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Understanding transit user satisfaction with an integrated bus system

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A R T I C L E I N F O

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A B S T R A C T

Understanding the factors and drivers of user satisfaction with public transportation (PT) systems has been a subject of research for decades, as it provides insight into influencing ridership increases. This research addresses user satisfaction using SEM-MIMIC models to analyze three PT bus subsystems in the same city (Bogotá Colombia): A Bus Rapid Transit, a formalized bus subsystem, and a semi-formalized one that operates simultaneously. After developing three independent models, we found the same three latent variables (LVs), namely subsystems "condition", "service", and "safety/security", in each one. However, the strength and significance of the direct and indirect effects among the three LVs vary from one subsystem to another. In general, satisfaction is initially based on a person's perception of the subsystem's condition and ends with his/her perception of the service, with safety and service being the mediating variables to explain satisfaction. Unlike previous studies, we were able to identify relationships among these three independent variables for each subsystem, allowing us to assess the direct and indirect effects on overall subsystem satisfaction. This research provides decision-makers with a broader understanding of how infrastructure, vehicles, operational attributes, and regulation processes influence user satisfaction through perceptions and how they can help improve the PT service for its users.

1. Introduction

In recent decades, academics and practitioners in transportation engineering have been working to unveil and understand the factors related to user satisfaction with public transportation (PT), as this understanding is key in terms of providing insights into trending modal shifts towards these services (Grujičić et al., 2014; Ojo, 2019). Field research on the topic usually focused on explaining the direct effects of different factors (e.g., reliability, cleanliness, punctuality) on user satisfaction with the systems. The related literature, however, does not tend to include studies that assess relationships between independent variables or some that assess different sub-systems within the same integrated PT system and city, in terms of delivered satisfaction.

In this paper, we compare and analyze three bus-based subsystems in Bogota, Colombia which are part of the city's integrated public transportation system. The three bus-based subsystems have been operating simultaneously in Bogota since 2012, providing a unique research opportunity. The Integrated Public Transportation System (SITP) comprises three bus-based subsystems: a trunk service (bus rapid transit – BRT), the formalized bus service (in mixed traffic), and semi-formalized bus service (in mixed traffic) (This bus service was fully formalized by January 2022, after this study ended) (see Fig. 1). In this study, we (i) identify how user-perceived satisfaction is explained for all three subsystems, (ii) compare user-perceived satisfaction for the three subsystems within the SITP by analyzing different effects on satisfaction, and (iii) determine similarities and differences in the assessment of satisfaction considering users' socioeconomic characteristics. To do so, we used confirmatory factor analysis (CFA) and structural equation

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Fig. 1. The three bus subsystems in Bogotá. On the left, the trunk (BRT); in the middle, the formalized (zonal), and on the right, the semi-formalized (provisional).

modeling (SEM), including multiple indicators, multiple causes (MIMIC) models to identify latent variables (LVs), and their relationships with each other and with users' perceived satisfaction.

2. Literature review

Disciplinary interest in the last two decades has focused on understanding user satisfaction with PT and its drivers because of the relationship between satisfied users and increased ridership via increased positive post-use behaviors (i.e., future use and whether or not users would recommend the system to others) (Zhao et al., 2014). Literature on PT assessment from the user's perspective has shown that satisfaction is commonly evaluated to identify factors that explain users' assessment of the PT systems (Litman, 2008b; Oña et al. 2013; Dell'Olio et al., 2011; Too and Earl, 2010; De Abreu E Silva and Bazrafshan, 2013; Lierop et al., 2018; Allen et al., 2019). This PT valuation can explain future behavioral intentions (Kim and Ulfarsson, 2012; Krizek and El-Geneidy, 2007; Lai and Chen, 2011; Allen et al. 2018) that positively influence loyalty to the systems (for both captive and non-captive users) and the likelihood of future use (Zhao et al., 2014). Increasing PT user satisfaction can be considered a strategy for ridership retention (Lierop et al., 2018) and even increased ridership (Minser and Webb, 2010; Figler et al. 2011; Carreira et al. 2014), which aligns with the sustainable transport agenda.

The literature highlights the use of several methodologies to understand satisfaction and quality of service; however, not much of this literature evaluates relationships between independent variables (e.g., the influence of speed perception on safety perception, both, common independent variables used to evaluate satisfaction), and temporal precedence analyses (i.e., whether some factors are perceived before others). The common approaches include regression models (Abenoza et al., 2017; Soza-Parra et al., 2019; Imaz et al., 2014; Kim and Ulfarsson, 2012; Rodriguez-Valencia et al., 2019; Garcia-Suarez et al., 2018), discrete choice modeling techniques (Hensher, Stopher, and Bullock, 2003; Dell'Olio et al., 2011; Morfoulaki et al., 2010), neural networks (Garrido et al., 2014), SEM (Pawlasova, 2015; Joewono and Kubota, 2007; Deb and Ali Ahmed, 2018; Zhang et al., 2016, 2019; Shen et al., 2016; Morton et al., 2016; Stuart et al., 2000; Şimşekoğlu et al., 2015; Eboli and Mazzulla 2015; Carreira et al. 2014; Lai and Chen, 2011), and SEM-MIMIC (Allen et al., 2018; Zhao et al., 2014; De Abreu E Silva and Bazrafshan, 2013; Allen et al., 2019; Allen et al. 2018).

However, we found that SEM-MIMIC approaches including analyses of the relationships between independent LVs identified by users' perceptions of the PT system appear to be very scarce. The most commonly used process to develop an SEM model is to identify the LVs and then describe how these variables directly explain a unique endogenous or dependent variable –a service or performance index– (e.g., satisfaction or quality of service), as shown in Eboli & Mazzulla (2007) and Allen et al. (2018). However, this generalized practice does not thoroughly assess the existing relationships between LVs, or the temporal precedence that can be analyzed in such models (Kline, 2016; Hair et al. 2014; Vallejo-Borda et al., 2020).

To identify the attributes that have been used to explain user satisfaction of different PT systems worldwide, we reviewed 51 studies from the last two decades. We found that the most commonly evaluated attributes in the literature are associated with the PT system's condition, the safety/security aspects of travel, and service delivery. As shown in Table 1, attributes related to these categories are present in 30 studies (the remaining 21 studies presented attributes from at least one of these categories).

The first group of factors, which frequently appears in the literature, is the condition-related attributes group (42 out of 51 studies). This group assesses the direct relationship between tangible contextual features (inside the stations, stops, or the vehicles) and users, such as perceived cleanliness, the facilities' quality, comfort, space, and seating. These features and their associated stimuli are the first to be perceived (Ma and Cao, 2019) and evaluating such perceptions is crucial. This is because it has been found in the literature that our perceptions of our surroundings influence our affective responses and behaviors such as avoiding or approaching a place or situation (Ortiz-Ramirez et al., 2021; Ma and Cao, 2019). The literature also highlights that explanatory attributes regarding the condition of the system include cleanliness (Eboli and Mazzulla, 2015; Zhao et al., 2014; Lombardo et al., 2019; Allen et al. 2018); comfortable or available seats and spaces (Nwachukwu, 2014; Susilo and Cats, 2014; Lierop et al., 2018; Eboli and Mazzulla, 2015); vehicle quality and condition (Crisci et al., 2014; Abenoza et al., 2017; Allen et al., 2018); environmental aspects such as temperature (Garrido, et al. 2014); and the condition of infrastructure and facilities, including stations (De Abreu E Silva and Bazrafshan, 2013; Zhang et al. 2016; Nwachukwu, 2014).

The second group of attributes identified in the literature is related to safety. Thirty of the 51 studies reviewed, included at least one attribute in this group, revealing that experiencing a safe trip/waiting time affects user valuation of PT performance. The literature has shown that safety can be related to a basic human need to be protected, which has been proven to be relevant as a PT performance predictor (Allen et al., 2019). Safety attributes include perceptions of road safety (Iseki and Taylor, 2010; Zhang et al. 2019; Stuart et al., 2000; Deb and Ali Ahmed 2018; Lombardo et al., 2019; Allen et al., 2019), personal security (Andaleeb et al., 2007; Crisci et al., 2014; Abenoza et al., 2017), and drivers' performance or behavior (Andaleeb et al., 2007).

The third group of attributes, namely service, is related to the user's assessment of the service received while using the PT system facilities, infrastructure, or vehicles. Service is delivered on demand by a provider, it is intangible (Rodriguez-Valencia et al., 2021; Pine and Gilmore, 1998; Rodriguez-Valencia et al. 2020), and pertains to aspects related to the whole trip. Attributes in this group relate to the extent to which the user's expectations of the trip (and its related service experience) are fulfilled. In this group, we found perceptions concerning travel speed and time (Castillo and Benitez, 2013; Stuart et al., 2000; Susilo and Cats, 2014; Abenoza et al., 2017); trip information in

Table 1
Identified attribute groups found in the literature review.

Reference including at least one attribute per group	N	Attribute groups*		
		Condition	Safety / Security	Service
(Stuart et al., 2000), (Weinstein, 2000), (Garrido et al., 2014), (Hensher et al., 2003), (Andaleeb et al., 2007), (Krizek and El-Geneidy, 2007), (Stradling et al. 2007), (dell'Olio et al., 2010), (Iseki and Taylor, 2010), (Minser and Webb, 2010), (Morfoulaki et al., 2010), (Too and Earl, 2010), (Eboli and Mazzulla, 2011), (Figler et al. 2011), (Kim and Ulfarsson, 2012), (Das et al. 2013), (De Abreu E Silva and Bazrafshan, 2013), (Crisci et al., 2014), (Susilo and Cats, 2014), (Zhao et al., 2014), (Eboli and Mazzulla, 2015), (Mouwen, 2015), (Zhang et al., 2016), (Abenoza et al., 2017), (Allen et al., 2018), (Deb and Ali Ahmed, 2018),(Lierop et al., 2018), (Allen et al., 2019), (Lombardo et al., 2019), and (Zhang et al. 2019)	30	X	X	X
(Burkhardt, 2003), (Eboli and Mazzulla, 2007), (Litman, 2008), (Dell'Olio et al., 2011), (Oña et al., 2013), (Castillo and Benitez, 2013), (Carreira et al., 2014), (Grujičić et al., 2014), (Nwachukwu, 2014), (Allen et al., 2018), (Güner 2018), and (Soza-Parra et al., 2019)	12	X		X
(Joewono and Kubota, 2007), (Tyrinopoulos and Antoniou, 2008), (Kuo et al., 2009), (Lai and Chen, 2011), (Ettema et al., 2012), (Pawlasova, 2015), (Shen et al., 2016), (Sumaedi et al., 2016), and (Ojo, 2019)	9			X

* We only reported the combination of groups that appeared in the revision (e.g., there was no study in which we exclusively found attributes for both groups Safety/security and Service)

stations and vehicles (De Abreu E Silva and Bazrafshan, 2013; Das et al., 2013; Tyrinopoulos and Antoniou, 2008); personnel behavior, including customer service, attention to complaints, and staff information and knowledge (Stuart et al., 2000; Crisci et al., 2014; Allen et al., 2019; Lierop et al., 2018); ticket booth service characteristics and network (Das et al., 2013; Mouwen, 2015; Abenoza et al., 2017); network coverage (Garrido, et al. 2014; Eboli and Mazzulla 2015); time reliability, punctuality, and frequency (Iseki and Taylor, 2010; Castillo and Benitez, 2013; Soza-Parra et al. 2019; Lombardo et al., 2019; Allen et al., 2019; Allen et al. 2018; Mouwen, 2015); fares (Das et al., 2013; Grujičić et al., 2014; Stradling et al. 2007); and transfers (Allen et al., 2018).

It is common to find attributes from the three groups explaining PT users' evaluation, but relationships between them are not commonly assessed in the literature. Attributes related to the service delivered appear as significant explanators in all the studies. In more than half (i.e., 27/51 studies), these attributes have a higher impact on the dependent variable. Condition and safety/security attributes are present and significant in most of the reviewed literature, but their effects on the PT performance evaluation vary significantly from study to study. In a few studies (i.e., 8/51 studies), condition-related attributes have a greater impact on PT performance, while in one study, safety/security-related attributes appear to have a greater impact on the dependent variable.

As mentioned above, studies that assess the relationships or associations between condition-, safety/security-, and service-related attributes (as independent variables), are scarce in the literature, as are precedence analyses. Besides showing the correlation between the independent variables (e.g., Nwachukwu, 2014; Minser and Webb, 2010; Zhao e al., 2014), in our literature review, only De Abreu E Silva and Bazrafshan (2013) and Stuart et al. (2000) have shown and discussed explicit relationships between them (i.e., condition-related variables influence safety/security-related variables). Hence, evaluating the relationships between explanatory variables could serve as an important contribution to the field of PT satisfaction analysis.

User characteristics encompass another aspect that has been found to influence users' PT system satisfaction or quality of service perception. For example, a transfer facility's frequency of use was positively associated with global satisfaction (De Abreu E Silva and Bazrafshan, 2013). Likewise, Stradling et al. (2007) found differences in service perceptions between frequent and non-frequent users. The access mode appeared to be relevant in forecasting two latent variables (i.e., safety and additional services) that explain overall satisfaction in the SEM-MIMIC model proposed by Allen et al. (2020). The authors found that using PT as an access mode to railway services affects latent variables less negatively than private modes do.

Other individual attributes such as age, income, sex, and education level have been found to be relevant in estimating service or performance indexes (dell'Olio et al., 2010). For instance, Allen et al. (2020) found that older adults (i.e., > 65 years old) have a greater perceived satisfaction and fidelity towards a PT system, while Stradling et al. (2007) found that differences between user groups' ages were significantly different when assessing a traveling experience. Income was also found to be a relevant individual attribute whereby Allen et al. (2020), Stradling et al. (2007), and Joewono and Kubota (2007) found that an individual's income is negatively related to the quality of service perception (that, in turn, impacts satisfaction). In terms of sex, De Abreu E Silva and Bazrafshan (2013) found that identifying as male positively impacts global satisfaction, while Allen et al. (2020) found that identifying as female harms overall satisfaction. Educational levels, on the other hand, present different associations with global satisfaction for these studies. Allen et al. (2020) find a negative association, while De Abreu E Silva and Bazrafshan (2013) find a positive one.

Some research had compared different transit systems before and after a reform. For instance, Allen et al. (2019) studied the effects of a reform on a bus system using longitudinal data but were not able to assess both stages simultaneously. This study, on the other hand, assess both formalized subsystems and those pending formalization which are currently operating in the city. As such, it contributes significantly to enriching the literature on user satisfaction by evaluating, analyzing, and comparing multiple PT subsystems within the same context.

3. Context

Three PT subsystems, with different physical and operational characteristics, ran simultaneously in Bogotá in 2019, providing a unique opportunity to analyze and understand user satisfaction with transit. Before the year 2000, a semi-regulated privately-operated bus system served the entire city. After 2000, new Bus Rapid Transit (BRT) lines have been implemented, adding up to over 114 kilometers and 152 stations. In 2008, the city launched a PT formalization reform to create an Integrated Public Transport System (SITP). The main features of the formalized system included granting operation permissions to private companies under concessions schemes, integrating and centralizing the fare system (with smart card), standardizing and renovating the fleet, and centralizing management in a single public agency. However, due to financial issues, in 2015, some concessionaries ceased operations. As a reactive emergency decision, the city gave former buses "provisional"

Table 2
Subsystem's characteristics in 2019.

Characteristic	Subsystem		
	SITP-T (trunk)	SITP-Z (formalized)	SITP-P (provisional)
Start of operations (year)	2000	2012	2012
Estimated fleet	1.400 buses	4.800 buses	4.400 buses
Service type	Trunk services	Services between zones, serving neighborhoods	Services between zones, serving neighborhoods
Right of way	Segregated BRT lanes	Mixed traffic lanes	Mixed traffic lanes
Fare[a] (COP)	2.500	2.300	1.900
Payment method	Smart card	Smart card	On-board in cash
Boarding infrastructure	Bus stations with prepaid zones	On-street designated bus stops	On-street hailing
Operational hours	From 04:00 am to 23:00	From 04:00 am to 23:00	From 04:00 am to 23:00
Estimated daily travel demand[b] (passenger)	2'400.000	1'500.000	900.000
Average bus capacity in the number of passengers	Dual: 80 Articulated: 160 Bi-articulated: 250	Bus: 50–60	Bus and minibus: 20–40

[a] 1 USD = 3.700 COP
[b] Bogotá's household travel survey 2019 (Alcaldía Mayor de Bogotá 2019).

permission to operate. We will hereafter refer to the BRT or trunk services as SITP-T, to the formalized bus services as zonal services or SITP-Z, and the semi-regulated services or provisional as SITP-P. Table 2 shows a comparison between the characteristics of the three subsystems, and Fig. 2 shows three maps displaying service coverage for the three subsystems.

4. Methods

Three different and independent transit user satisfaction surveys were conducted between 2016 and 2017 in Bogotá (according to the data annually reported by TransMilenio S.A., Bogotá's SITP service provider, the characteristics of supply for the three subsystems in 2016 and 2017 were similar to those displayed in Table 2 for 2019, except for fares: 2.200, 2.000, and 1.650 for SITP-T, SITP-Z, and SITP-P respectively). The first survey was implemented in November 2016 and targeted a representative sample of SITP-T users (N = 338). The surveys applied to both SITP-Z (N = 202) and SITP-P (N = 117) users were similar to the one used for the SITP-T survey and were conducted between November and December 2017. Table 3 shows the basic sociodemographic data obtained for each subsystem in terms of sex, age, income, and educational level.

All surveys gathered information on overall user satisfaction with the services, their perceptions on subsystem attributes, service quality, users' behavioral intentions towards the services, and sociodemographic characteristics. Table 4 presents the survey's variables.

Regarding the modeling approach, we identified latent variables (LVs) and implemented a Multiple Indicator Multiple Cause (MIMIC) model for the three PT subsystems. LV approaches have often been used to assess user satisfaction with PT systems (Eboli and Mazzulla, 2015) , as, among other aspects, they provide information on how measured perceptions (i.e., indicators) can account for unobservable dimensions of cognitive, affective, and behavioral responses. We initially developed an Exploratory Factor Analysis (EFA) using the variables presented in

Fig. 2. Service coverage maps for the subsystems, from left to right SITP-T, SITP-P, and SITP-Z.

Table 3
Basic sociodemographic data of the sample.

Indicator	SITP-P (%)	SITP-Z (%)	SITP-T (%)
Sex			
Female	59.83	50.99	50.30
Male	40.17	49.01	49.70
Age			
Millennials	53.85	63.37	69.82
Older than 36	46.15	36.63	30.18
Income			
Low income	50.43	43.07	47.04
Middle income	46.15	49.50	48.22
High income	3.42	7.43	4.73
Educational level			
Non-high educational level	53.85	44.06	48.22
High educational level	46.15	55.94	51.78

Table 4, where we identified three LVs. For the EFA, a VARIMAX orthogonal rotation method was assumed to produce a set of uncorrelated measures, which is common practice in structural equation models. We determined the number of LVs using a scree test with the R function “nScree” of the “nFactors” package (R Core Team, 2021; Raiche and Magis, 2020). Next, we specified a Structural Equation Model (SEM) using the EFA results to understand the relations between such LVs, including precedence and effects among them (Kline, 2016; Vallejo-Borda et al., 2020).

To uncover the direct and indirect effects of the identified LVs on satisfaction for each subsystem, we proposed restrictions based on the literature related to temporal precedence or the assumption that some attributes are perceived before others and, hence, one LV could be perceived before another LV (Bollen, 1989; Kline, 2016). The SEM analysis was carried out considering a maximum likelihood estimation and was estimated using the R function “sem” of the “lavaan” package (Rosseel, 2012; R Core Team, 2021). Finally, we used a MIMIC model to define the latent variables identified using the SEM approach, as suggested in the literature (Bollen, 1989). By using MIMIC models, we can explain the identified LVs with the objective user and PT subsystem characteristics (Ortúzar and Willumsen, 2011) (see Table 5). The different relationships were tested, and those with p-values lower than 0.15 were not considered for the different models.

MIMIC models are based on the estimation of a structure based on perceptions and composed of latent variables ($\boldsymbol{\eta}$), indicators ($\boldsymbol{y}$), and objective measured attributes ($\boldsymbol{x}$). The relationship between the latent variable and the indicators represents the measurement part of the model and can be calculated using Eq. (1). The relationship between the objective measured attributes and the latent variable represents the structural part of the model and can be calculated using Eq. (2) (Vallejo-Borda et al., 2020; Bollen, 1989; Ortúzar and Willumsen, 2011).

$$y = \Lambda_y \eta + \varepsilon \tag{1}$$

$$\eta = \Gamma x + \zeta \tag{2}$$

In Eqs. (1) and (2), $\boldsymbol{y}$ represent the indicators vector that identifies the latent variable; $\boldsymbol{\Lambda_y}$ is the coefficient vector that indicates the change in the value of the indicators if there is a change of one unit in the latent variable; $\boldsymbol{\eta}$ is the latent variable vector; $\boldsymbol{\varepsilon}$ is the error vector associated with the indicators; $\boldsymbol{\Gamma}$ is the structural parameter row vector that indicates the change in the value of the latent variable if there is a change of one unit in the respective objectively measured attribute; $\boldsymbol{x}$ represents the objectively measured attributes column vector; $\boldsymbol{\zeta}$ is the latent variable random error vector. We assumed the error terms (i.e., ε and $\boldsymbol{\zeta}$) to be normally distributed with an expected value of 0 (Bollen, 1989).

To test the goodness of fit of the SEM results, we used four parameters and the standard thresholds used in the literature (Hair et al., 2014; Hu and Bentler, 1999; Vallejo-Borda et al., 2020): the normed chi-square - χ^2/df (< 3.0), the root mean square error of approximation - RMSEA (< 0.06), the standardized root mean square residual - (SRMR) (< 0.08), and incremental fit indices (comparative fit index - CFI) (> 0.95). The good indicators of all models satisfy strict thresholds, however, it would be useful to have more observations (especially for SITP-P).

Table 4
Survey indicators and measurement scales.

Variable	Description	Scale	
		SITP-T	SITP-Z and SITP-P
Cleanliness	Bus cleanliness	1–5	1–5
Road safety	Road safety during the trip	1–5	1–5
Security	Security regarding crime	-1–1	1–5
Comfortable seats	The vehicles' seats are comfortable	-1–1	1–5
Speed	When traveling on the bus, the trip is fast	-1–1	1–5
Time reliability	Trip time is trustworthy (waiting and travel time)	NA	1–5
Driver's performance	Driver's driving behavior	NA	1–5
Noise	Noise in the bus (engine, card machine for SITP-Z, music)	NA	1–5
Sudden braking	Drivers frequently brake suddenly	NA	1–5
Lighting	Illumination within the buses	NA	1–5
Information	User information about routes and time schedules	NA	1–5
Staff information knowledge	Staff information knowledge	1–5	NA
Drivers	Rate drivers	1–5	NA
On-station security	Rate on-station security	1–5	NA
Near-station security	Rate near-station security	1–5	NA
Ticket booth agility	Rate ticket booth agility	1–5	NA
Station gates	Rate station gates	1–5	NA
Station floors	Rate station floors	1–5	NA
Bus condition	Usually, the vehicles have mechanical failures during the trips	-1–1	NA
Infrastructure	TM has good infrastructure (stations, bridges, roadways…)	-1–1	NA
Station space	TM stations are spacious	-1–1	NA
Coverage	TM coverage (in terms of stations and stops) works for you	-1–1	NA
Fare	The TM ticket is expensive	-1–1	NA
Transfers	Usually must make many transfers to complete the trip	-1–1	NA
Frequency panel	Board information reliability	-1–1	NA
Staff	Staff's job is well performed	-1–1	NA

Table 5
Objectively measured variables.

Variable	Description	Scale	
		SITP-T	SITP-Z and SITP-P
Operational			
Frequency 4 +	Whether the respondent uses the subsystem four or more days a week	Yes = 1; No = 0	Yes = 1; No = 0
Peak hour	Whether the respondent frequently travels at on-peak hours	Yes = 1; No = 0	Yes = 1; No = 0
Access mode SITP-Z	Whether the respondent uses SITP-Z to access to SITP-T	Yes = 1; No = 0	NA
Demographics			
Age	The respondent's age	Numeric	
Gender	The respondent's gender	Male = 1; Female = 0	
Socioeconomic strata[a]	The respondent's socioeconomic strata	1–6: with 1 being the poorest and 6 the richest	
Educational level	The respondent's educational level	0 = None 1 = Elementary education 2 = High school 3 = Technical education 4 = Undergraduate degree 5 = Graduate degree	

[a] In Colombia, the socioeconomic strata is an official classification of households as a proxy variable for income (Cantillo-García, Guzman, and Arellana, 2019)

5. Results

Descriptive results, directly estimated from the surveys' responses, indicate that users are more satisfied with SITP-P services (3.15/5.00 - SD = 1.11) than they are with SITP-T services (2.69/5.00 – SD = 0.93) or SITP-Z (2.70/5.00 – SD: 1.00). The overall ratings for each subsystem attribute (Table 6) show that most attributes perform below the minimum acceptance threshold of 3.00/5.00 (Some attributes over 3.00 capture negative perceptions and are shown in the table with a star). Safety and security perceptions are, on average, the worst-rated attributes across all three subsystems.

We compared the sample composition in terms of gender, age, schooling level, and socioeconomic strata with the household travel survey 2019 (Bogotá, 2019) for the three subsystems. We found that the resulting data for the various subsystems is somewhat similar, but as the data was not gathered for this study, we decided not to expand the sample to the population. Hence, we did not seek representativeness in the following analyses. Rather we focus on proposing a cognitive structure that can explain satisfaction for the observed data.

We conducted an independent EFA for each of the three subsystems. Results from the three analyses unveiled the same three LVs, namely *service*, *condition*, and *safety/security* in each subsystem, as presented in Table 7. Although the three measurement models include the same three LVs, there are differences between indicators and loadings across subsystems. For instance, the measurement SITP-T model includes indicators regarding both stations and vehicles, implying that the LVs represent user perceptions of these two components of the subsystem. In contrast, for SITP-P and SITP-Z, the LV indicators only correspond to the vehicles' measured variables, as long as they have on-street stops. *Service* explains indicators related to speed, information, and reliability for the three subsystems. *Condition*, involves cleanliness and comfort-related variables as the LV in the three subsystems. *Safety/security* showed road safety and security related measured variables as LV indicators in all cases.

Three independent SEM-MIMIC models were developed to explain user satisfaction with each subsystem. All three models were implemented and a similar structure (see Fig. 3) and good fit indicators were obtained for all of them, under the recommendations by Hu and Bentler (1999) and Hair et al. (2014). Despite the astonishing similarities when independently grouping perceptions into the constructs (LVs), the structural relations and the strengths among LVs (represented as circles in Fig. 3) vary among subsystems (i.e., different relationships were significant for different subsystems). Fig. 3 provides a graphic representation of the direct effects in SEM-MIMIC models to explain satisfaction.

Table 6
User ratings of SITP subsystem attributes.

Attribute (scale: 1–5)	Mean	s.d.
Cleanliness SITP-P	2.73	1.20
Comfortable seats SITP-P	2.75	1.18
Lighting SITP-P	3.55	1.06
Noise SITP-P*	3.00	1.33
Driver's performance SITP-P	3.13	1.13
Security SITP-P	2.30	1.25
Road safety SITP-P	2.60	1.25
Sudden braking SITP-P*	4.08	1.19
Speed SITP-P	2.91	1.22
Time reliability SITP-P	2.72	1.31
Information SITP-P	2.70	1.29
Cleanliness SITP-Z	3.27	1.18
Comfortable seats SITP-Z	2.81	1.13
Lighting SITP-Z	3.82	0.94
Noise SITP-Z*	2.85	1.35
Security SITP-Z	2.52	1.21
Road safety SITP-Z	2.84	1.18
Sudden braking SITP-Z*	3.94	1.21
Speed SITP-Z	2.94	1.13
Time reliability SITP-Z	2.29	1.25
Information SITP-Z	2.62	1.21
Station gates SITP-T	2.10	0.96
Station floors SITP-T	3.19	0.96
On-station security SITP-T	2.68	1.08
Near-station security SITP-T	2.31	0.97
Ticket booth agility SITP-T	3.31	1.09
Drivers SITP-T	3.01	1.06
Staff information knowledge SITP-T	3.77	1.10
Cleanliness SITP-T	3.08	1.02
Road safety SITP-T	2.55	1.06
Attribute (scale: −1 to 1)	**Mean**	**s.d.**
Infrastructure SITP-T	0.11	0.96
Bus condition SITP-T	-0.27	0.92
Station space SITP-T	0.07	0.96
Staff SITP-T	0.39	0.88
Coverage SITP-T	0.61	0.78
Frequency panel SITP-T	-0.21	0.95
Fare SITP-T*	0.46	0.87
Transfers SITP-T	-0.16	0.97
Comfortable seats SITP-T	0.00	0.96
Security SITP-T	-0.53	0.82
Speed SITP-T	0.61	0.77

[*] These variables capture negative perceptions of the attribute (e.g., "noise bothers me" or "fare is expensive")

Based on the temporal precedence between the established relationships (Hoyle, 2012), for all three models, we found that the *condition* perception initiated the cognitive process of defining users'

Table 7
Measurement model for the three subsystems.

SITP-T indicators	Latent variable	Λ_y	z-statistic
Cleanliness	Subsystem condition	1.00	
Station gates		0.85	10.76
Station floors		0.77	9.84
Infrastructure		0.67	6.93
Bus condition		-0.57	-5.54
Comfortable seats		0.54	5.24
Station space		0.55	5.08
Road safety	Safety/security	1.00	
On-station security		0.99	20.11
Security		0.84	13.49
Near-station security		0.79	16.06
Staff	Service	1.00	
Ticket booth agility		0.87	9.62
Coverage		0.84	6.48
Frequency panel		0.78	6.43
Drivers		0.75	8.70
Speed		0.62	5.50
Staff information and knowledge		0.62	6.68
Fare		-0.54	-4.21
Transfers		-0.46	-3.87
SITP-Z indicators	**Latent Variable**	Λ_y	**z-statistic**
Cleanliness	Subsystem condition	1.00	
Comfortable seats		1.11	8.65
Lighting		0.93	7.72
Noise		-0.49	-3.56
Security	Safety/security	1.00	
Road safety		0.96	5.84
Sudden breaking		-0.26	-1.84
Speed	Service	1.00	
Time reliability		0.88	7.83
Information		0.75	7.15
SITP-P indicators	**Latent Variable**	Λ_y	**z-statistic**
Cleanliness	Subsystem condition	1.00	
Comfortable seats		0.76	10.63
Lighting		0.58	7.68
Noise		-0.53	-6.29
Driver's performance	Safety/security	1.00	
Security		0.63	6.42
Road safety		0.72	8.76
Sudden breaking		-0.27	-2.22
Time reliability	Service	1.00	
Speed		0.99	10.11
Information		0.86	7.87

perceived satisfaction. We also found that *condition* directly influenced the users' perception of *safety/security*. We demonstrated that *service* is directly related to satisfaction in the three cases, as the literature suggests, and identified that both the *safety/security* and *service* could mediate between the perception of *condition* attributes and the users' perceived satisfaction. We also found that the effects of each of the analyzed LVs on satisfaction are different for each subsystem. Table 8 illustrates that as the subsystem changes, so do values of the total effects of each LV on satisfaction. This implies that regardless of the structure of the relationships, the LVs can be expected to have diverse effects within the different subsystem models.

The SEM-MIMIC approach adds objectively measured attributes to define the latent variables and enhance the structural model (hereafter referred to as "regressors" and shown as squared boxes in Fig. 3). Each one of the regressors may explain both the latent variables and the perceived satisfaction. For SITP-T users (see Fig. 3a), both being a millennial and part of a higher socioeconomic level directly increases satisfaction with the subsystem. Using the subsystem four or more days a week decreases the perception of the *condition,* and users that access the subsystem using SITP-Z have a better perception of the *service* provided by SITP-T. Regarding the SITP-Z subsystem (see Fig. 3b), riding these buses at peak hours decreases users' level of satisfaction. Conversely, being part of a higher socioeconomic level directly increases the perception of satisfaction. Users with a high educational level perceive a reduced performance for *safety/security* for this subsystem, and user perception of the *condition* with regards to buses is worse for female users. For the model on SITP-P user satisfaction (see Fig. 3c), only two regressors were found to be relevant. First, while the perception of the service provided improves for male users, the perception of the *condition* worsens. And, secondly, riding these subsystem buses at peak hours also worsens user perception of the *condition*.

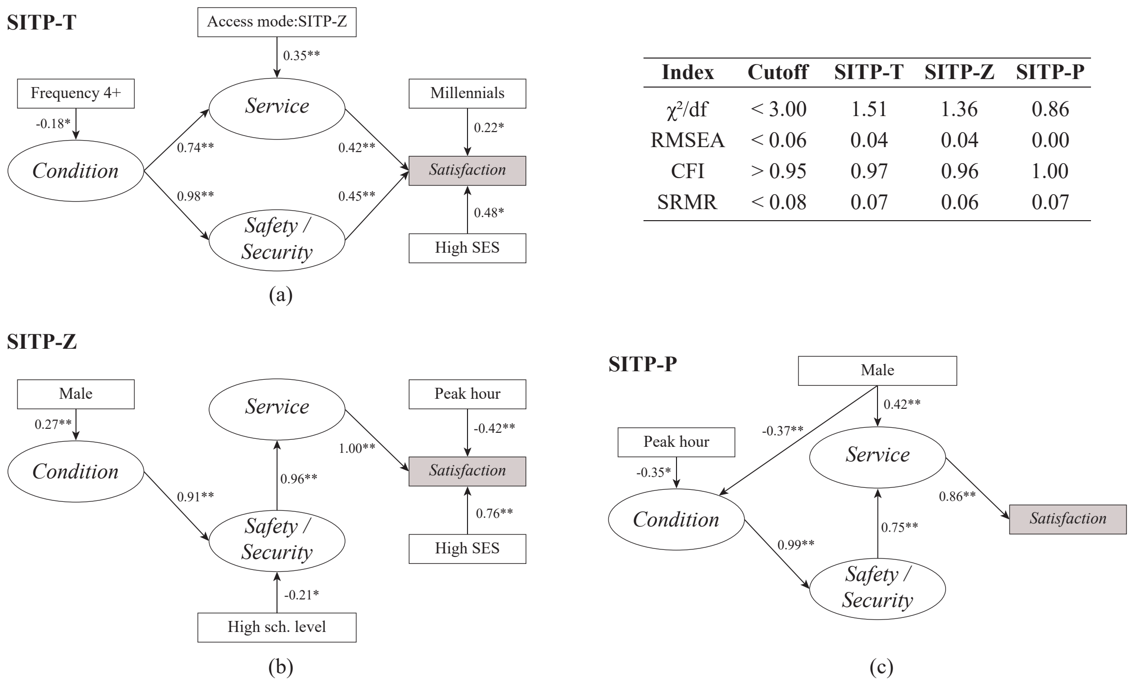
6. Analysis and discussion

In this paper, we explored user satisfaction with three bus subsystems using independent SEM-MIMC models. By doing so, we identified valuable insights into similarities and differences between the subsystems and the cognitive processes behind user satisfaction with them. As previously mentioned, reducing the dimension of the data or each subsystem led us to confirm the existence of the same three LVs (i.e., *condition*, *safety/security,* and *service)*. We also found that these three LVs and their relationships could explain how user satisfaction develops. Despite the similar average satisfaction rating for the three subsystems (i.e., near 3.0/5.0), the models presented in Fig. 3 prove that the process behind user satisfaction development in the three subsystems is not the same. This difference evinces the importance of identifying how these ratings are achieved rather than just focusing on the average values. A deeper understanding of the cognitive process behind satisfaction is key to explaining how each subsystem's characteristics impact user perceptions.

6.1. The cognitive process of satisfaction

According to our findings, the cognitive process behind user satisfaction with the subsystems differ and these differences can be associated with the subsystems' features, characteristics, and type of operation. Our results show that the BRT (SITP-T) is different from the other two when analyzing the structural relationships that explain user satisfaction. SITP-Z and SITP-P showed the same significant structural relations: a sequential chain, with the *condition* first, then *safety/security*, and finally the *service* that solely impacts satisfaction. In contrast, the SITP-T does not show a sequential process but a simultaneous effect of *condition* on *safety/security* and *service*, which directly influence satisfaction. In this case, the difference between structures seems to be related to operational features. Let us recall that the SITP-T operates in segregated lanes. We also found that the level of formalization does not affect the structure, as long as the same structure is consistent for non-formalized and formalized SITP-P and SITP-Z.

The differences identified between total effects consistently show that differences between operation and formalization levels influence perceived satisfaction. To further analyze the differences between subsystems' operational characteristics and technology (regular buses vs. BRT) to explain perceived user satisfaction, we calculated the standardized total effects (i.e., the sum of direct and indirect effects presented in Table 8) of the satisfaction LVs. Again, there is a difference between the subsystems operating in mixed traffic, with on-street boarding, versus the SITP-T, which operates in segregated lanes with platform boarding and a pre-paid zone. In the case of the SITP-P and SITP-Z, the *service* LV shows the highest effect on satisfaction (as shown in the literature), while for the SITP-T, the LV with the highest effect on satisfaction is its *condition*. Less interaction with traffic, a high frequency of buses, greater reliability, and station comfort increase user expectations of the fulfillment of SITP-T *service*-like attributes. According to Oliver (1980), satisfaction is related to the service received versus service expectations. It is reasonable to consider that SITP-T users, who expect a frequent and swift service, focus on non-*service*-related attributes. Likewise, the SITP-Z and SITP-P have less infrastructure to be evaluated, and the service can be less frequent, less reliable, and less rapid. Furthermore, the stop points for these services



Index	Cutoff	SITP-T	SITP-Z	SITP-P
χ^2/df	< 3.00	1.51	1.36	0.86
RMSEA	< 0.06	0.04	0.04	0.00
CFI	> 0.95	0.97	0.96	1.00
SRMR	< 0.08	0.07	0.06	0.07

Fig. 3.. *SEM*-MIMIC models *for (a) SITP-T, (b) SITP-Z, and (c) SITP-P*. * * p-value < 0.05. * p-value < 0.15.

Table 8
Total effects of each LV over perceived satisfaction.

	SITP-T		
	Service	Condition	Safety/Security
Satisfaction	0.416 (**0.278**)	0.754 (**0.513**)	0.452 (**0.367**)
z-statistic	*3.054*	*11.096*	*4.885*
	SITP-Z		
	Service	**Condition**	**Safety/Security**
Satisfaction	1.000 (**0.633**)	0.874 (**0.487**)	0.956 (**0.513**)
z-statistic	*8.304*	*6.607*	*6.154*
	SITP-P		
	Service	**Condition**	**Safety/Security**
Satisfaction	0.856 (**0.622**)	0.636 (**0.553**)	0.640 (**0.529**)
z-statistic	*7.879*	*7.953*	*7.828*

Note: Standardized values between parenthesis and in bold font

can serve for other modes (e.g., taxi cabs), reducing the direct association of infrastructure and *condition*.

The differences among the total standardized effects of the *condition* and *safety/security* LVs on satisfaction for the non-segregated subsystems can correspond to their level of formalization. As shown in Table 8, for formalized buses (i.e., SITP-Z), *safety/security* has a greater effect on satisfaction than *condition*. In contrast, the opposite is true for the non-formalized subsystem (i.e., SITP-P). As the SITP-P buses are the oldest and do not necessarily follow strict maintenance protocols, the vehicles offer a relatively lower overall condition (poor seating quality, difficult boarding systems, low lighting, high noise levels, poor maintenance) compared to the SITP-Z. On the other hand, the formalized SITP-Z is in better condition, is more up-to-date, and all vehicles have a standardized image and characteristics. The above could account for the higher *condition* valuation for the non-formalized SITP-P. Interestingly, in this respect, SITP-T is similar to SITP-P, with *condition* having a greater effect than *safety/security* on satisfaction. However, in the case of SITP-T, the *condition* assessment considers vehicles and stations, which implies that this assessment is made during different travel stages (accessing the station, waiting time, traveling on the vehicle, transferring). With more direct subsystem interactions (i.e., inside the vehicle and the station), the valuation of the *condition* could be expected to have a greater effect on satisfaction because of the influence of the direct context on perceptions and behaviors (Ma and Cao, 2019).

Safety/security is directly influenced by the *condition* LV in the three subsystems, aligning with findings by De Abreu E Silva and Bazrafshan (2013) and Stuart et al. (2000). For all three subsystems, *condition* has a direct and positive effect on *safety/security,* and the perception of a deteriorated *condition* of vehicles and stations, equals a perception of less *safety/security.* This is proposed in the Broken Windows Theory presented by Wilson and Kelling (1982), which links disorder with poor safety levels. The theory is based on a simple premise that implies that, in an urban setting, an “unrepaired broken window is a signal that no one cares” (Wilson and Kelling, 1982), and hence, breaking other windows will be unconsequential. In such a setting disorder and vandalism are expected to grow, partially due to the condition of the windows. Besides this, user perception of poor vehicle condition in the SITP-P and -Z relates to a stronger safety effect on satisfaction when compared with SITP-T.

6.2. The influence of objective attributes on satisfaction

When analyzing sociodemographic and other objective variables and their influence on the cognitive process that leads up to satisfaction, we again found patterns among three subsystems. We found that socioeconomic stratum (SES) is a common indicator in SITP-T and SITP-Z models, highlighting the relevance of formalization in PT services. Like, Cantillo-García et al. (2019), we found that SES can be used as an income proxy, due to the high correlation between SES and income. Also, higher income can be associated with higher expectations regarding the delivered service. Let us recall that the fulfillment (or not) of these expectations corresponds to the development of satisfaction (Oliver, 1980). In fact, a relationship between income and general expectations has been documented in other research fields such as education (Yu and Daraganova, 2015; Sandefur et al., 2006), mobility intentions (Crowder, 2001), and economic behavior (Ben-David et al. 2018). In our study, user income (or SES) is only significant when explaining user satisfaction with SITP-T and SITP-Z, the formalized subsystems. Users with a higher income (or SES) may have developed higher expectations from these services because of their level of standardization. Thus, formalized subsystem users can more clearly assess to what extent their expectations are (or not) fulfilled by the subsystems. Similarly, although not directly, users' educational level was found to affect their satisfaction with SITP-Z. The negative association between high education level and user perception of the safety and security of SITP-Z services (see Fig. 3) indicates that there are opportunities for improvement in the management of some SITP-Z routes. Routes serving people from universities and higher education institutions should receive special attention to enhance their users' perception of safety and security, increasing overall satisfaction with the service. The direct influence of individuals' age on user satisfaction was positively significant for SITP-T and not significant for any of the other systems. Millennial users may be more open to modern PT alternatives which show an alternative to congested mixed ways, explaining the increases in their perceived satisfaction with SITP-T.

Differences between operational characteristics arise again when the user's gender is evaluated. The relevance of gender as a regressor to explain user satisfaction is based on men and women's different sensitivities to changes in the environment, with women being more sensitive to such changes (Sánchez and González, 2016). Overall satisfaction with SITP-Z and SITP-P services decreases for female users as a result of a worse perception of *condition* for the SITP-Z, and *service* for SITP-P. In this case, the non-segregated subsystems' cognitive processes proved to be sensitive to differences in users' gender. This gives rise to an issue of differentiated perspective that considers that women would perceive the *condition* and *service* of traditional buses in the subsystems with no exclusive infrastructure (lanes and stations) as poor.

Riding the non-segregated subsystems at peak times decreases user satisfaction directly (SITP-Z) and indirectly (SITP-P). Given that these two subsystems run in mixed traffic lanes, the inherent congestion of peak hours affects their operation. This effect also implies delays, unreliability, crowded buses, and unsafe driving by operators trying to meet schedules, which eventually leads to reduced overall satisfaction. Another relevant aspect to consider is the frequency with which users use the subsystem. The SITP-T model suggests that the perception of the *condition* worsens for frequent users (those who use the subsystem four or more days a week), constituting an opportunity to increase overall user satisfaction with this subsystem by improving several features (see Table 7) with relatively little effort.

6.3. Applications and implications

Understanding user satisfaction is key to the success of PT systems, namely, making PT massively attractive to current and potential users. The similarities in the identified LVs and their relationships among three different and independent bus subsystems in Bogota suggest a possible framework for users' cognitive processes. Understanding how these satisfaction development processes occur for different PT bus subsystems helps to elaborate on measures that can be incorporated to retain users and enhance ridership.

Regardless of the cognitive process (relationships among LVs), *condition* did not appear to have a direct influence of satisfaction. This finding shows that condition-related attributes mainly influence satisfaction indirectly through *safety/security* and or *service* aspects of the operation. As we found that *condition* is perceived before any other set of attributes, we can propose that providing and maintaining the appropriate quality of the infrastructures and vehicle conditions is the ground for enhancing satisfaction indicators. The direct and significant effect of *condition* on *safety* LVs in all three bus systems suggests that interventions and investments in physical aspects associated with vehicles and infrastructure (stations, stops, terminals, etc.) affect overall safety. Furthermore, considering that this study reveals the positive relationship between satisfaction with a specific subsystem and satisfaction with the integrated PT system, *service* enhancements will always be relevant in terms of increasing satisfaction with a subsystem. The theory on post-purchase behavior states that greater satisfaction is associated with loyal customers (PT riders retainment) and recommendation (attracting new riders) (Lierop et al., 2018), and hence, assessing these three LVs following the structure found can provide insights into how to ehance services to encourage loyalty and recommendation.

Our results show that formalized PT systems can attract more users from higher income levels. Regarding the objective (non-perceptual) variables, the relationship between greater satisfaction with the formalized bus subsystems and higher SES provides clues to reducing automobile dependency, as long as high SES levels are associated with higher motorization worldwide (Schafer et al., 2000) and in Bogotá (Acevedo et al., 2009). Providing attractive, satisfactory, and efficient public transportation alternatives is essential in reducing car use (associated to high motorization rates). Formalized PT systems increase the possibility to attract automobile users. In Bogota, particularly in the coming years, the complete abolition of SITP-P by 2022 and the entry of a massive number of new electric buses between 2020 and 2022 are crucial to the sustainability of the entire transportation system and offer great potential to attract new customers. However, as presented in this paper, service indicators are crucial for SITP-Z users, therefore, working on issues such as poor reliability, bus bunching, and big gaps between buses, will be a priority.

Our results show that sex, age, income, and education level affect satisfaction with public transportation, and as relevant attributes, they should be considered when it comes to enhancing public policy development. Considering users´ habits in terms of accessing the system and the time of day when they use the facilities and vehicles can provide information on how to increase satisfaction at specific times. Finally, our results also demonstrate that increasing the integration of these subsystems can serve as a strategy to enhance satisfaction with PT.

7. Conclusions

The independent evaluation of three bus systems in simultaneous operation suggests that a generalizable framework could be derived from the similarities and commonalities to explain user sastifaction. The three independent models gravitated into the same three constructs (LVs): *condition, safety/security,* and *service*. Besides this, the structural relations among LVs presented the *condition LV* as the first step in the assessment of user satisfaction process. Similarly, the *service* LV has always directly and significantly affected overall system satisfaction. The *safety* LV conversely shows much more heterogeneity in its relationship with other LVs, and, depending on how the *condition* is perceived, has a direct or indirect effect on overall satisfaction.

The simultaneous operation of three bus systems allowed us to analyze how user sastifaction is constructed depending the features of each system, e.g., the level of formalization, segregation, the stations, etc. The exact replication of the structural relationship for bus systems operating in the mixed traffic (i.e., SITP-Z and SITP-P) suggests that users of the two subsystems go through the same internal process to evaluate their overall satisfaction with the service. Results suggest that a generic framework can be developed for subsystems with similarities in terms of right of way and boarding. This suggests that the level of formalization (the main difference among these subsystems) does not affect the process. Since the generalizations are based on the three bus systems in Bogota, developing similar studies in other cities could confirm, refine, or contest the suggested early bird framework. Further research should also account for possible correlations between the proposed latent variables to improve the theoretical meaning of this framework.

Users' ratings, qualifications, and perceptions can provide highly valuable information about what really needs to be addressed in any transportation service or infrastructure. In fact, a recent research on active modes has shown a four-fold effect of perceptions on service quality compared with traditional supply measures (Rodriguez-Valencia et al., 2021). User ratings and perceptions of attributes can also be used to design transportation systems to maximize quality of service or satisfaction levels (Barrero and Rodriguez-Valencia, 2021), which subsequently affect post-purchase behaviors such as using the system again and recommending it.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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