesquita (72%), São João de Meriti (48.15%), Nilópolis (48.65%) and Belford Roxo (43.90%). Changes in the work regime and in the destination point were, in turn, the main reasons cited in the municipalities of Niterói, Rio de Janeiro and São Gonçalo.

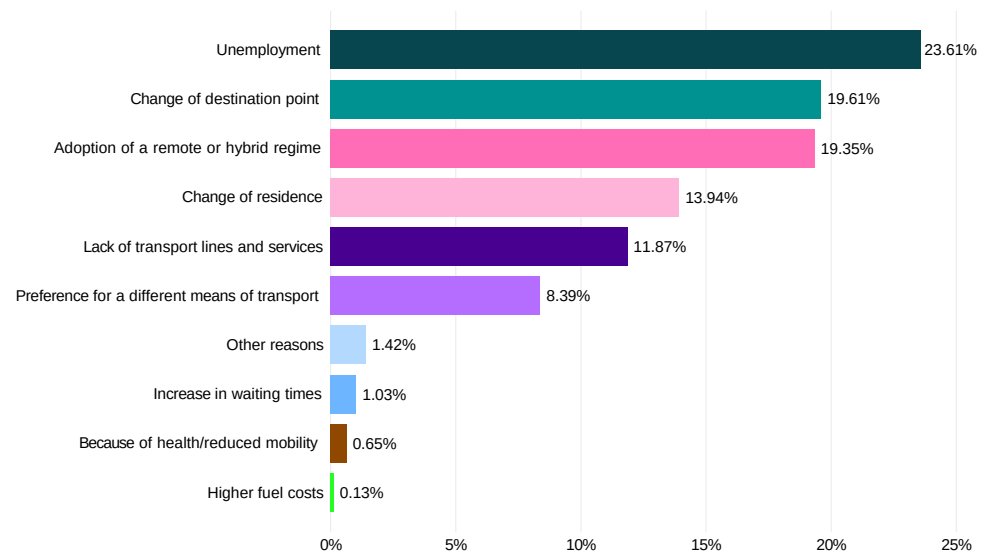


Figure 6. Reasons for changes in travel patterns.

It was also noted that the municipalities with the highest rates for unemployment are also those with the lowest income levels, among those interviewed who changed their travel patterns. In contrast, the municipalities where hybrid or fully remote work was adopted were also those with the highest income levels, with the exception of Maricá. But the main reasons for changes in Maricá's travel patterns were changing the place of residence (46.67%), changing the destination point (26.67%) and preference for another means of transport (20.00%).

4.4. Reasons for the Choice of Transport Means

Another feature noted in the research is that, for those individuals who do not use buses, cost is not a priority (Figure 7). Time, comfort, and public safety were the most commonly mentioned criteria when choosing the means of transport.

Sizeable groups of causes can be perceived from the criteria that were highlighted, where one can recognize operational factors (travel time and waiting time) and service quality factors (physical and thermal comfort) and public safety as the ones that most affected the reasons for not using the bus system, accounting for more than 70% of the total.

Among the participants who use buses, the main reason for choosing this means of transport was that it costs less when compared to other available means (55.83%), followed by not having any other available means of traveling (29.86%), as shown in Figure 8.

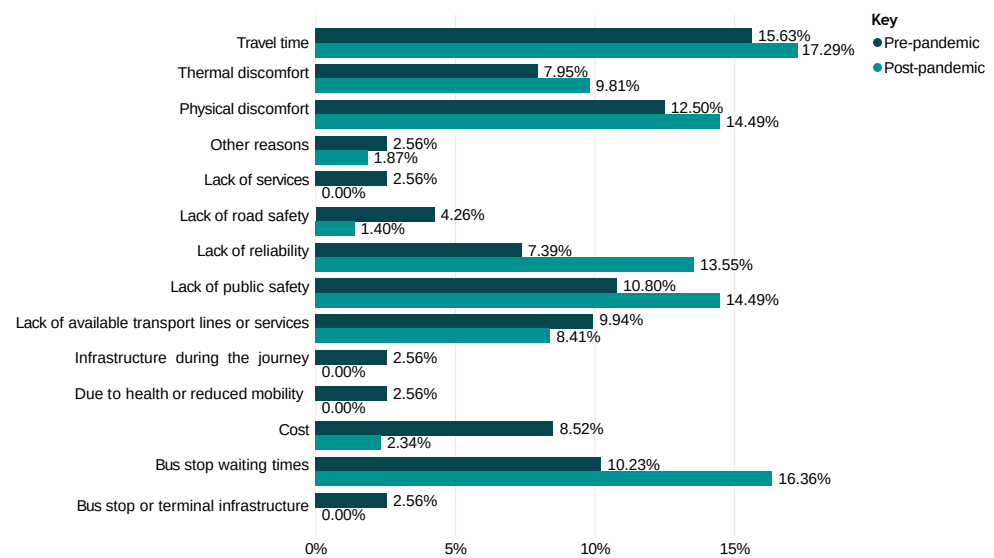


Figure 7. Reasons for not using buses during the pre- and post-pandemic periods.

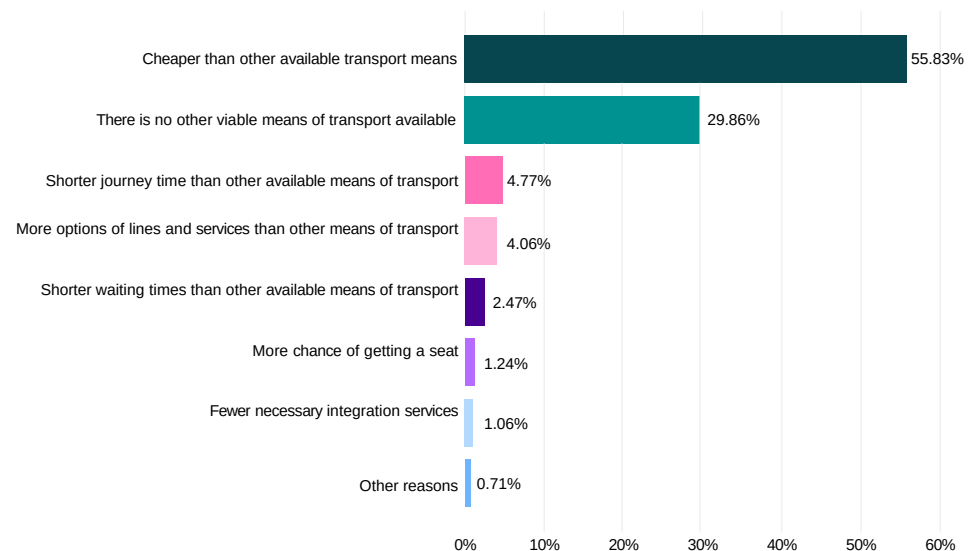


Figure 8. Reason for using buses during the post-pandemic period.

In an integrated analysis comparing the gross monthly income and the means of transport used in the pre- and post-pandemic periods (Figure 9), it was concluded that:

- Between 1 and 3 minimum wages: there was no significant change;
- Between 3 and 5 minimum wages: there was an increase of 7.86% in the use of other means of transport and a reduction in the integration of buses with other means (3.93%) and in the exclusive use of buses (3.06%);
- Between 5 and 7 minimum wages: there was an increase of 12.12% in the use of other means of transport and a reduction in journeys made sometimes by bus, sometimes by other means (3.03%) and in the exclusive use of buses (9.09%);
- Between 7 and 10 minimum wages: there was a 32% increase in the use of other means of transport and a reduction in journeys made sometimes by bus, sometimes by other means (16%) and in the exclusive use of buses (12%);
- Above 10 minimum wages: there was an increase of 7.41% in the use of other means of transport and a reduction in journeys made sometimes by bus, sometimes by other means (7.41%) and in the exclusive use of buses (3.71%).

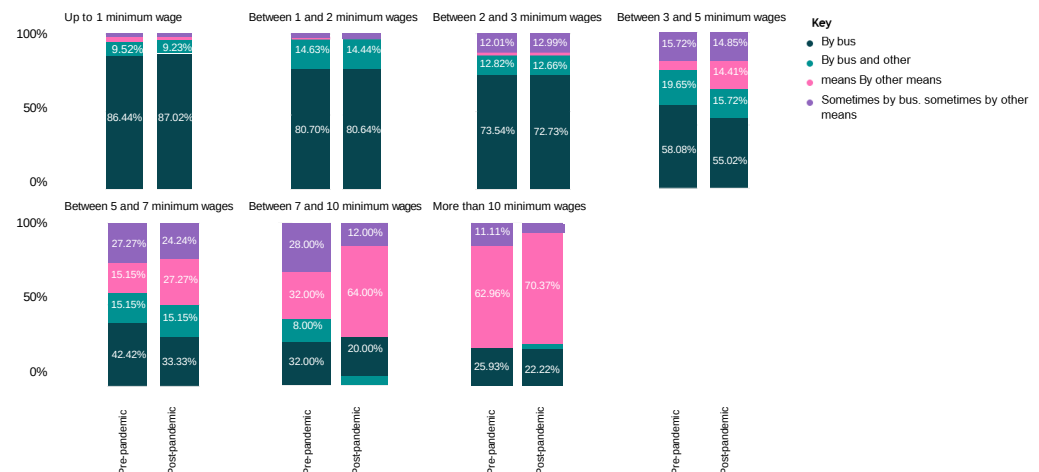


Figure 9. Means of transport, per gross monthly income group.

It is clear that there is greater diversification in travel options among individuals with a higher gross monthly income, although the latter opted for another means of transport, such as a car or app-based transport.

5. Proposals to Encourage and Improve Public Transport

It was noted that the main reasons for not using buses after the pandemic were travel time, waiting time at bus stops and a lack of physical comfort. The main reason for using the bus is the matter of cost. Therefore, this study considers these factors as a basis for proposing measures aimed at improving and encouraging the use of public transport.

5.1. Solutions Indicated by a Review of the Literature

The database search process yielded 1000 articles. All the repeated studies were eliminated from the sample. The sample was then refined by reading all the titles, abstracts, and key terms. Finally, the portfolio having been reviewed and analyzed in more detail, comprised 63 articles that aligned more closely with the aims of the survey.

Figure 10 illustrates the analysis of the key terms found in the selected articles, with the colors representing the different groups of coinciding words. The greater the circumference, the more common its occurrence. Taking a closer look at the keywords, one can see three main analysis groups. The first group, represented by the color red, addresses the choice of means of transport, directly relating it to travel time. Other terms in this group relate to quality, sustainability, and the daily work commute. In the second group, in green, one can see the importance of looking at transport as a system and a connected network. It also highlights the need to prioritize public transport and the use of systems such as BRT. Taking a similar line to the second group analyzed, the third group, in blue, addresses the design of the networks, exclusive bus lanes and the impact of these measures.

This key term analysis coincides with what had already appeared in the research regarding the choice of means being directly related to travel time, as well as certain possibilities for responding to the population's needs.

The results of the literature review reveal worldwide concern over the situation of public transport in the post-pandemic period. Responses ranging from more operational solutions, such as personalized routes, on-demand bus transport and preferential lanes, to measures to encourage the use of public transport, are recounted below, including improvements to the infrastructure and accessibility at the stops, among other steps. Some measures will also influence behavioral changes and suggest steps such as cost reductions to stimulate the use of public transport systems.

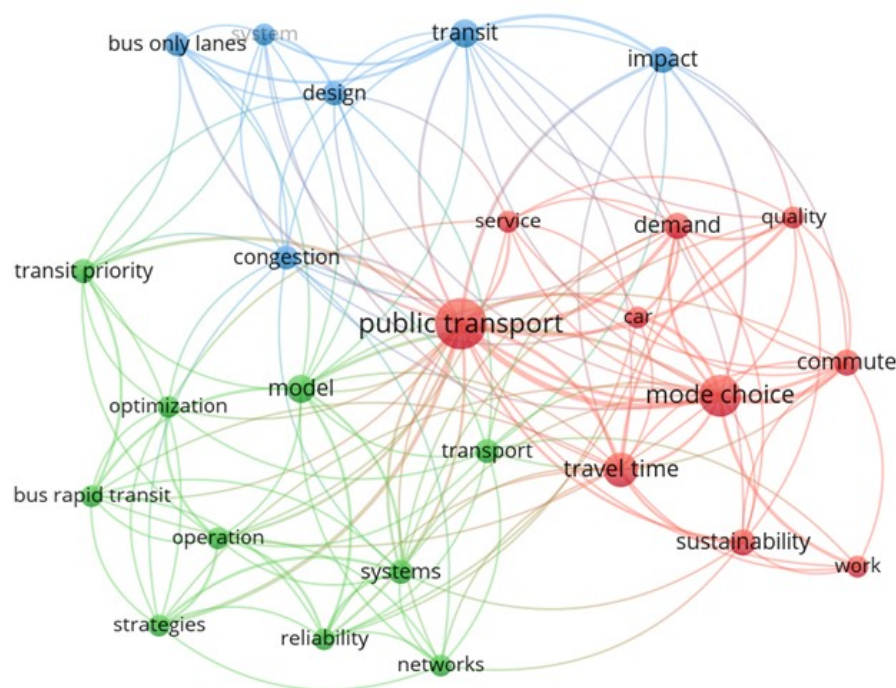


Figure 10. Coinciding of keywords in the selected articles.

A study carried out in China by ref. [28] suggests, for example, the introduction of buses with personalized routes, to attract mainly middle-class users, in the aftermath of the lockdown period. The authors also affirm that the key to successfully promoting sustainable travel behavior in the post-pandemic period is to focus on public health safety, in the short term, and on dedicated bus lanes and priority at traffic lights, over the long term. The use of on-demand public transport services, which aim to meet the demand for personal travel through the use of shared vehicles that circulate on flexible routes, utilizing advanced tools for dynamic scheduling, has been raised by other authors, such as Ref. [29], who used the city of Melbourne, in Australia, as a case study, and Ref. [30], who performed a study in Singapore that showed the importance of regulating this system, to avoid significant increases in congestion. Moreover, according to Ref. [31], by combining BRT and on-demand services, a city can offer its residents comfortable, accessible, and efficient transport options, while effectively mitigating congestion.

Each group, with its different characteristics, must be offered services geared towards user value and policies that encourage users to stop using cars to get around. In the same vein, ref. [32] observed a major shift towards private vehicles (cars) following the lockdown period and, based on a study carried out in India, affirms that efforts should be directed towards restoring the users' confidence, by providing a safe protected environment that is healthy for public transport users.

Also, attempting to understand the radical shift to individual means in recent years, ref. [33] showed that travel cost, followed by travel time and travel distance, are the most important factors in determining the choice of means of transport in Bangalore, India. Furthermore, the authors say that a unified transport authority, coordinating the public transport of a city under a single body, can provide the necessary synergy between individual policies and maximize the intended impact.

Also, analyzing the reasons behind the choice of transport means, ref. [34] observed that a high level of public transport usage requires efficient travel times, direct routes or few transfers and a high service frequency. If any of those requirements is not met then the use of public transport is significantly reduced.

With regard to integration, ref. [35] emphasizes that public transport planners must develop integrated systems with interconnectivity between routes. These systems must work as a single unit and provide users with plenty of destination options. In addressing the relative cost of public transport and mirroring a situation similar to that seen in the RJMA, a study carried out in Chile highlighted deep disparities regarding the financial burden public transport places on the income of the most vulnerable. Moreover, it ascertained that there were longer travel times, due to the distance between their homes and places of work, high unemployment rates and a lower level of private vehicle ownership [36].

Nevertheless, looking at public transport means looking at the entire transport network, including the initial and final stretches and the conditions while waiting for transport. To increase the market share of journeys using public transport, it is essential to improve the accessibility of the stops [37]. A study carried out in South Africa, by Ref. [38], shows that passengers place a high value on safety against crimes taking place in the initial/final stretch, in addition to the travel time and cost. Another point raised by the authors is that the quality of the initial/final stretch varies substantially between locations, and particularly between suburban areas and the urban center.

It is also important to offer basic amenities as widely as possible at stations and stops within the public transport system, with special attention given to low-frequency stops and those in less safe areas [39]. It is necessary to concentrate investment in the public transport system to progress towards an integrated multimodal system that can compete with private cars [40].

Looking at the questions of travel times and reliability, it is noted how it is necessary to guarantee not only speed but also headway within service delivery, as well as to improve operational issues. Increased speed not only enables faster journeys, but also greater frequency, using the same fleet, thereby reducing waiting times and crowding within the vehicles. However, ref. [41] also emphasizes the importance of regular intervals, as they have a positive effect on comfort, reliability, travel and waiting times, operating costs, and even certain urban effects of the bus services.

Therefore, the emphasis of the public transport bodies and operators must be placed on reliability, in order to make public transport an attractive travel option. Looking at operational stability, the results of a study performed in China by ref. [42] revealed that the stations with the most unstable intervals are located in the suburbs and in peripheral areas of the city center, so special attention is needed in those places. To avoid increasing the variability of the intervals, ref. [43] says that the most effective measures are segregated corridors and stops where payment is made outside the bus. This should be helpful in guiding interventions in the system's operations, infrastructure, and contracts, all aimed at improving reliability.

The lack of priority given to public transport compared to individually owned travel means makes the conditions of accessibility and urban mobility worse in the metropolitan context [44]. A study carried out in Croatia by ref. [45] showed that priority reduced travel time by public transport in certain corridors by between 7.64% and 18.76% during the morning peak period, and by 5.60% to 22.50% during the afternoon peak period. Similar results were obtained by ref. [46] in Rome, Italy, where they observed that a dedicated bus lane reduced the bus travel time by around 18%. Various other studies address the importance of an exclusive lane in improving the quality indicators, as affirmed by ref. [47,48].

In relation to behavioral change, ref. [49] states that, in addition to access/exit time, interval, travel time inside the vehicle and number of transfers, it is necessary to offer amenities such as air conditioning and Wi-Fi and that the service must be at an affordable price. It is worth mentioning that the study by ref. [50], carried out in France, points out that, on interurban journeys, the value of time is lower than the level of perceived comfort. Another point is raised in the study by ref. [51], who concluded that there is a risk that the most active smartphone users will develop negative attitudes towards public transport if their experiences are not improved, given that they have developed higher expectations

regarding travel by public transport. Moreover, real-time information is becoming more important every day to improve the public transport experience. The results of the study by ref. [52] show the importance of having access to information prior to the journey, especially for longer trips lasting more than an hour, so people can plan in advance and thus optimize their waiting time.

A study presented by ref. [53] shows that increasing the frequency of public transport and reducing the fares can boost public transport use, which can lead to overall revenue gains. The authors argue that policymakers need to consider fare policy reform along with built environment and demographic factors, in order to increase the service availability and ensure that the services are accessible to the general public. As for subsidizing public transport, ref. [54] offers an important consideration: that it is a widely used policy with a redistributive objective, but it is also necessary to pay attention to the onboard capacity.

To encourage the use of public transport, it is also necessary to discourage the use of private vehicles, as substantial savings in travel time are possible, especially when the use of cars is limited, by restricting their space and increasing their costs [55]. A study carried out by ref. [56] showed that restrictive policies (such as urban tolls) generally reduce total demand, while policies of encouragement increase it (e.g., improving the access time to public transport by integrating it with a bike-sharing system). The most effective measures are usually found in hybrid policies, such as increasing automobile travel time while decreasing the travel time on public transport.

Ref. [57] compared the contribution of three policy measures—urban tolls, accompanied by improvements in public transport; remote work; urban densification—in facing different urban challenges. The results indicated that the three measures contributed to meeting the challenge of time efficiency, by saving travel time, reducing congestion and improving the traffic flow during peak hours, with remote work being the most effective. For accessibility to public transport, the most effective measure was the urban toll. However, the only measure that really contributed to meeting the energy, emissions and pollution challenges was urban densification, which reduced the travel distances and encouraged mobility that relies more on public transport and non-motorized means.

Along similar lines, a study by ref. [58] showed that a 50% increase in parking fees, combined with an urban toll and a 10% reduction in travel time using public transport services (carried out after recycling toll revenues) were important measures to encourage changing the means of transport and reduce emissions. Increases in the cost of driving will lead to a major reduction in automobile demand, as the high value attributed to travel time variations has implications for transport policy, in terms of decision-making regarding new pricing strategies [59].

Measures such as park and ride (P&R), an intermodal point where the users of private vehicles transfer to public transport to make a prearranged journey, can also contribute to a multimodal approach. Ref. [60] demonstrated, through a multinomial logistic regression, that the travel time of a public transport vehicle and the transfer time at the P&R station are the main factors affecting people's decisions in choosing public transport, while the parking fee is an additional factor that affects driver choices.

Another measure observed in the literature was a service that plans the routes and intermediate stops of transport lines, based on the current observed demand, offering a reduced walking distance to the station and a shorter total travel time, compared to fixed lines [61].

In view of the above, it was noted that the literature emphasizes the following points to encourage the use of public transport:

- (i) investment in infrastructure in the initial and final stretches of the journey and at bus stops;
- (ii) improving the supply of public transport, using technology that enables on-demand transport;
- (iii) using demand management measures, such as urban tolls and parking restrictions;
- (iv) subsidies to reduce the amount charged for the fare;

- (v) building infrastructure devoted to public transport, such as exclusive lanes;
- (vi) using technology to improve communication with users prior to and during the journey.

As for the challenges related to energy use, emissions and atmospheric pollution, it is understood that the measure that has proven to be effective is urban densification, due to the reduction in distances and the enhanced possibility of using public transport and non-motorized means. It should be emphasized that the measures must focus on reducing the cost and travel time and improving the supply, geared to system reliability.

5.2. Meeting the Experts

On 8 December 2023, during the 20th Rio Transport Congress, a meeting was held involving academics and operators of the RJMA transport systems, including representatives of CCR (ferries), Supervia (trains), MetrôRio (subway) and SEMOVE (buses), to discuss the results of the field research.

Given the data collected, the guests were asked to present the main challenges in their area of activity. For CCR Barcas, the difficulties involve a lack of financing and physical and fare integration, how to improve the attractiveness of public transport and the absence of a metropolitan authority. For MetrôRio, the lack of integration and overlapping and the absence of subsidies are the most significant points to be addressed. For Supervia, in addition to a metropolitan authority, it is necessary to reorganize the transport network as a whole, in order to promote integration. Matters related to public safety were also mentioned. For SEMOVE, the challenge is mainly related to the cost and financing of operations and infrastructure, improvements in transport quality, increasing attractiveness, and reducing congestion.

Another matter raised was about the principles for the sustainability of urban transport, which would be the most important for your area of activity and why. For SEMOVE, the road network and its utilization must be optimized (adopting measures such as implementing priority lanes to improve travel time and feed high-capacity transport means), making improvements in public transport, to make it more attractive, controlling the use of vehicles and managing parking (discouraging the use of privately owned transport). Public transport needs to be efficient and of high quality, so that individuals feel motivated to use it and stop opting for cars/motorcycles.

For Supervia, the most important principles involve developing cities geared to public transport (building cities that aim to serve individuals through the organization of the network), optimizing the road network and its utilization (taking into account the vocation of each means of transport) and making public transport improvements (enhancing the existing infrastructure). Complementing the principles mentioned by SEMOVE and Supervia, CCR Barcas emphasized the need to thoroughly address the challenges (with the drawing up of public policies). MetrôRio also mentioned the planning of dense cities on a human scale (e.g., with urban densification along public transport corridors and around stations). Summarizing, the principles mentioned involve sustainable cities, and the provision of a high-quality public transport network, so that passengers have a choice, encouraging public transport and developing public policies that make these things possible.

In the last round of the discussion, perceptions regarding the current transport situation in the RJMA were presented, addressing issues related to fleet renewal, solutions to reduce congestion, and the implementation of dedicated public transport lanes and exclusive transport routes, among others. Based on the presentation of these ideas, the operators were invited to give their opinions on what other practices could be adopted to improve public transport.

For Supervia, a more comprehensive view must be adopted, with impartiality towards solutions that are already known (metropolitan authority) and investment in the rehabilitation of the existing infrastructure (stations and surrounding areas). For MetrôRio, connecting the network and transversal connections between the transport means are necessary. The possibility was also mentioned of using property resources to finance public transport. For CCR Barcas, effective planning and action by the public authorities is

necessary. Finally, SEMOVE pointed out the need for sustainable subsidies that can be maintained over time and, above all, with clarity regarding the source of funding, along with better regulation and new contract models that, for example, enable the supply to be adapted to the demand.

Table 3 indicates that the challenges mentioned by the RJMA operators converge with the proposed needs for which solutions were recommended.

Table 3. Main challenges facing the transport operators.

Bus	Train	Subway	Ferryboats
Cost and financing of infrastructure and operations	Need for reorganization of the transport network	Lack of integration and overlapping	Lack of financing
Transport improvements to enhance the attractiveness	Absence of a metropolitan authority	Lack of subsidies	Lack of physical and fare integration
Alleviation of congestion	Questions related to public safety		Improve the attractiveness of public transport
			Absence of a metropolitan authority

6. Conclusions

This study used a detailed and comprehensive methodology to analyze the transport system in the RJMA, focusing on bus transport, due to its significant market share of the number of journeys. The adopted approach sought to capture the complexities of the system, ranging from the road infrastructure to the connectivity between the different travel means, to provide a holistic view of the urban scenario. The study comprised three distinct phases. First came the choice of the study area. That was followed by field research, which included interviews with the local population. Then the conclusions and recommendations were drawn up, based not only on a review of the literature but also on a meeting with operators working within the Metropolitan Area.

The strategic selection for analysis of municipalities in the RJMA was based on geographical and population criteria, aimed at ensuring comprehensive representation. The data collection process involved a reliable sample of 4323 interviews, conducted in person and online and allocated according to the population of each municipality. Analyzing the RJMA scenario, the study revealed a predominant profile of the interviewees, highlighting women and individuals with a family income of up to two minimum wages, aged between 25 and 54 years old and amongst whom a significant portion had completed their secondary education. Changes in post-pandemic travel patterns were more evident among those with a higher income and higher level of education.

The study also identified the main reasons for the changes in travel patterns, such as unemployment, changes in destination and adoption of the remote work regime. Furthermore, a detailed analysis revealed that the reasons for the changes in travel patterns are directly related to income and level of education. It was also noted that there was an increase in the use of app-based transport and a reduction in the exclusive use of buses, especially among those with higher incomes.

Another observation is that the evidence presented here is not limited to Rio de Janeiro but can also be of use to other locations. That is because the study emphasizes not only the outcomes observed in the post-pandemic period but also provides an understanding of the underlying reasons and factors that contributed to that scenario. As a result, this study can serve as a guide for places that have faced similar challenges. What is more, the inferences offer detailed guidance on promoting sustainable mobility, thereby assisting decision-makers and scholars in the field.

The results of the analysis of gross monthly income and the means of transport used during the pre- and post-pandemic periods indicate a greater diversification of travel options, particularly among individuals with an income of more than five minimum wages, who demonstrated an increase in the use of transport that does not include buses. That suggests a significant adaptation in mobility behavior, reflecting a response to changes in the urban scenario, the job market, and the individual needs of the residents within the RJMA.

In brief, changes were noted in the post-pandemic travel patterns, especially in relation to the preference for using app-based transport and aspects of critical immobility—undesired circumstances imposed upon the individual, such as the unemployment reported in the field research. It is also evident that, with the increase in remote and hybrid work, many people choose to remain in a specific location, with no desire to move around or travel (desired immobility). Nevertheless, for those who remained within the system, it has become imperative to encourage sustainable transport, to develop more livable, efficient and environmentally friendly cities. Moreover, the adoption of social measures, such as funding programs and investment in education and infrastructure projects, is important for stimulating the job market and promoting an active lifestyle, thereby helping to mitigate the negative impacts on mobility.

To achieve that objective, a series of principles must be followed that guide policies and practices related to the planning and operation of the transport system in urban areas. One of the key principles is the planning of dense, human-scale cities, where infrastructure and services are close and accessible to the citizens, thus reducing the need for long-distance motorized travel. That will help to reduce traffic congestion and pollution emissions.

What is more, it is essential to effect changes in cities with a view to facilitating the use of public transport, with efficient and comprehensive systems that encourage its use, to the detriment of privately owned transport. This can be achieved through investment in infrastructure, affordable fares, and integration between the different means of transport. Optimizing the road network and its utilization is also crucial to promoting urban transport efficiency and reducing congestion and travel times. It involves the intelligent planning of routes, giving priority to public transport and measures for managing traffic and travel demand. These investments contribute to improving public transport, making it more attractive for those who choose other modes, such as application-based transport. By ensuring that the public transport system is efficient, safe, clean and accessible, passengers can feel more comfortable using it. This reduces the need to spend more to achieve quality, as is often required in app-based transportation, or to avoid crowded environments, as was necessary during the COVID-19 pandemic.

Encouraging walking and cycling is another important principle, which will benefit the health of the citizens and contribute to reducing carbon emissions and improving air quality. To that end, it is necessary to invest in adequate infrastructure, such as safe sidewalks and protected cycle paths, to implement measures focusing on sustainable mobility.

Making improvements in public transport, controlling the use of private vehicles, managing parking and promoting the use of non-polluting vehicles are complementary measures that will help to make the urban transport system more sustainable and efficient. Looking at the cost of transport for the population, there is a clear need for subsidies, in order to charge a fare that is socially reasonable and improves access to the network.

Finally, it is essential to comprehensively communicate the solutions and address the challenges, to ensure the success of sustainable urban transport policies. The active participation of the community and dialogue among the various stakeholders are fundamental principles in this process. After holding a meeting with experts, it became evident that dialogue between academics and transport operators is crucial, to identify the main obstacles faced by transport systems within the RJMA. The discussions revealed a series of challenges, including a lack of financing for infrastructural improvements and fleet renewal, physical and tariff integration, overlapping services and a lack of subsidies.

It made clear the complexity of the challenges faced by public transport and the importance of integrated and coordinated approaches when facing up to them. Collaboration between academics, transport operators and government authorities is crucial to identify effective solutions that promote more sustainable and efficient urban mobility, not only in the RJMA but also in other locations. This integration between academic research and operational practice is essential for the development of strategies that meet the requirements and demands of public transport users. Studies like this one can, therefore, offer guidance for the development of targeted and effective public policies.

As a suggestion for future research, it is proposed to evaluate the degree of effectiveness of the measures suggested here for the area under study, aimed at encouraging the use of public transport. This could be conducted through further consultation with users regarding the possibility of using on-demand transport to improve the quality of the first and last-mile services, a survey of possible interventions aimed at creating new centrality and enabling the implementation of new medium- and high-capacity transport corridors. Additionally, it is suggested to maintain the frequency of behavioral change studies and monitor possible medium-term developments. It is also recommended that origin-destination matrix research be carried out to investigate new centrality and the potential for urban development and also to investigate whether, in addition to migration between transport means, there was also migration of destinations.

Furthermore, it is suggested to complement the current methodology with longitudinal methods. Including long-term studies will allow for a more detailed and accurate analysis of post-pandemic travel behavior changes. In addition to validating observed trends through self-reported data, this approach will help better capture the temporal dynamics of mobility behavior changes in the Rio de Janeiro Metropolitan Area. This methodological expansion will not only strengthen the robustness of the findings but also provide more substantial insights for the development of effective public policies and urban planning strategies.

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Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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