Public bus transportation analysis: a case study of sustainable mobility in Argentina

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1. Introduction

Examining mobility decisions can pose challenges, especially in a context where environmental concerns are becoming increasingly prevalent. Cities are expanding, the vehicle fleet is continuously growing, greenhouse gas emissions are increasing and exacerbating the phenomenon of climate change, and society's demand for access to public transport is growing. These issues affect many cities worldwide. Active mobility and public bus transport can be attractive alternatives to car drivers, as they allow for the avoidance of traffic and parking problems, reduce per capita energy consumption so they are friendlier to the environment. In relation to the emission of greenhouse gasses, a bus with 50 people allows reducing per capita CO2 emissions by 91% compared to 50 vehicles with a single occupant.

This work is part of an inter-institutional applied research project approved by the Inter-American Organization for Higher Education, which aims to multidimensionally analyze sustainable urban mobility proposals and collaborate with their implementation in Bahía Blanca, Argentina -a Latin American medium-sized city. The project is specific to a university collaborative research call on the application of the sustainable development goals (SGD) of the United Nations.

Previous studies in Bahía Blanca city found that the probability of using public mobility by bus is negatively influenced by age, car ownership, and comfort as a key factor in mobility decisions. In contrast, the probability of taking the bus increases for female gender, undergraduate student role, and the distance to travel[1]. However, weather conditions can also affect the choice to use this mode of transport in different ways, such as the frequency of use, the number of people who opt for this mode of transportation, and the amount of time users are willing to wait.

Considering the previous ideas, this paper aims to analyze the demand for public bus transportation services in the city of Bahía Blanca (Argentina) by using multiple regression analysis and exploring its correlation with adverse weather conditions. Collected data on meteorological conditions (rain and wind) and the demand for public transportation services includes years pre (2019) and post (2022) COVID-19 pandemic lockdown.

[1] Pesce et al. "Understanding urban mobility habits and their influencing factors on a university campus in Argentina".

The article presents in section 2 the conceptual framework, in section 3 the methodological details, and in section 4 the results organized as follows: (4.1) the characteristics of public transport by bus in the Bahía Blanca city, (4.2) a description of meteorological conditions in the city, and (4.3) an analysis of the link between bus trips and weather aspects. Finally, conclusions and future research are mentioned in point 5.

2. Conceptual framework

2.1. Studies about factors affecting the use of public transportation

Several aspects that affect the demand for public transportation could be used as input to achieve a sustainable public transportation system. Among them, weather can affect the activities that cause people to travel and also the travel experience[2]. Internationally, there has been growing interest in investigating the influence of weather conditions on public transportation decisions. Previous studies have looked into how rain, temperature, and wind affect public transport ridership, considering the climatic conditions of cities or the cultures in which they are immersed[3] [4], which are often different from Argentina.

By linking the bus ridership with climatic factors according to the seasons of the year, a study conducted between 2006 and 2008 in Pierce County, Washington (United States of America, USA), found that strong winds have a negative impact on the number of bus passengers in winter, spring, and autumn. Low temperatures result in a decrease in the number of bus passengers during winter. Rain has a negative effect in all four seasons, and snow is associated with fewer bus passengers in autumn and winter.

Using bus demand data from the Salt Lake City metropolitan area (USA), it is found that extreme weather (very high or low temperatures and heavy rains) lead to a decrease in the number of public transport passengers. Moreover, it is noted that bus stop shelters have a modest effect in alleviating passenger losses resulting from these adverse weather conditions[5]. Likewise, data on weather conditions and the number of bus passengers in a city can be used to train and improve models to forecast the demand for urban public transport[6] [7].

On the other hand, by investigating the relationship between the day of the week and mobility decisions, a study shows that the bus service is more reliable during weekends and in summer, when relatively fewer students need public transportation, and also reveals that the high volumes of bus passengers cause a significant increase in the variation of the reliability of the service they provide[8].

In turn, an empirical research in Beijing (China) finds that the effects of weather during weekends or holidays have a more substantial influence on the fluctuation of the number

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2 Stover & McCormack, "The Impact of Weather on Bus Ridership in Pierce County, Washington", 96.

3 Kim, "Effects of Weather and Calendar Events on Mode-Choice Behaviors for Public Transportation".

4 Rudloff et al., "Influence of Weather on Transport Demand", 110.

5 Miao, Welch & Sriraj, "Extreme weather, public transport ridership and moderating effect of bus stop shelters".

6 Correia, Fontes & Borges, "Forecasting of urban public transport demand based on weather conditions".

7 Silva & Martins, “Traffic flow prediction using public transport & weather data: medium sized city case study”.

8 Paudel, "Bus ridership and service reliability: the case of public transportation in Western Massachusetts".

of bus passengers than on weekdays and adds that weather conditions generally have less impact on regular trips to work than on discretionary trips[9]. Similarly, a study in Brisbane (Australia), reveals that bus ridership per hour on weekends is significantly more affected by changes in weather conditions than on weekdays, indicating that weekday bus use is predominantly determined by people's routine behavior patterns (commuting to work) and less governed by weather[10].

Another study conducted in Brisbane (Australia), that includes ferry and train services within the analysis of public transport, suggests that the impact of weather on the total number of public transport passengers fluctuates throughout the day. Specifically, during the morning and afternoon peak hours, the weather's influence appears to be weaker compared to other periods throughout the day[11].

Finally, regarding the effects of the pandemic on mobility decisions in public transport, a study carried out between 2020 and 2021 in 15 European cities from 11 different countries, reported a decrease in its use that, in some cities, recovered more quickly and in a more significant way than in others. It demonstrates that the resilience of public transport during the pandemic has depended mainly on the change in shopping and recreation routines[12]. In Latin America, a research carried out in Santiago (Chile), reveals that government policies considerably reduced crowding on public transport during the confinement phase and the results suggest that the poorest municipalities returned more quickly to levels of crowding similar to the previous to the pandemic[13].

2.2. Empirical background on public transport in Argentina

In Argentina, different authors investigate urban public transport, although it is not linked to weather conditions. A study analyzes the distances traveled and the demand for tickets in public transport in Resistencia, Chaco, using an empirical function called the distance decay curve[14]. In order to analyze the effects of COVID-19 on public transport, another study refers to the changes in urban mobility in the Buenos Aires Metropolitan Area -due to fear of contagion- noting modal changes: the use of public transport reduces and private transportation increases, especially in forms of active mobility such as walking and cycling[15]. Concerning the bicycle, during the pandemic the Government of Buenos Aires took measures to encourage its use, such as the construction of bicycle lanes[16].

Regarding the perception of the quality of the public transport service, through a survey

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[9] Lin et al., "Analysing the relationship between weather, built environment, and public transport ridership".

[10] Tao et al., "To travel or not to travel: 'Weather' is the question. Modelling the effect of local weather conditions on bus ridership", 165.

[11] Wei et al., "The influence of weather conditions on adult transit ridership in the sub-tropics".

[12] Manout et al., "On the bumpy road to recovery: resilience of public transport ridership during COVID-19 in 15 European cities", 14.

[13] Basso et al., "Crowding on public transport using smart card data during the COVID-19 pandemic: new methodology and case study in Chile".

[14] Cardozo & Da Silva, Funciones distance decay y Sistemas de Información Geográfica (SIG) para la estimación de demanda potencial en el Transporte Público de Resistencia (Chaco, República Argentina)

[15] Velázquez & Singh, " Movilidad cotidiana en pandemia: prácticas y percepciones del transporte público en Buenos Aires", 146-147.

[16] Piza Fontes et al.,"Planificación urbanística en pandemia: Cambios en cuatro ciudades latinoamericanas", 28.

carried out in October 2020, it is shown that in Buenos Aires the comfort index was the one with best performance, which is possibly associated with low vehicle occupancy in the context of restrictions on mobility and activity during the pandemic [17].

In the city of Bahía Blanca, there is research on urban traffic in the microcenter that studies the means used and how they contribute to the emission of polluting gasses into the environment[18]. About this topic, there is an analysis on the effects of COVID-19 on urban mobility, mainly how transport by bicycle and motorcycle increases, with a reduction in car use in months with extreme measures and the increase in generalized traffic in line with the gradual reopening of circulation[19]. Regarding public transport by bus in the city, a paper analyzes the efficiency of passenger transport operators and how the number of lines and companies that provide the service varies, finding that the level of efficiency has not changed significantly from 2007 to 2014, despite the departure of operators with poor service performance[20].

3. Methodology

The methodology employed in this research is of a non-experimental nature, where involved variables are not manipulated or modified as they have already occurred. The study proposes an investigation with a descriptive correlational scope, adopting a quantitative approach. The descriptive scope is justified by measuring components of the studied phenomenon in a univariate manner; in this case, bus trips and meteorological data in the city of Bahía Blanca. On the other hand, the correlational scope is based on examining the joint relationship between the variables of interest: meteorological conditions and bus ridership.

The data for this work is derived from secondary sources, provided by the National Meteorological Service (SMN) and the Municipality of Bahía Blanca (MBB) city through the databases of the Electronic Unified Ticket System (SUBE), a service that enables payment for bus trips, subways, trains, and river transportation using a single card. The data provided by the SMN includes daily precipitation measured in mm/day and the calculation of the average daily wind speed derived from hourly data measured in km/h. This data corresponds to each day in the months of April, May, and June for the years 2019 and 2022 in the city of Bahía Blanca. Within the same timeframe, data from SUBE regarding the number of daily trips made on public transportation by buses in the city are available. The consolidated database comprises 177 complete daily data points, with five records containing incomplete or missing data being excluded, from a total of 182 observations. To establish time series data, we consider the COVID-19 pandemic, as the intermediate years are not representative of the normal activity of urban transportation due to government-imposed circulation restrictions. Therefore, the aim is to establish an interannual comparison between two time periods that can be compared meaningfully.

The data are processed using spreadsheets and Stata v.14 econometric software and analyzed through descriptive statistical techniques during the initial analysis phase.

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[17] Moviblog, "Innovación en el diagnóstico de la movilidad urbana de Bogotá y Buenos Aires”.

[18] Grassi, Brignole & Díaz, "Pandemic impact on air pollution and mobility in a Latin American medium-size city".

[19] Grassi, Brignole & Díaz, “Effects of Covid-19 pandemic on urban mobility in Bahía Blanca (Argentina) during the second semester of 2020”.

[20] Viego & Volonté, “Eficiencia del transporte urbano de pasajeros en la localidad de Bahía Blanca”, 52.

Subsequently, correlation and linear regression analyses are conducted to explain the behavior of the daily number of trips (dependent variable) based on a set of climatic and control variables (independent variables) (equation 1). The meteorological variables considered are daily precipitation (Pp_t) and average daily wind speed (WS_t). The control variables include dichotomous variables that indicate the day of the week (M for Monday, Tu for Tuesday, W for Wednesday, Th for Thursday, F for Friday, and S for Saturday), with Sundays or holidays as the base when the level of trips is at its lowest. Additionally, a binary variable is included to represent the year 2019, thereby capturing the difference in trips before and after the pandemic.

$$Qtrips_t = \hat{\alpha} + \widehat{\beta_1} * Pp_t + \widehat{\beta_2} * WS_t + \widehat{\gamma_1} * M + \widehat{\gamma_2} * Tu + \widehat{\gamma_3} * W + \widehat{\gamma_4} * Th + \widehat{\gamma_5} * F + \widehat{\gamma_6} * S + \widehat{\gamma_7} * Year + \varepsilon_t$$ **Equation 1**

The hypotheses regarding the expected relationships in equation 1 are as follows:

- H1) Days with adverse weather conditions have a positive impact on the number of bus trips due to the substitution effect from other modes of transportation, such as walking, cycling, etc.
    - H1.a) Rainy days increase the number of bus trips.
    - H1.b) Windy days lead to a higher number of bus trips.

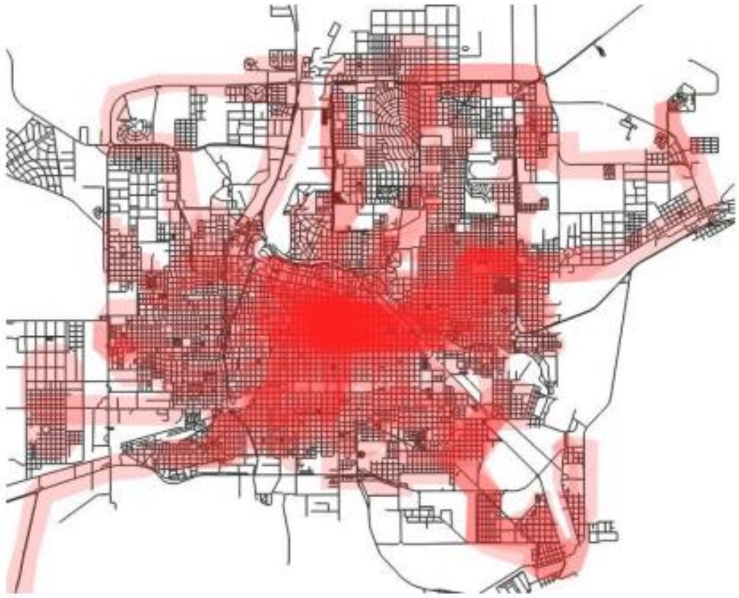
  Hence, the expected sign for the estimated coefficients $\widehat{\beta_1}$, and $\widehat{\beta_2}$ is positive.
- H2) Weekdays with active work schedules exhibit a higher number of daily trips compared to the base category of Sundays and holidays. Therefore, the expected signs for the estimated coefficients $\widehat{\gamma_1}, \widehat{\gamma_2}, \widehat{\gamma_3}, \widehat{\gamma_4}, \widehat{\gamma_5}$, and $\widehat{\gamma_6}$ are positive.
- H3) The number of trips in the year 2019 is higher than that in 2022 due to the collateral effect of the COVID-19 pandemic. As a result, a positive coefficient is expected for $\widehat{\gamma_7}$.

4. Results and discussion

4.1. Description of the bus transportation system in the city

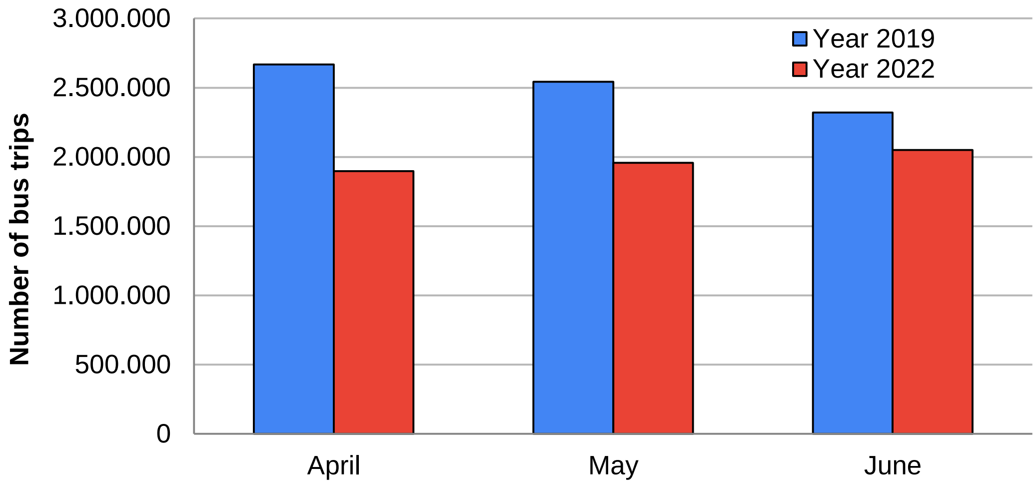
The public bus transportation system in Bahía Blanca is composed of 18 lines. Among them, 14 lines operate exclusively within the city, while the remaining lines provide interurban services, connecting Bahía Blanca with the towns of Ingeniero White, General Daniel Cerri, and Cabildo. The bus network covers approximately 90% of the city's urban area. Each bus line extends its coverage to a three-block radius around its route. The figure 1 illustrates the area covered by the bus lines. Note that the area of higher concentration corresponds to the city center, which is intersected by most of the bus lines.

Figure 1. Coverage of the current bus network in Bahía Blanca. Source: MBB (2020).



Regarding the demand, the average annual number of bus trips undertaken between the years 2008 and 2018 amounts to approximately 27 million passengers. Based on the municipality's measurements, it is estimated that one-third of the inhabitants of Bahía Blanca city use public bus transportation for their travels. The analyzed data in this study allows for the grouping and comparison of trips during two periods of time, namely the years 2019 and 2022. Figure 2 illustrates the total number of bus trips in relation to the months of April, May, and June, revealing a decline in the volume of passengers transported during all three months of analysis in 2022.

Figure 2. Quantity of bus trips per month. Source: own elaboration.



Furthermore, in Figures 3 and 4, the relative representation of data is presented graphically, expressed as a percentage of the total, showcasing the number of bus trips per day of the week and the number of bus trips per hour, respectively.

Figure 3. Share of bus trips per day. Source: own elaboration.

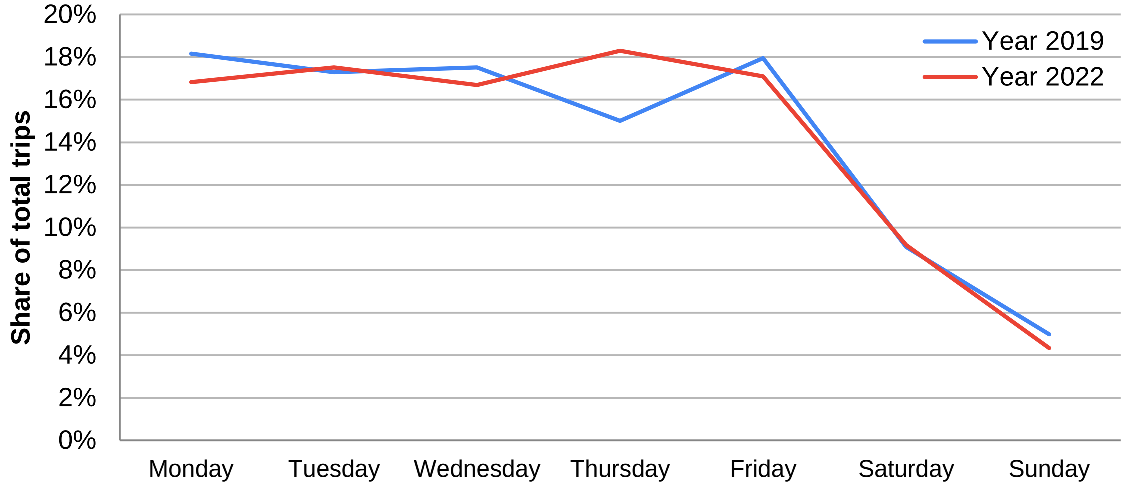
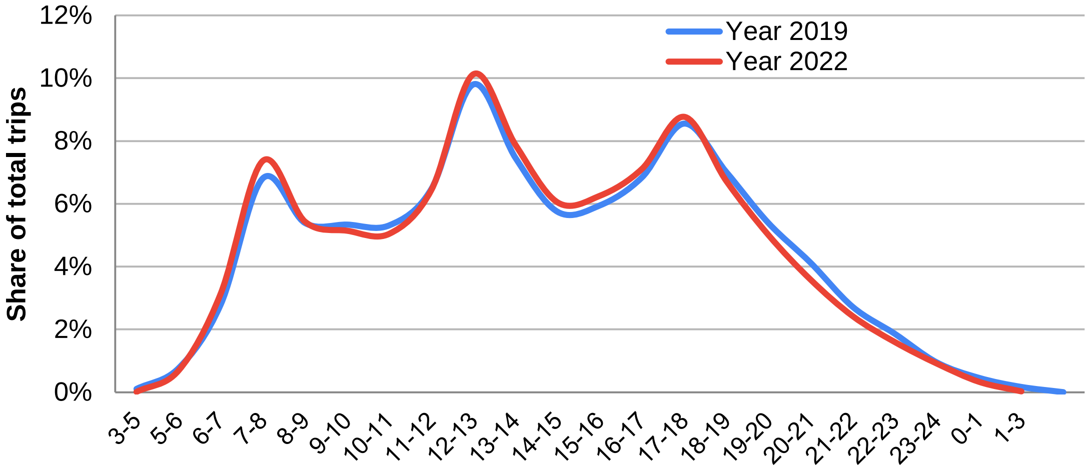


Figure 4. Share of bus trips per hour. Source: own elaboration.



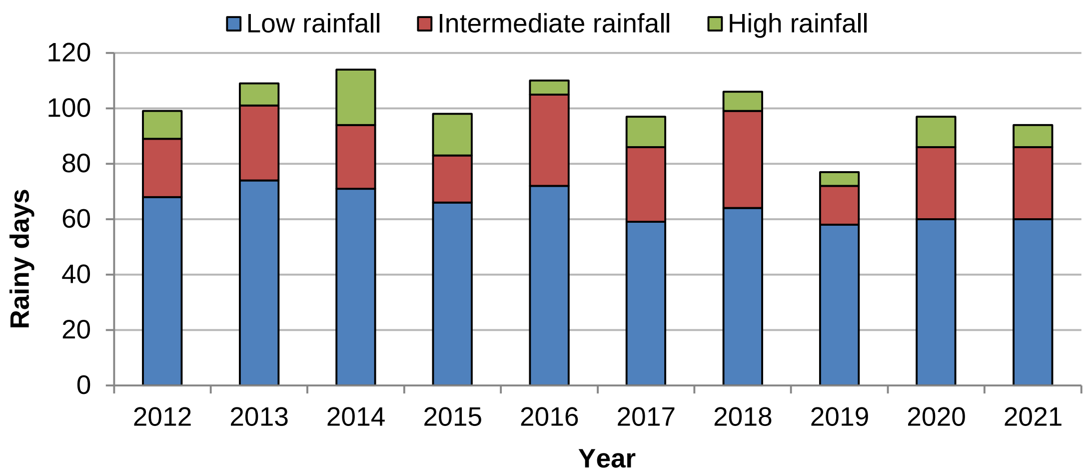
From the aforementioned figures, the following results and discussions regarding the demand for public bus transportation in the city of Bahía Blanca can be derived. From the weekdays' perspective, Monday to Friday accounts for approximately 15% to 18% of the total trips during the analyzed periods. Saturdays exhibit a halved proportion, hovering around 9% in both years. Sundays comprise approximately 4% to 6% of the total trips. These results align with the higher demand observed on weekdays, in contrast to Sundays or holidays when the number of passengers transported significantly decreases. Unlike Saturdays, the other weekdays show a change in trend between the years 2019 and 2022, where the day that previously held more weight becomes less predominant in 2022, and vice versa. This change is even more pronounced on Thursdays, as it becomes the day with the highest relative weight in 2022. Regarding the number of bus trips per hour, three clearly defined peaks are observed during the time intervals “7-8”, "12-13", and "17-18", representing periods with a higher concentration of passengers. This could be attributed to the hours when school students enter or exit or coincide with the beginning or end of the working day in a significant number of jobs. In comparison to 2019, the peaks of activity in 2022 are slightly more pronounced.

4.2. Description of Bahía Blanca's weather conditions

Bahía Blanca is a medium city located in the southern part of the Buenos Aires Province, Argentina. The city experiences a temperate climate, with average annual temperatures ranging between 14°C and 20°C and well-defined seasonal variations. The prevailing winds come from the northwest quadrant, with an average annual wind speed of 24 km per hour. The rainfall pattern is characterized as sub-humid or transitional. Concerning the annual distribution of average precipitation in Bahía Blanca, the highest amount of rainfall occurs between the months of December and March, with March being the rainiest month.

Based on meteorological data spanning from 2012 to 2021 for the city of Bahía Blanca, it can be observed that on average, approximately 10% of the days each year experience medium to high precipitation. It is important to note that, in the scale used, precipitation is considered low when it is less than 4 millimeters per day, medium between 4 and 16 millimeters, and high when it exceeds 16 millimeters. Figure 5 provides a breakdown of the number of days per year with precipitations and the magnitude of such precipitation based on the mentioned scale. Within the same years, the wind data shows that there is a 78.7% probability of the average daily wind speed ranging from 10 to 25 km/h. The interval of 15 to 20 km/h encompasses the highest number of days throughout the year.

Figure 5. Number of days per year with precipitation. Source: own elaboration.



4.3. Relationship between bus trips and weather conditions

Table 1 presents the results for the model expressed in equation 1, described in the methodology section. The coefficients determine how the variables under study influence the quantity demanded of public bus transportation tickets, while controlling for other potentially influential variables. Using a t-test, the estimated coefficients have an associated p-value that indicates the probability that the observed differences in the sample are due to chance. Within the analyzed data, the probability that the deviations can be attributed to chance is low. For coefficients related to the day of the week and the year in question, this value is less than 5% ($p < 0.05$), indicating that the variables are statistically significant. In the analyzed database, the adjusted coefficient of determination, R-squared (R2), is 0.8445. This value indicates how well the equation fits the data[21], and in this case, it reflects that 84.45% of the quantity demanded of bus trips can be explained

[21] Anderson, Sweeney, & Williams. "Statistics for Business and Economics".

by the considered variables.

Table 1. Multiple regression model. Source: own elaboration.

Variables	*Coefficients*	*P-value*
Interception ($\hat{\alpha}$)	9698.26	0.02
Rainfall (mm/day) ($\widehat{\beta_1}$)	-271.69	0.22
Wind speed (daily average km/h) ($\widehat{\beta_2}$)	276.57	0.12
Monday ($\widehat{\gamma_1}$)	72381.22	0.00
Tuesday ($\widehat{\gamma_2}$)	67905.44	0.00
Wednesday ($\widehat{\gamma_3}$)	70075.91	0.00
Thursday ($\widehat{\gamma_4}$)	67267.04	0.00
Friday ($\widehat{\gamma_5}$)	73802.96	0.00
Saturday ($\widehat{\gamma_6}$)	24313.95	0.00
Year 2019 ($\widehat{\gamma_7}$)	20348.48	0.00

Based on the presented results, it can be asserted that all the formulated hypotheses are supported, except for H1.a. The estimated coefficient $\widehat{\beta_1}$ is not statistically significant at 95% level of confidence and this weak result may be influenced by the months under study, considering that they are months with relatively low rainfall. In contrast, the estimated coefficient for $\widehat{\beta_2}$ has a positive sign and indicates that during the analyzed period, wind has a positive impact on the quantity of bus trips within the city. This variable is marginally significant at a confidence level of 89%.

As stated in hypothesis H2, the results yielded by the estimated coefficients $\widehat{\gamma_1}, \widehat{\gamma_2}, \widehat{\gamma_3}, \widehat{\gamma_4}, \widehat{\gamma_5}$ and $\widehat{\gamma_6}$ are positive and statistically significant at a confidence level of 99%. The quantity of bus trips increases significantly during weekdays compared to Sundays and holidays. On average, between Monday and Friday, approximately 70,000 more tickets are demanded compared to the reference day. Regarding Saturdays, the number of tickets demanded also increases, but to a lesser extent, around 24,000 tickets.

As regards the inter-annual analysis, it is estimated that in the case of 2019 approximately 20,000 more people are transported per day than in 2022. Regarding the effect of the year in which the trip is taken (H3), the estimated coefficient of the dummy variable is positive and statistically significant at a confidence level of 99%, indicating that in the year 2022, there is a decrease in the demand for bus trips compared to 2019.

5. Conclusion

This paper seeks to know the factors linked to the demand for bus transportation in a medium-sized city in Argentina, especially weather conditions, business days and the post-pandemic effect, aspiring to be able to work on such determinants in order to promote means of sustainable mobility such as public transport. Our results indicate that the demand for public bus transportation services is significantly lower to pre-pandemic levels (inter-annual analysis), and increases on weekdays as compared to Sundays and holidays (weekly analysis). Moreover, there is a positive correlation between adverse weather conditions and the demand for public bus transportation services, especially on days with strong winds.

These results can be useful for transportation providers to identify the impact of adverse weather conditions on the demand for public bus transportation services and other influencing factors. By understanding the correlation between weather conditions and public transport demand, providers of transportation services can adjust their schedules and routes, increase the frequency of service, and provide adequate shelter at bus stops to meet the needs of their users. Although it is uncertain how people who stopped using buses during the pandemic are currently commuting, it is possible to analyze alternatives to encourage the reutilization of public transportation or other sustainable means like active mobility.

In sum, the article findings can be used as a local perspective to plan and operate transportation services more efficiently and effectively, contributing to the SDG achievement from a multidimensional perspective. Furthermore, the paper establishes the basis to quantify the energy impact of variations in bus transport demand and contributes to delineate actions to reduce the environmental impact of urban daily mobility.

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