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Public Transport COVID-19-Safe: New Barriers and Policies to Implement Effective Countermeasures under User's Safety Perspective

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Abstract: The COVID-19 emergency forced cities worldwide to adopt measures to restrict travel and implement new urban public transport solutions. The discontinuity and reduction of services made users recognize public transport systems as contamination vectors, and the decrease in the number of passengers can already be seen in several places. Thus, this study assessed the impact of the COVID-19 pandemic on urban public transport. We used hybrid choice models (HCMs) to identify the new barriers and potential solutions to increase users' perception of safety, considering preexistent perceptions of public transportation quality. We used data from an online survey with users of public transportation in a metropolitan area in southern Brazil. We identified that the main barriers to using public transport during virus transmission are related to the system characteristics that force constant interaction with other passengers. Crowded vehicles and crowded stops/stations were considered the most detrimental factor in feeling safe while riding in the COVID-19 outbreak. Countermeasures that reduce the contact with other passengers—directly (limit the number of passengers in vehicles) or indirectly (operate with large vehicles)—and increase offers are possible solutions to make users feel safe while riding. The results of this research might help reduce passenger evasion and migration to more unsustainable transport modes.

Keywords: COVID-19; public transport; hybrid discrete choice models; infection prevention policies

1. Introduction

At the end of 2019, an aggressive virus with the ability to spread worldwide appeared to change the norms for social relations, consumption, and mobility patterns. The SARS-CoV-2 virus, which caused a worldwide COVID-19 (Coronavirus Disease 2019) pandemic, has infected more than 100 million and killed more than 2 million people worldwide, with numbers still rising [1]. While scientists were still learning about this new virus behavior, cities adopted different strategies to prevent its spread, acting to restrict travels with measures such as controlled distance and more severe ones, such as the lockdown [2,3].

During the pandemic, passenger transport stopped or suffered a drastic reduction [4], either due to reduced demand or due to the users' perception that transport systems are potential transmission vectors. However, it is necessary to emphasize that reducing supply affects a fundamental citizen's right: access to transport. About a third of Brazilian citizens, the case study analyzed in this paper, are users of urban public transport (PT) and rely on this transport mode for daily commuting [5]. The offer reduction also results in reduced access to health services. A study performed in the twenty largest cities in

Brazil showed that more than half of the vulnerable population could not walk to health assistance, requiring public transport services [6].

The main risks in the use of PT are associated with: (i) confined spaces and limited ventilation of vehicles; (ii) scarce access control to identify passengers who may be ill; and (iii) the existence of multiple surfaces, such as seats, handrails, doors, and ticketing machines, which easily transfer the virus and are inevitably touched [7]. Due to the risk perception associated with the use of PT, studies have shown that this scenario favors the greater use of private motorized vehicles to the detriment of collective transportation modes to avoid contact with unknown people [8]. Even regular PT passengers tend to change their travel behaviors, replacing transit for motorcycles, rides with on-demand service apps, or bicycles [9]. In Brazil, the National Association of Bus Operators reported an average reduction of 71% in demand for public bus passengers during the first wave. That is, 30 million passengers stopped traveling across the country [10].

The PT sector perspective is even darker since it was already suffering from passenger reduction before the pandemic. The number of paying passengers reduced by more than 25% in Brazil from 2017 to 2019 [11]. The evasion is due to low service quality, an unpleasant environment, and public-security-related problems that affect the overall satisfaction of users of different age groups [12]. Brazil is not an exception. The number of users of public transport is also decreasing in other countries around the world [13–16]. The pandemic aggravates this scenario, creating new obstacles to choose commuting by PT and making it necessary to implement actions and policies to maintain the service financially [17].

As a result of the COVID-19 pandemic, major transport authorities around the world have reported up to a 95% reduction in users [18]. Thus, researchers and specialists strive to analyze the consequences and impacts of SARS-CoV-2 and their different variants in PT [19]. Subbarao and Kadali [20] suggested a methodology for post-lockdown PT system operation: (a) creating a public database for screening, (b) strategy for the public transport operating system, (c) control measures for the public at transit stations and vehicles, (d) public transport disinfection system, and (e) strengthening of the public transport system and addressing ridership issues. Mesgarpour et al. [21] used a machine learning approach that violated an optimal range of temperature, humidity, and ventilation rate to maintain human comfort while minimizing the transmission of droplets.

Aghdam et al. [22] investigated COVID-19-related behaviors in the public transport system; their results suggest that gender, type of vehicle, age, and SES were significant predictors of nonadherence to COVID-19 preventive behaviors in public transport during the pandemic. Still, some authors have attempted to understand public transport satisfaction after the COVID-19 pandemic [23]. Other several studies evaluated the impact of COVID-19 on the sustainability of the transport system and human mobility [24–30].

Although these research studies brought relevant contributions, it is essential to identify new barriers and potential solutions that prevent user migration to less sustainable transport modes. To the best of our knowledge, most studies were carried out in other contexts. Perceptions and cultural issues can vary in different contexts, as can the dependence and quality of the public transport system. In this way, researchers and experts in public transport could use scarce resources more accurately.

In this context, three questions arise. First, which are the new barriers to the use of PT created by the COVID-19 disease? Second, which immediate measures (countermeasures) can increase users' perception of protection while riding PT? Finally, how do the preconceived perceptions of PT quality affect the perception of safety for the barriers and countermeasures under study? Answering these questions can help governments and operators implement more effective actions to increase user perception that PT is COVID-19-safe. This research assessed the impact of the COVID-19 pandemic on PT under the users' perspective in the context of Latin American cities. The general perception that PT is unreliable and unsafe, the long commuting hours, and the more restrictive transportation option due to the strong impact of transportation cost on families' budget [31] brings to the discussion local specificities that affect user experiences before and after COVID-19. We

aimed to control the effects of the previous experiences with latent variables constructed from PT quality indicators. Using these data from an online survey applied to PT users throughout a metropolitan area in southern Brazil, we estimated three different hybrid discrete choice models to understand the barriers and countermeasures to contain the SARS-CoV-2 outbreak.

2. Background on COVID-19 in Public Transport

COVID-19 is a relatively new disease. Different research areas are struggling to understand its consequences on health and its social and economic impacts in various communities. This section presents a brief background focused on its implications in PT. This item offers a small discussion about countermeasures implemented in different countries and how perceptions play a central role in travel behavior. Since the subject is still new and more research is continually being published, we do not pretend to exhaust the scientific information hitherto known but highlight points that are essential for further discussions.

2.1. The Roles of Urban Public Transport: From High Risk to Essential Service

Since the beginning of the COVID-19 crisis, public transport has been seen as an infectious disease vector.

The transmission can occur in two ways: (i) by inhalation and (ii) by contact [32]. These ways of infection bring pieces of evidence about the need for constant surface hygiene and ventilation. Inhalation is the primarily responsible type of contagious indoor infections [33]. The contact, on the other hand, can be direct or indirect. Direct contact is related to close contact and direct fluid exchange. Indirect contact infection occurs when a healthy individual touches the mouth, nose, or eyes after touching a contaminated surface touched and infected by sick individuals. Studies with other SARS-CoV family viruses demonstrated that the virus could persist on inanimate surfaces for nine days, depending on temperature and surface materials [34].

During the pandemic, a few solutions to identify ill individuals and prevent infection are proposed based on these symptoms such as the use of facial masks, trying to avoid droplets spread by cough, or fever screening. Screening is a solution used in different countries as a way to prevent disease spread. However, this is an "imperfect barrier to spread", missing 50–75% of the infected cases [35]. During the incubation period, the symptoms cannot be detected, and some individuals might be asymptomatic [36]. The possibility of contaminated individuals being asymptomatic makes it challenging to recognize them and forces governments to promote preventive actions such as social distance or lockdown.

Experience with other respiratory viruses has shown that some infection clusters originated in transport systems [37,38]. This assumption is based on the fact that closed environments can increase the contamination value (R0), reaching a number close to 2.8 [39]. These values indicate that vehicles and terminal passenger transport stations can produce "overspread" events contaminating a large number of users. Other studies conducted in New York City (USA) and Wuhan (China) reported a high correlation between the rail system and new infections [40,41]. However, the studies missed some critical factors to attest cause–effect and did not significantly correlate to other PT modes. Therefore, there is still no evidence that PT is responsible for increasing infections, perhaps due to the rapid response of operators and governments to introduce countermeasures that prevent virus spread. However, it is true that the transport public system environment bunches a set of conditions that can favor the virus transmission.

PT vehicles (e.g., buses, trams, rails, and subways) usually are closed spaces with deficient ventilation [37]. System operators also admit, and expect, a high concentration of users during peak hours, where the recommended social distancing is not possible to maintain. The high number of passengers makes the control system more complicated, and there is a probability of not detected ill individuals being close to non-ill. Finally, users

need to contact different surfaces that can be contaminated, such as handrails, turnstiles, and even ticket money [7].

In Latin American cities, the risk could be higher due to the long journey trips and the length of the exposure time window [37]. Long commuting is already associated with different health impacts, such as depression [42]. It is related to unequal patterns in access to jobs and public services, generating a substantial effect on the population travel pattern [43]. Groups with lower incomes are usually spatially segregated and limited regarding mobility and accessibility conditions [44]. Additionally, the PT service offered is unreliable, and transport costs substantially impact the family budget [31]. However, in some cases, public transportation is the main or the only option for vulnerable communities.

Since the mobility pattern and opportunity distributions are not equal in different populations, it is expected that lockdown measures would not have the same impact [45]. The equity implications are significantly higher for essential workers that do not have teleworking as an option. Many of these workers are in low-income groups (e.g., supermarket employees) and depend on public transit to keep working [41,46]. A study conducted in seven regions in Colombia reinforced these arguments [47]. The authors found a lower demand reduction in public transit than car trips, mainly because essential workers use PT to continue working.

Therefore, improving travel conditions on public transport is a matter of social equity and public health. Studying solutions to guarantee safe journeys and increase the perception of safety by users is essential. It is vital to organize robust emergency management programs to ensure that essential services keep working, and managing a resumption of economic activities is necessary for social well-being [48].

2.2. Making Transit Systems COVID-19-Safe

There is an effort to establish procedures that guarantee the safety of users and onboard crew in PT. Experiences worldwide have helped create a portfolio of countermeasures that focus on cleaning vehicles and stops/stations, mask use, and providing social distancing between users. There are examples of vehicle hygiene procedures in different parts of the world [49,50]. Pilots with ultraviolet light were conducted on buses and trains in New York City in an effort to make the transit system safer [51]. However, the effectiveness of this sanitized effort on vehicles is undermined. They also are human-resources-consuming and time-demanding [45,47].

Regarding vehicles, another vital measure is ventilation, which is particularly essential for an onboard crew that spends many hours a day inside the vehicles [7]. Ventilation can be a particular issue in metro systems, where natural ventilation is not possible. There are a few pieces of evidence of air conditioning spreading contaminated droplets [52], but no studies have been conducted so far on an inside vehicle environment.

Extensively used in some Asiatic cultures, the use of masks is passing through a popularization process during the COVID-19 pandemic. Studies show that face covers can be more effective in reducing virus spread than disinfection and frequent handwashing [53]. This measure relies on the user's response to a social appeal since they are responsible for having their own proper mask and wearing it correctly [37]. In different countries, their use became mandatory in closed spaces and public transit to guarantee users' protection.

Another essential countermeasure is the maintenance of social distancing. It is one of the solutions that have the most consensus in the scientific community. Studies show that a 1–2 m distance is enough to reduce virus transmission by droplets [54], and public transit operators are trying to adapt their vehicle layout to this parameter. For instance, this means that a standard-size 12 m bus will only be allowed to transport 18–20 users because the position of seated and standing passengers matters [55]. As a consequence of the capacity reduction, there are expected revenue impacts since it will be necessary to maintain a certain level of service to meet demand [9], and it might be unsustainable for massive systems. Despite the financial impact and the difficulty of inspecting, several Brazilian cities have adopted passenger capacity limits for bus transit systems [56–59].

There is still a group of measures that seek to avoid the demand for transport and thus guarantee a smaller number of passengers in the system. Some examples are actions that encourage telework, virtual meetings, and distance learning. The pandemic forced many companies to adopt this type of strategy during the lockdown. Experience in practice can help companies understand teleworking not as an emergency measure but as an opportunity to improve working conditions and reduce commuting [45]. Other actions, such as different work schedules, can also prevent crowding at the peak hour, spreading demand over the day and on different days of the week. Some Brazilian cities adopt staggered hours as a countermeasure and a peak spreading strategy. The city of Fortaleza identified a demand reduction of 26% in the morning peak and 19% in the afternoon peak. The city of Goiânia also found positive impacts: terminal overcrowding reduction and reduction in public transport complaints [60].

Finally, there are other types of countermeasures with a few pilot experiments in different cities. Pre-booked seating, temperature checks, only virtual payment, and better information to passengers regarding bus occupation and location are a few examples of other possible solutions to make public transit COVID-19-safe [7,55]. However, since all of these solutions impact operation and costs, it is essential to understand the user's safety perceptions and what would make them rely on PT when they need to use it.

2.3. User's Perception of Transport Quality and Transport Safety

In some cities, public transport usage was reduced by up to 90% during the pandemic [61]. Although part of this reduction is a consequence of social distancing and lockdown restrictions, the other part derives from the perception that public transportation is not safe [47]. Perceptions play a central role in travel attitudes. They help measure the individual's cognitive ability to represent and evaluate the levels of attributes of different alternatives. The choice process depends on how the levels of attributes are perceived by individual beliefs [62].

During the pandemic, the choice of using public transport is related to (i) the impossibility of traveling using other modes due to financial, social, or housing restrictions or (ii) the positive perception of quality and safety. Some authors believe that service quality results from comparing consumers' expectations with their perception of the actual service received [63]. However, there are often gaps between different perceptions of quality, and these gaps can be significant obstacles in trying to deliver a service that consumers perceive as a good service. Hence, it is crucial to implement measures that prioritize the quality and level of safety perceived by users [64].

Since COVID-19 is a new disease and information is continually changing over time, the users may have misperceptions about how safe it is to use PT. Therefore, communication plans are essential to provide information on how safe users are during the ride and promote safer behaviors [37].

3. Data

The data used in this study came from an online survey built using the Google Forms platform. In an initial stage, a pilot survey was performed to verify the applicability and test question understanding. After that, the final survey was conducted between 20 June and 24 July 2020. The online survey was disseminated through email lists and social media networks. In total, 700 responses were obtained across the country. We selected residents from the Metropolitan Region of Porto Alegre (RMPA) in southern Brazil. The RMPA was chosen for the significant proportion of answers and to maintain the PT service characteristics locally since they might vary across the country. Finally, from the 314 residents in the select area, we used the 150 individuals that use PT service at least once a week.

In order to identify countermeasures to increase safety for users regarding COVID-19 infections in PT systems, the questionnaire included the following items.

1. The general impact of COVID-19: identification of respondents' perceptions regarding: (i) belonging to the risk group, (ii) living with people from the risk group, (iii) fear of contagion, and (iv) the pandemic situation in the city of residence.
2. Description of mobility patterns during the pandemic: assessment of changes in mobility pattern, including mode and the main reason for travel.
3. Description of mobility patterns before the pandemic: analysis of the main reason for travel, transport mode, and PT users' identification.
4. Description of travel using PT: identifying the type of PT used and week and daily frequency and evaluating PT quality attribute perception—using a four-point Likert scale (strongly disagree, disagree, agree, strongly agree).
5. Barriers to the use of PT (perception of risk): ordering from 1 to 7 of the barriers that make users feel unsafe regarding COVID-19 infections when using PT.
6. Countermeasures to eliminate the barriers (perception of safety): ordering 1 to 7 the two groups of solutions that users perceived as the safest regarding virus transmission while using PT.
7. Respondent profile: identification of socioeconomic characteristics of the individuals.

Questions related to travel on PT and barriers and countermeasures that increase the feeling of safety were applied only to respondents who declared using public transportation at least once a week. Concerning the countermeasures, they were presented to respondents divided into two categories. Group 1 of measures is the most commonly adopted in public transport systems—users who continue to use public transport during the pandemic may already have experiences with them in place. Group 2 is composed of less applied measures, generally because they have higher implementation costs or greater operational complexity; therefore users might be less familiar with them. Table 1 presents the descriptive statistics of the variables used in the models.

Table 1. Variables' descriptive statistics.

Variable Group	Variable	Frequency/Mean—Std.
Individual socioeconomic characteristics	*Income*	0—Without income: 5 (3%) 1—Up to 1 Brazil minimum wage: 4 (3%) 2—Between 1 and 2 Brazil minimum wages: 21 (14%) 3—Between 2 and 5 Brazil minimum wages: 42 (28%) 4—Between 5 and 8 Brazil minimum wages: 33 (22%) 5—More than 8 Brazil minimum wages: 44 (30%)
Explanatory variables	*Risk group proximity*	1—Yes: 64 (43%) 0—No: 85 (57%)
	Pandemic controlled in the city	1—Yes: 30 (20%) 0—No: 119 (80%)
	PT use weekly frequency	1—4 or more times a week: 101 (68%) 0—less than 4 times a week: 48 (32%)
	PT use daily frequency	1—3 or more times a day: 61 (41%) 0—less than 3 times a day: 88 (59%)

Table 1. *Cont.*

Variable Group	Variable	Frequency/Mean—Std.
Latent indicators	*PT is good*	1—Totally disagree: 21 (14%) 2—Disagree: 73 (49%) 3—Agree: 53 (36%) 4—Totally agree: 2 (1%)
	PT users are polite	1—Totally disagree: 23 (15%) 2—Disagree: 68 (46%) 3—Agree: 57 (38%) 4—Totally agree: 1 (1%)
	PT is comfortable	1—Totally disagree: 24 (16%) 2—Disagree: 71 (48%) 3—Agree: 52 (35%) 4—Totally agree: 1 (1%)
	PT is clean	1—Totally disagree: 24 (16%) 2—Disagree: 70 (47%) 3—Agree: 54 (36%) 4—Totally agree: 1 (1%)
	PT is usually empty	1—Totally disagree: 68 (46%) 2—Disagree: 70 (47%) 3—Agree: 10 (7%) 4—Totally agree: 1 ($\approx$0%)
	I feel safe from robbery while I'm using PT	1—Totally disagree: 74 (50%) 2—Disagree: 38 (26%) 3—Agree: 35 (23%) 4—Totally agree: 2 (1%)
	I feel safe from traffic crashes while I'm using PT	1—Totally disagree: 23 (16%) 2—Disagree: 33 (22%) 3—Agree: 78 (52%) 4—Totally agree: 15 (10%)

We tested different explanatory variables collected in the questionnaire in the models. The only four that presented significant results are shown in Table 1. The *Risk group proximity* variable aimed to identify if the respondents fear contagion not only for themselves but also for the risk group individuals they may live with. On the other hand, *Pandemic controlled in the city* aimed to identify which respondents consider the pandemic uncontrolled in their towns, representing high-contamination-risk perception.

4. Method

In order to assess the impact of COVID-19 on the use of PT under the perceptions of safety, we used hybrid choice models (HCMs). Hybrid choice models are a rational choice to accomplish the study's goal. Beyond the ambition of identifying the relative importance of a set of alternatives for barriers and countermeasures that led to using a hierarchical choice model, we wanted to evaluate how pre-conceived perception of public transportation affects how users perceived the COVID-19 response. Therefore, it was necessary to construct latent variables to incorporate attitudinal attributes into the utility function. The possibility to address unobserved heterogeneity between respondents has increased the use of the method in transport models. Perceptions and attitudes influence the decision-making process, and the incorporation of latent variables that represents these psychological factors into the model structure helps to understand choice behavior [62,65].

The HCM is composed of two parts: a latent variable model and a choice model. The choice model differs from the usual only by incorporating the latent construct. However, the choice probability is derived from both latent variables and observed variables [66].

The random utility of alternative formulation is represented by Equation (1), (V_i) refers to the deterministic portion of the utility, and ε_i is the error [67].

$$U_i = V_i + \varepsilon_i \tag{1}$$

In the case of the HCM, V_i is presented in two parts: the observable (X) and unobservable (X^*) (Equation (2)).

$$V_i = V_i\,(X, X^*; \beta) \tag{2}$$

The unobservable part is accounted for in the latent model, and the structural relation is described in Equation (3), where X^* is a function of the explanatory variables (X) and random disturbance terms (η).

$$X^* = h\,(X; y) + \eta \tag{3}$$

Finally, Equation (4) presents the MNL formulation. The utility function's random term is identically and independently distributed according to a Gumbel distribution (Extreme Value type I) [68].

$$P(y_i = 1 \mid X, X^*; \beta, \Sigma_\varepsilon) = \frac{e^{(V_i)}}{\sum_{j \epsilon C} e^{(V_{ji})}} \tag{4}$$

Three different responses were modeled: (i) user's perception of barriers to the use of public transport while there is an active virus transmission (Model 1); (ii) user's security perception regarding common countermeasures applied to reduce transmission (Model 2); and (iii) user's security perception regarding bold countermeasures to reduce transmission (Model 3). Figure 1 presents the theoretical framework proposed for the models.
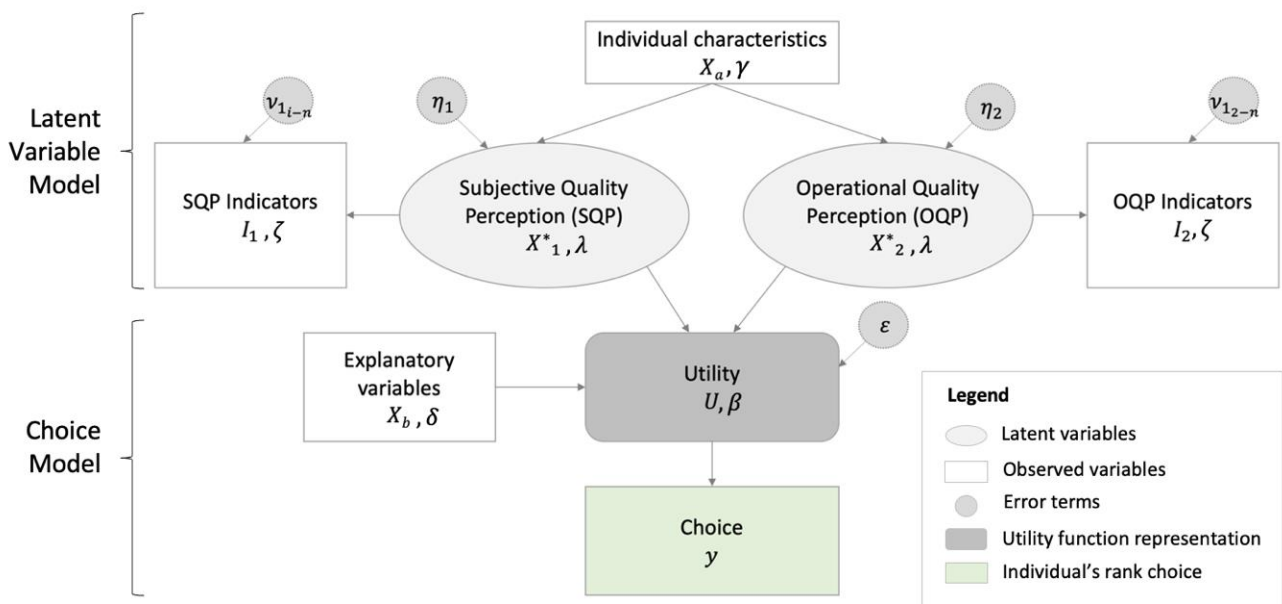

Figure 1. Theoretical framework of the study models (Observable (X) and unobservable (X^*) independent variables).

The results were evaluated based on the significance of the loads ($\gamma, \zeta, \lambda, \delta, \beta$). We tested significance using robust t-ratio values. T-ratios are calculated by dividing the load per standard errors. Values over 1.96 indicated the load is statistically significant at 95% confidence level. The log-likelihood and the Akaike information criterion (AIC) are presented to compare the model in different contexts further.

Models 1, 2, and 3 focus on public transport users. The two latent variables used in the model aim to represent preview perceptions regarding the transportation system's

overall quality before the pandemic. The *Subjective Quality Perception* (SQP) latent variable indicator represents subjective quality characteristics, such as perception if the PT service is good and comfortable, if the other users are polite, and if they like to use PT. On the other hand, the *Operational Quality Perception* (OQP) latent variable indicators focus on vehicle and security characteristic perception regarding operation quality. Vehicle cleanliness and crowdedness, together with personal security and road safety, are the indicators of the latent variable OQP.

The choice variable represents the respondent ordering (ranking) of a set of characteristics related to insecurity (barriers) and security (countermeasures) presented in the questionnaire. The ranking responses were modeled using HCMs after exploding ranking responses into N-1 statistically independent choices [69], reconfiguring the answers as a series of decision-making processes. Applications of the exploded ranking technique could be found in other studies, such as those performed by [70–72]. However, the use of exploded ranking and HCMs to identify barriers and countermeasures is considered a new approach.

5. Results and Their Implications for Transport Policies

This section presents and discusses the results of the three models estimated.

5.1. Model 1: Barriers That Increase Risk Perception of Using PT during COVID-19 Pandemic

Emphasizing that public transport users perceive transport as a contamination vector, Model 1 aims to identify which operation intrinsic features can act as barriers to the use of PT during the COVID-19 pandemic. Table 2 presents the HCM results, separated into three parts: the latent model, the choice model's utility function, and the choice order results.

The latent model comprises two latent variables (*Subjective Quality Perception* (SQP) and *Operational Quality Perception* (OQP)) with three and four indicators, respectively. The most important indicator was the perception that PT is good (−1.293) for the SQP latent variable and the perception that PT is usually empty (not crowded) (1.440) for the OQP latent variable. All the indicators are significant, but the SQP indicators present a negative load. The negative loads mean that the latent variable represents the disagreement with the sentence proposed for the respondents, indicating a negative perception about the service quality. Regarding the socioeconomic characteristics, only income was significant for the two latent variables but with opposite signs compared to the indicator. In this case, the opposite signs mean that the wealthiest individuals have lower quality perceptions over operational and subjective perspectives (−0.342; 0.252). The other explanatory variables tested (age and gender) did not result in significant estimates. This means that individuals form different gender and different age ranges evaluating the quality of the PT differently, and then the models could not capture any tendency of these characteristics clearly.

Regarding the utility function, we estimated the latent variables with specific parameters for each function. All of the loads represented a positive effect on barriers' utility. The bigger loads for both latent variables are in the barrier number 2 utility function (SQP: 4.024; OQP: 3.090). Barrier 2 represents crowded vehicles. Therefore, the lower the users perceive the subjective quality of transport to be, the more important the level of crowdedness in the vehicle is for users to feel insecure, compared to the other barriers. In the case of the operation quality, the lower they perceived the quality of operational features to be (cleanliness, loaded levels, safety, and security), the more critical it is to spend more time inside of the vehicle (B7).

The crowded vehicles (*β*: 3.835, 1st) and stops and stations (*β*: 3.137, 2nd) that regularly happened in PT daily operations are the main barrier for the interviewed users. Users might be less likely to use PT, especially in situations where the presence of a high number of users in the same vehicle is intrinsic to the operation, such as in high-capacity systems and at peak hours. Therefore, recommended solutions for infectious diseases that seek social distance might make users feel more confident that PT is safe.

Table 2. Result for Model 1—Barriers.

Latent Model			
Latent Variable	**Indicators**	**Loads (ζ)**	**Robust t-Ratio**
SQP	*PT is good.*	−1.293	−2.382
	PT' users are polite	−1.151	−3.700
	PT is comfortable	−0.749	−2.791
	PT is clean	0.885	2.804
OQP	*PT is usually empty*	1.440	3.090
	I feel safe from robbery while I'm using PT	0.977	2.918
	I feel safe from road crashes while I'm using PT	1.256	2.451
Latent Variables	**Indiv. Characteristics**	**Loads (γ)**	**Robust t-Ratio**
SQP Indv. Characteristics	*Income*	0.252	2.085
OQP	*Income*	−0.342	−3.125
Choice Model—Utility Function			
Utility Function	**Latent Variables**	**Loads (λ)**	**Robust t-Ratio**
B1	*SQP Latent variable*	3.430	3.705
	OQP Latent variable	2.473	3.306
B2	*SQP Latent variable*	4.024	5.670
	OQP Latent variable	3.090	4.833
B3	*SQP Latent variable*	2.797	4.556
	OQP Latent variable	2.187	4.726
B4	*SQP Latent variable*	1.939	4.011
	OQP Latent variable	1.436	3.372
B5	*SQP Latent variable*	1.215	3.004
	OQP Latent variable	0.965	2.467
B6	*SQP Latent variable*	1.035	3.815
	OQP Latent variable	0.767	3.355
Choice Model—Choice Ranking Results			
Order	**Choice Alternatives**	**Loads (β)**	**Robust t-Ratio**
1°	*B2—Crowded vehicles*	3.835	2.592
2°	*B1—Crowded stops and stations*	3.137	2.605
3°	*B3—Circulation of many different people*	2.860	2.724
4°	*B4—Vehicles are closed places*	2.312	3.039
5°	*B6—Need to touch where other people have touched*	1.510	3.063
6°	*B5—Air conditioning always on*	1.352	2.481
7°	*B7—Need to stay a long time in the vehicle*	0.300	Fixed

LL: −3841.53, AIC: 7779.07.

The third barrier in the rank also refers to interaction with other users. The presence and exposure of many different people (β: 2.860, 3rd), followed by the need to touch places where other people touched (β: 1.510, 5th), reinforce the idea that the unsafe feeling on PT is based on mistrust of other users. They may not believe that other individuals will respect the COVID-19 social agreement since the virus can be transmitted between people through direct, indirect, or close contact. Realizing that the other user is taking the necessary measures to prevent infections can make users feel safe.

The fourth important barrier is vehicles are closed spaces (β: 2.312, 4th), which might help to spread the virus. Although air conditioning is also a possible enhancer for air transmission, this barrier only appears in the sixth position (β: 1.352, 6th). Finally, the last important barrier is the time spent in the vehicle (β: 1.352, 7th). However, it is noteworthy that the practical risk and the perception of risk are different measures. Thus, it is necessary to address solutions beyond guaranteeing social distancing to increase users' safety regarding infection and spread of SARS-CoV-2 and incorporate measures that increase security perception.

5.2. Model 2: Countermeasures That Increase the Perception of Safety on Using PT during COVID-19 Virus Pandemic—Group 1

After identifying the barriers of use, it is essential to evaluate what countermeasures operators and public authorities can implement to guarantee that users will continue using PT and avoid migration to private modes. Thus, Model 2 seeks to rank a repertoire of countermeasures according to users' perception of safety regarding infections by SARS-CoV-2. This model represents the first group of countermeasures that comprise solutions to reduce contagion comprehensively applied. Users who continue to commute during the pandemic may have already experienced it or are familiar with this countermeasure group. Table 3 presents the estimation results for Model 2.

Table 3. Results for Model 2—Countermeasures Group 1.

Latent Model			
Latent Variable	**Indicator**	**Loads (ζ)**	**Robust t-Ratio**
SQP	*PT is good.*	−1.145	−2.864
	PT' users are polite	−1.571	−3.472
	PT is comfortable	−0.967	−2.937
	PT is clean	0.611	2.160
OQP	*PT is usually empty*	1.200	3.253
	I feel safe from robbery while I'm using PT	1.085	3.135
	I feel safe from road crashes while I'm using PT	1.187	2.593
Latent Variables	**Indiv. Characteristics**	**Loads (γ)**	**Robust t-Ratio**
SQP Indv. Characteristics	*Income*	0.313	2.731
OQP Indv. Characteristics	*Income*	−0.290	−3.044
Choice Model—Utility			
Utility Function	**Latent Variables**	**Loads (λ)**	**Robust t-Ratio**
C1.1	*SQP Latent variable*	1.730	2.594
	OQP Latent variable	1.734	2.086
C1.2	*SQP Latent variable*	1.626	2.621
	OQP Latent variable	1.553	1.933
C1.3	*SQP Latent variable*	1.464	2.304
	OQP Latent variable	1.051	1.171
C1.4	*SQP Latent variable*	1.062	2.280
	OQP Latent variable	1.193	2.023
C1.5	*SQP Latent variable*	0.210	0.310
	OQP Latent variable	0.056	0.071
C1.6	*SQP Latent variable*	0.175	0.442
	OQP Latent variable	0.243	0.584

Table 3. *Cont.*

Latent Model		
Explanatory Variable (Is Fixed for All the Utility Functions)	**Loads (δ)**	**Robust t-Ratio**
PT use weekly frequency	-1.020	-2.456
Choice Model—Choice Results		

Order	Choice Alternatives	Loads (β)	Robust t-Ratio
1°	*C1.3—Limit the number of people in vehicles*	4.793	4.994
2°	*C1.5—Use of mask*	4.237	5.526
3°	*C1.2—Vehicle hygiene*	3.830	4.090
4°	*C1.4—Turn off the air conditioner*	3.018	3.842
5°	*C1.1—Blocking and demarcation of places*	2.889	2.992
6°	*C1.6—Availability of alcohol gel*	2.555	3.943
7°	*C1.7—Temperature measurement*	0.300	Fixed

LL: -3800.25, AIC: 7710.5.

The latent variables were estimated once again in Model 2. Equally to Model 1, all the indicators are significant and with the same indicator signs. The most important indicator was the perception that users are polite for the SQP latent variable (-1.571). As occurred in Model 1, PT is usually empty (not crowded) and is the most important indicator for the OQP latent variable (1.200). Regarding the socioeconomic characteristics, again, only income was significant for the two latent variables (SQP: 0.313; OQP: -0.290).

In Model 2, the latent variables are not significant for countermeasures 5 and 6, compared to countermeasure 7 (robust t-ratio < 1.96). These three countermeasures represent the use of masks, alcohol gel availability, and temperature measurement. These three countermeasures are probably the most COVID-19-dependent. In other words, they are the most directly related to the disease. Despite having an impact on the virus spread, the other four countermeasures are more related to PT users' routine demands and, therefore, more connected with the system's perceived quality before the pandemic. The OQP variable was also not significant for countermeasure 3, which aimed to limit the number of people in the vehicle.

We aggregated one explanatory variable to understand user countermeasure choice: their weekly PT use frequency. The variable presented a negative sign (-1.020). Frequent users show to be less likely to feel safe even with the countermeasures in place.

5.3. Model 3: Countermeasures That Increase the Perception of Safety on Using PT during COVID-19 Virus Pandemic—Group 2

Model 3 aims to test additional countermeasures that are less common, and few users have seen them applied in practice. The results are presented in Table 4. The latent variables in the model also presented significant indicators. The perception that users are polite (1.298) and that the PT vehicle is usually empty (1.400) is the most important SQP latent variable and OQP latent variable. This is consistent with the previous results. Different from Model 2, for Model 3, the SQP latent variable indicators presented positive signs, showing that the latent variable represents a high perception of subjective quality.

Table 4. Results for Model 3—Countermeasures Group 2.

Latent Model			
Latent Variable	**Indicator**	**Loads (ζ)**	**Robust t-Ratio**
SQP Indicators	*PT is good.*	1.106	3.076
	PT' users are polite	1.298	3.181
	PT is comfortable	0.882	3.131
	PT is clean	0.887	3.332
OQP Indicators	*PT is usually empty*	1.400	3.549
	I feel safe from robbery while I'm using PT	1.103	3.570
	I feel safe from road crashes while I'm using PT	1.242	3.004
Latent Variables	**Indiv. Characteristics**	**Loads (γ)**	**Robust t-Ratio**
SQP	*Income*	0.269	2.511
OQP	*Income*	0.285	2.828
Choice Model—Utility			
Utility Function	**Latent Variables**	**Loads (λ)**	**Robust t-Ratio**
C2.1	*SQP Latent variable*	1.758	4.752
	OQP Latent variable	−1.581	−3.052
C2.2	*SQP Latent variable*	1.546	4.857
	OQP Latent variable	−1.755	−3.898
C2.3	*SQP Latent variable*	0.910	2.981
	OQP Latent variable	−1.324	−3.295
C2.4	*SQP Latent variable*	0.536	1.902
	OQP Latent variable	−1.293	−3.736
C2.5	*SQP Latent variable*	0.208	1.129
	OQP Latent variable	−0.654	−3.373
C2.6	*SQP Latent variable*	−0.057	−0.222
	OQP Latent variable	−0.429	−1.465
Explanatory Variables (Are Fixed for All the Utility Functions)		**Loads (δ)**	**Robust t-Ratio**
Risk group proximity		0.717	2.336
Pandemic under control in the city		0.863	2.300
PT use daily frequency		−0.655	−1.979
Choice Model—Choice Results			
Order	**Choice Alternatives**	**Loads (β)**	**Robust t-Ratio**
1°	*C2.5—Operate with larger vehicles*	2.574	3.384
2°	*C2.7—Increase offer*	2.480	2.550
3°	*C2.2—Change activity start time*	2.289	6.034
4°	*C2.3—Inform the number of passengers in vehicles*	2.145	5.109
5°	*C3.6—Separation of seats with acrylic protection*	1.985	2.469
6°	*C2.4—Seat reservation*	1.774	3.146
7°	*C2.1—Discount for off-peak travel*	0.900	NA

LL: −3902.802, AIC: 7915.6.

The latent variables presented to be most significant for the choice utility function of the countermeasures from Group 2. The exceptions are the SQP latent variable for countermeasure 5 (operate with large vehicles) and latent variables SQP and OQP for countermeasure 6 (separation of seats with acrylic protection), where the robust t-ratio preset values are lower than 1.96. Therefore, in these cases, it is impossible to say if the latent variables contribute to the choices' utility more than for countermeasure number

7 (increase offer). The other three explanatory variables included in Model 3 were also significant.

Countermeasures from Group 2 contribute to users with risk group individuals in their family units to feel safe using PT (0.717). Those who believe the pandemic is under control in their cities will also feel safer (0.863). These results might indicate that insecurity levels depend on how the individuals perceived the pandemic situation as a whole. The same is not valid for those who use PT three times or more on the same day. The negative sign (−0.655) shows that frequency affects the perception of countermeasure safety.

Looking at the countermeasure ranking results, Model 3 shows that the most important countermeasure was the availability of larger vehicles (β: 2.574, 1st), followed by increase in frequency (β: 2.480, 2nd). These countermeasures may have stood out since they are old demands of users, even during a typical situation, without the fear of getting the disease. This result is contrary to what has been adopted in many Brazilian cities, where service offers were reduced. The reduction in supply can make the system less reliable and still contribute to increased contagion by promoting crowded vehicles in the remaining hours as well as the high presence of users at stop points and stations [6]. Together with the third-placed countermeasures, changing start times of activities (β: 2.289, 3rd), they are also related to the understanding that it is necessary to reduce contact with other users. C2.2, being the third countermeasure in the rank results, shows that users can also perceive value in an indirect public transportation solution that can reduce crowdedness in public transportation. In addition, public transport operators participate in regulatory agencies so that they can be regulatory agents of a flexible schedule policy.

In the fourth position is the information regarding the number of passengers in the vehicles (β: 2.145, 4th). This solution may not have been identified as more important since some users cannot wait, for example, for an empty vehicle due to time and frequency restrictions. Its implementation may be more accepted by users who use the subway or train services since its frequency is higher than in bus systems. The least safe measures are separating seats with acrylic protection (β: 1.985, 5th), seat reservation (β: 1.774, 6th), and discount for off-peak travel (β: 0.900, 7th).

6. Countermeasure Implementation and Policy Implications for Public Transport in a COVID-19 Reality

The COVID-19 pandemic promoted disruptive social changes in different aspects of our daily lives. In transportation, although there are shreds of evidence of commute reduction based on teleworking strategies and cycle lanes are popping up in different cities, policies to keep urban transit operating are crucial to Brazilian cities' resilience [73]. Especially for low-income groups in developing countries, public transportation is essential, and a key player in promoting equity [44]. Therefore, the discontinuity of the service in a few Brazilian cities during the pandemic should not be an option.

Regarding this study's results, some countermeasures cannot be implemented by operators without legal sustenance (e.g., the use of masks). Therefore, public authorities need to work closely with operators to legislate and make mandatory specific actions that rely on users' behavior when applicable. However, operators can support monitoring compliance, support guidance, and act as an information source to passengers. Measures such as vehicle hygiene and the inclusion of separators in the seats, on the other hand, can be implemented on operators' initiatives, and the results show that they are in line with the users' desire and increase their perception of safety.

The perception of safety is also high in solutions that significantly impact service offer and, consequently, operation costs. High frequency, use of larger vehicles, and limiting the number of passengers might be suitable for users but unbalance the financial system. This solution directly impacts services costs, and this risk is allocated to operators in most Brazilian contracts [17]. Negotiation with public authorities is an alternative for operators who have failed to maintain the service since circulation restrictions and capacity limits reduce operators' revenue [74]. The number of passengers will also decrease, either

because of the economic crisis or working habits [75]. Therefore, it is urgent to find ways to guarantee the financial viability to keep the service operating. More than resorting to economic aid packages, the governments at local and national levels need to work on public policies that guarantee system sustainability in the long term. Public urban transport should be a priority agenda. It is urgent to retain passengers, and this study's results can help attract new users and change the direction of allocating indirect public subsidies.

The bright side is the opportunity that arises with the demand reduction during a lockdown or while no one has returned to normal activities. There is an open door to rethink routes and redesign vehicle internal layout. Creating more internal space can respond to users' demand for larger vehicles in bus and rail systems, guaranteeing social distance. Especially for bus systems, route optimization, new integration points, and stop reallocation can increase the frequency and, consequently, the offer to address users' demand.

It is essential to highlight that our results are based on users' perceptions. That is, users need to be informed of all the initiatives to reduce COVID-19 infections. Countermeasures such as vehicle hygiene may not be perceived easily by users, and a positive impact on the perception of safety might be missed. Therefore, communication plays a central role in avoiding passenger evasion.

Other measures included in this study require a more comprehensive social agreement, such as peak spreading strategies. This countermeasure was already advocated in many opportunities by urban mobility specialists, but it may now be enhanced by the benefits linked to public health. Local governments can support these initiatives with fiscal incentives to companies. Indeed, many of the solutions proposed in this study need the support of public policies. However, citizens' collective actions are determinant to the success of these policies that have been tested during the pandemic [76].

It is also essential to highlight that frequency results as a negative factor to the countermeasure models. Individuals who use PT more often were even more exposed to Latin American transport systems' everyday problems in the pre-pandemic period. Reinforced by the latent variable results, it is possible to say that users who have more discredit of the PT quality are also more insecure about the countermeasures' efficiency. The same is true for those whose cities' situations are uncontrolled, showing that external factors matter. The importance of macro policies to control the pandemic and reduce the level of contagion is crucial to a new normal that supports the use of public transportation.

7. Final Remarks

PT has been suffering from user losses and the consequent reduction in the service's quality. With the arrival of a viral disease, characteristics intrinsic to the PT service make public transport a potential vector for transmitting the virus, and the fear of infection can further reduce the number of users. Therefore, it is essential to analyze which variables contribute to users' feeling unsafe riding and what is necessary to make them feel safe during commuting. In this context, this study used hybrid discrete logit choice models to identify the new barriers to the use of PT that arise with the new disease and the possible solutions to make users feel safe using PT systems, considering prior attitudes and perceptions regarding PT quality.

The results answered the three research questions proposed for this study. Firstly, we identified the new barriers to the use of PT created by COVID-19. The high number of users in the vehicles and the need to interact with many different people are the users' primary concerns. Crowded vehicles (first) and crowded stops and stations (second) are the two most important barriers to users feeling safe on PT. These results extend the existing evidence to the Brazilian context.

Secondly, we identified which immediate measures (countermeasures) can increase users' perception of protection while riding PT or those they perceive as safer. The countermeasure rank is one of the big contributions of the work since we could not identify other studies specifically focused on public transportation measures. Analyzing the results,

we can say that the unsafe perceptions were reinforced when we looked at the perception related to countermeasures. Measures to prevent contagion inside the vehicle, such as limiting the number of people in the vehicles (first), masks (second), and vehicle hygiene (third), were perceived as the safer countermeasures that PT operators more commonly implement. Users demonstrate that they would feel safer onboard larger vehicles (first), if the offer increased (second), and if authorities implemented more comprehensive mobility policies to change activity start time (third) and consequently reduce peak demand.

Finally, we can say that the preconceived perceptions of PT quality affect the perception of safety for the barriers and countermeasures under study. As more users positively evaluated the operational quality of PT, they considered the measures to be safer. On the other hand, those who negatively evaluated the subjective quality believed that PT is not good and is uncomfortable, and they did not see the other users as polite or perceived the measures as safe. The same is true for barriers. Therefore, COVID-19 measures are essential to regain users' trust and increase the quality perception. The result of this study might help operators and policymakers target actions during or after the COVID-19 outbreak to increase confidence in PT quality.

PT provides, indeed, an essential service. It promotes access to health systems and transports workers that guarantee the maintenance of essential services. Identifying measures that prevent infections in PT systems and are valued by users allows investments to be directed to provide a high-quality perception of the service. Users must identify the implemented solutions in such a way that they recognize that the public transport environment is not the primary transmission vector. This way, governments and operators can maintain PT users and seek to attract new users.

The present study complements the evidence available on the impact of COVID-19 in public transportation. It brings an insight on how to overcome the challenges imposed by the pandemic for the users. With the evolution of the pandemic, it is expected that changes in users' perceptions and attitudes and new technologies might increase the set of countermeasures available. Therefore, longitudinal studies that assess the progress of these aspects over time are needed. Still, studies can be carried out in other contexts for cross-region comparison and to evaluate the influence of the developing world context on the study results.

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