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ORIGINAL RESEARCH

Three's a crowd? Examining evolving public transit crowding standards amidst the COVID-19 pandemic

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Abstract

The COVID-19 pandemic dramatically affected public transit systems around the globe. Because transit systems typically move many people closely together on buses and trains, public health guidance demanded that riders should keep a distance of about two meters to others changed the definition of "crowding" on transit in 2020. Accordingly, this research examines how U.S. public transit agencies responded to public health guidance that directly conflicted with their business model. To do this, we examined published crowding standards before the COVID-19 pandemic for a representative sample of 200 transit systems, including whether they started or changed their published standards during the pandemic, as well as the reasons whether agencies publicize such standards at all. We present both descriptive statistics and regression model results to shed light on the factors associated with agency crowding standards. We find that 56% of the agencies surveyed published crowding standards before the pandemic, while only 46% published COVID-19-specific crowding standards. Regression analyses suggest that larger agencies were more likely to publish crowding standards before and during the COVID-19 pandemic, likely because they are more apt to experience crowding. Pandemic-specific crowding standards, by contrast, were associated with a more complex set of factors. We conclude that the relative lack of pandemic standards reflects the uncertainty and fluidity of the public health crisis, inconsistent and at times conflicting with the guidance from public health officials, and, in the U.S., a lack national or transit industry consensus on appropriate crowding standards during the first year of the pandemic.

Keywords Transit · Crowding · Load factors · Social distancing · COVID-19

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1 Overview

Congestion on transportation systems is an age-old problem. Congestion in shipping canals, at airports, on urban highways, and on public transit systems increases travel times, decreases reliability, and increases energy consumption and emissions. Public transit buses and trains can fall victim to two forms of congestion: with other vehicles on streets and rail rights of way, and inside of vehicles, at stops, and at stations when the number of passengers exceeds the capacity of transit vehicles. This latter form of congestion, crowding, occurs when there is insufficient seating and standing room for passengers to ride comfortably, or at all. In such cases, those who manage to board a transit vehicle must cope with discomfort and/or inappropriate contact with other passengers, a particular issue for passengers who identify as female (Ceccato and Loukaitou-Sideris 2020), while those who cannot board are both delayed and, usually, their uncomfortable ride is simply postponed.

Crowding is a major issue for public transport in cities around the world (Li and Hensher 2013). Substantial previous research has investigated the influence of various transit service qualities affecting transit use, though the effects of crowding have been comparatively understudied. In the 1970s, researchers proposed economic models to investigate the relationship between service levels (such as passengers-per-vehicle revenue hour (UPT/VRH)) and the generalized cost of travel (Mohring 1972). Other work examined the relationship between the number of passengers on board and the time cost borne by passengers to determine optimal bus fares (Turvey and Mohring 1975). More recently, researchers modeled and refined crowding cost functions for transit vehicles, concluding that the marginal generalized cost borne by passengers increases rapidly as crowding levels increase (Celebi and Imre 2020; Qin 2014).

The COVID-19 pandemic, however, made transit systems and their riders far more sensitive to the spacing of passengers, particularly amidst evolving and sometimes conflicting guidelines from public health authorities. To slow the spread of COVID-19 in the U.S., the Centers for Disease Control and Prevention (CDC) at first advised against riding public transit at all, and then subsequently published and regularly revised guidelines for transit systems and passengers (Centers for Disease Control and Prevention 2021). Public health in the U.S. is largely decentralized, with the national government providing guidance, while most public health regulations are set and enforced by states and their sub-units, counties. These various levels of public health governance in the U.S. frequently offered conflicting guidance to the traveling public and to public transit systems during the COVID-19 pandemic. Indeed, a survey of public transit operators, conducted as part of this larger research effort, found that U.S. public transit agencies collectively relied on all levels of government for public health guidance: counties (59%), states (49%), the federal government (38%), and local governments (28%) (Speroni et al. 2023).

As a result, U.S. transit agencies adopted widely varying policies and public health guidelines during the first year of the COVID-19 pandemic, and those that addressed passenger crowding did so in varying ways as well. Given all this variance, and the fundamental challenge of limiting close passenger contact on systems designed to facilitate such proximity, this article investigates to what extent transit agencies addressed passenger crowding in the COVID-19 pandemic and what explains the observed differences among them.

2 Defining and measuring crowding on transit

Transit crowding has been defined as "having a significant number of people sharing a limited space while using a public transport service" (Tirachini et al. 2013). What differentiates acceptable passenger loads from overcrowding on transit vehicles also varies depending on the local social and cultural environments, as well as passengers' individual cognitive perceptions of crowding (Cox et al. 2006). Crowding on transit can be defined and measured both objectively, through density, and subjectively, through passenger perceptions (Turner et al. 2004; Li and Hensher 2013; Tirachini et al. 2013).

While vehicle manufacturers typically establish maximum loading capacities based on loading and evacuation considerations, transit agencies may adjust their standards from these manufacturer-recommended baselines to account for (1) the quality of rider experience considerations (which would tend to lower maximum standards) and (2) system-operational goals of minimizing the passing waiting passengers at stops and stations due to full vehicles (which would tend to increase maximum standards) (Kittelson and Associates, Inc. et al. 2013). If crowding standards are set so high that crowding regularly occurs on public transit vehicles, passengers are likely to have negative perceptions on the travel time reliability of the transit service (Li et al. 2016).

Another important measure of transit service quality is passenger comfort. In many travel-demand models, passenger comfort is an important component of transit travel cost functions (Haywood et al. 2017), given that crowding is closely related to perceived comfort levels (Celebi and Imre 2020; Li and Hensher 2013; Li et al. 2016). Specifically, crowding negatively affects passenger comfort in three ways: (1) dissatisfaction with standing over sitting, (2) diminished opportunity to use time efficiently (reading, working, etc.) while riding, and (3) forced close physical proximity to other passengers (Haywood et al. 2017).

People are concerned about physical proximity with others for many reasons, including sexual harassment on crowded transit vehicles. Surveys of university students in 18 cities around the world yielded the universal conclusion that females are much more likely than males to experience sexual harassment on transit vehicles and that crowded transit environments facilitate improper touching and discourage travelers, especially women, from riding (Ceccato and Loukaitou-Sideris 2020).

The demand for transit becomes more elastic as crowding levels increase. The marginal disutility of travel time in a crowded vehicle (0.17 m^2/standees) has been measured to be 2.5 times higher than in a vehicle with available seats (Batarce et al. 2016). A model of the cost function of transit travel shows this effect of crowding as well (Fig. 1) (Celebi and Imre 2020).

Many public transit agencies considered crowding as a key service attribute (Li and Hensher 2013), which is addressed in the U.S. by federal regulations. U.S.

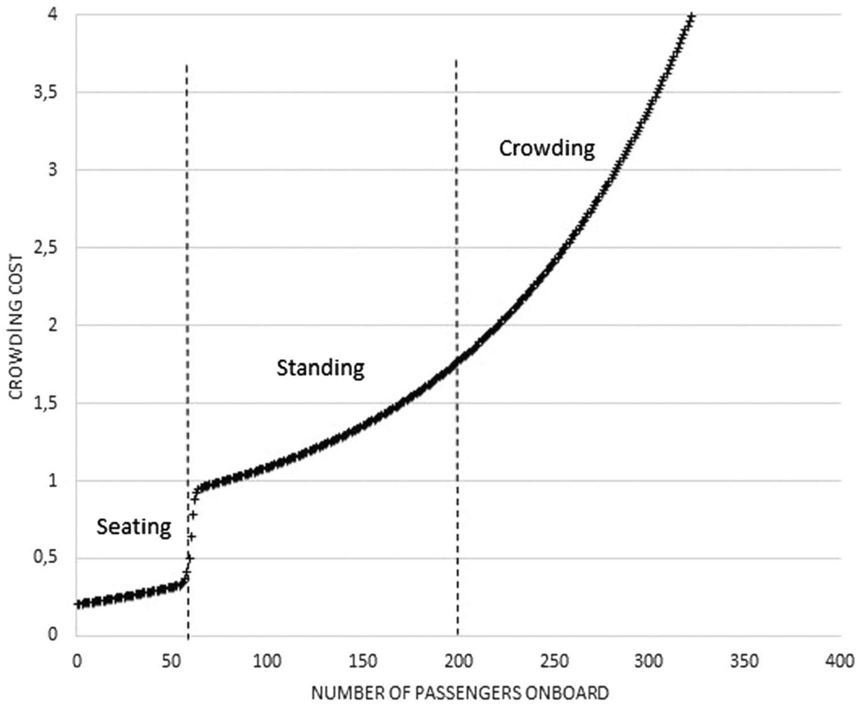


Fig. 1 The marginal cost of crowding on rail transit as a function of the number of passengers onboard (Celebi and Imre 2020)

regulations administered by the Federal Transit Administration (FTA) to ensure compliance with Title VI of the Civil Rights Act of 1964 stipulate that all transit agencies offering fixed-route services with federal funding must set system-wide policies and standards on maximum vehicle passenger loads, in addition to vehicle headways, on-time performance, and service availability (Federal Transit Administration 2012). In contrast to these latter service measures, crowding standards are most relevant to agencies operating service in dense, high-transit-demand environments, particularly during peak periods (Mistretta et al. 2009).

Before the pandemic, the 3rd edition of the Transit Capacity and Quality of Service Manual (TCQSM) (2013) was often used by U.S. transit operators to set, or at least initially establish, crowding standards for various bus models (Table 1.) (Kittelson and Associates, Inc. et al. 2013). The TCQSM crowding standards were established based on the length, number of doors, and number of seats on buses.

Note that the TCQSM crowding standard – the sum of the number of seats and the maximum number of standees – is given in terms of the total number of permitted passengers. In fact, there are other ways to define crowding, such as the maximum load factor (total passengers / seats) and maximum floor area per standee (or standees per unit floor area). While many U.S. transit agencies use load factors to describe crowding, other countries around the world, such as UK and Australia, more often use standees per unit floor area as a measure of crowding (Li and

Table 1 Bus crowding standards suggested by the Transit Capacity and Quality of Service Manual Source: TCQSM, Third Edition (2013)

Bus type	Length (ft)	Doors	Seats	Maximum Standees
Small bus/minibus	18–30	1	8–30	NA
Standard bus	35	2	30–40	NA
	40	2	37–47	30–46
	40	3	33	49
Double-deck	40	2	79–89	10–15
Motor coach	45	1	53–65	0[a]
Articulated	60	2–3	58–65	53–57
	60	3–4	43	57
Purpose-built BRT	60	4	27	90
	60	3/6[b]	37	67

NA: Not available from the manufacturer

[a]Typically used in high-speed environments where all passengers are expected to be seated

[b]Options for three doors on both sides

Hensher 2013). The TCQSM provides descriptions of transit crowding using both definitions (Table 2).

However, the advent of the COVID-19 pandemic in early 2020 caused transit agencies to radically alter both their definitions of crowding, as well as the purpose for setting crowding standards. The new focus was on public health broadly, and slowing the spread of the SARS-CoV-2 virus in particular. Public transit was considered a high-risk environment, especially early on when the means of virus transmission were not well understood. First, there are many common "touch points" on transit where respiratory and sinus droplets from infected passengers may land and spread the virus to other passengers who later touch the surface. Second, the fact that many of those who spread the disease are themselves asymptomatic, combined with the relatively unencumbered movement of passengers onto and off of buses and trains, make it almost impossible to identify and segregate infected passengers. Finally, large numbers of passengers congregating in confined transit vehicles with limited ventilation can spread the virus as well. It turned out that improved ventilation, universal mask wearing, and, importantly for this analysis, social distancing would be the three critical elements of keeping transit passengers and operators safe prior to the availability of vaccines (UITP 2020). Given this, social distancing (or the absence of crowding) became a central element of public health early in the pandemic (Tirachini and Cats 2020).

In 2020 and 2021, the CDC published and periodically revised guidelines for transit agencies and passengers, including, "maintaining 6 feet social distance between passengers," "enter and exit the vehicle through rear doors," and "consider skipping a row between passengers" (Centers for Disease Control and Prevention 2021). In addition to these general guidelines, the CDC also advised passengers to obtain up-to-date instructions from local transit agencies. In response, many, but by

Table 2 Crowding service levels defined by load factors and area by standee Source: TCQSM, Third Edition (2013)

Service level (load factor / area by standee)	Passenger perspective	Operator perspective
< 0.5 / > 1.0 m^2	No need to sit next to one another / Passengers are able to spread out	Unproductive service if this is at the peak hour or at maximum load points
	Perceived travel time = actual travel time	
0.5–0.8 / 0.5–1.0 m^2	Passengers have some freedom to choose where they sit / Comfortable standing load that retains space between passengers	Marginally productive service for buses
	Perceived travel time = actual travel time	Peak-hour design standard for high-quality rail service
0.8–1.0 / 0.4–0.5 m^2	All passengers can sit / Standing load without body contact	Productive service
	Perceived travel time = up to 1.1 × actual travel time	Service standards for commuter bus and commuter rail
1.0-1.25 / 0.3–0.4 m^2	< 20% of passengers must stand	Very productive service
	Standees may need to shift position at each stop / Occasional body contact	Service standards for off-peak bus service
	Seated passengers: Perceived travel time = up to 1.25 × actual travel time	Longer dwell times and slower travel speeds
	Standees: Perceived travel time = up to 2.1 × actual travel time	
1.25–1.5 / 0.2–0.3 m^2	< 1/3 passengers must stand	Very productive service
	Difficult for alighting passengers to get to doors	Maximum service standards for peak bus services
	Boarding passengers must get others to move	Longer dwell times and slower travel speeds
	Seated passengers: Perceived travel time = up to 1.4 × actual travel time	Increases chances of vehicle bunching
	Standees: Perceived travel time = up to 2.25 × actual travel time	
> 1.5 / < 0.20 m^2	Crush load conditions	Likely to generate complaints
	Delays for waiting passengers	Longer dwell times and slower travel speeds
		Increases chances of vehicle bunching

no means all, U.S. transit agencies set pandemic-specific passenger limits for their vehicles, while a few stopped their services all together (Gkiotsalitis and Cats 2021). Gkiotsalitis and Cats (2021) suggest that the six-feet social distancing rule would mean a service capacity drop of 60–90%, and Kamga and Eickemeyer (2021) suggest that many transit agencies simply halved their pre-pandemic maximum passenger limits or set the passenger limit per vehicle at 15.

Besides CDC guidance, some transportation consulting firms examined what was known early on about COVID-19 spread on transit vehicles and published service modification recommendations. In particular, the consulting firm WSP published guidance for transit agencies, and their passengers, on appropriate levels of crowding during the pandemic. It specified that bus operators should leave three to five rows immediately behind them blocked from passenger use, and that maximum passenger loads should be reduced to 50% of pre-pandemic levels (WSP 2020). Many researchers offered recommendations on public transportation planning during the COVID-19 pandemic and identified future research needs (Gkiotsalitis and Cats 2021). While recommended pre-pandemic crowding standards for public transit are widely available, and the COVID-19 pandemic prompted multiple agencies and firms to propose pandemic-specific crowding standards, we could find little previous research on the actual adoption of crowding standards, and communication of these standards to passengers, either prior to or amidst the pandemic. Further, while there is a body of research on the costs and consequences of crowding on transit, particularly with respect to the effect of crowding on mode choice, stop and station vehicle dwell times, and sexual harassment on transit, we found little examination of the factors motivating transit agencies to adopt and publish such standards. We therefore aim to address these two gaps in the literature in this article.

3 Research design

We used a random stratified sampling method to select 200 transit agencies from a universe of 1658 transit agencies across the U.S. in the American Public Transportation Association (APTA) database. The county-based spatial distribution of the 200 transit agencies is shown in Fig. 2.

For each of the 200 transit agencies, we employed a systematic investigation method to standardize our examination of the sampled agencies (Fig. 3). We were particularly interested in the crowding standards for peak hours, when crowding is more likely to occur, though we noted all mentions of such standards. There are no easily available data sources on transit crowding standards, so data on crowding standards for our sample of 200 transit agencies were collected manually.

Transit agencies vary substantially in the service they offer. While such services are typically distinguished by mode (local bus, express bus, light rail, heavy rail, commuter rail, etc.), given our focus here on transit vehicles, we categorized transit agencies in terms of five vehicle types operated: small bus (30 feet or less in length), full-size bus (35 or 40 feet in length), articulated bus (60 feet in length), light rail vehicle (LRV), and heavy rail vehicle (HRV). The crowding standards we identified were then recorded in terms of maximum passenger capacity for each vehicle type.

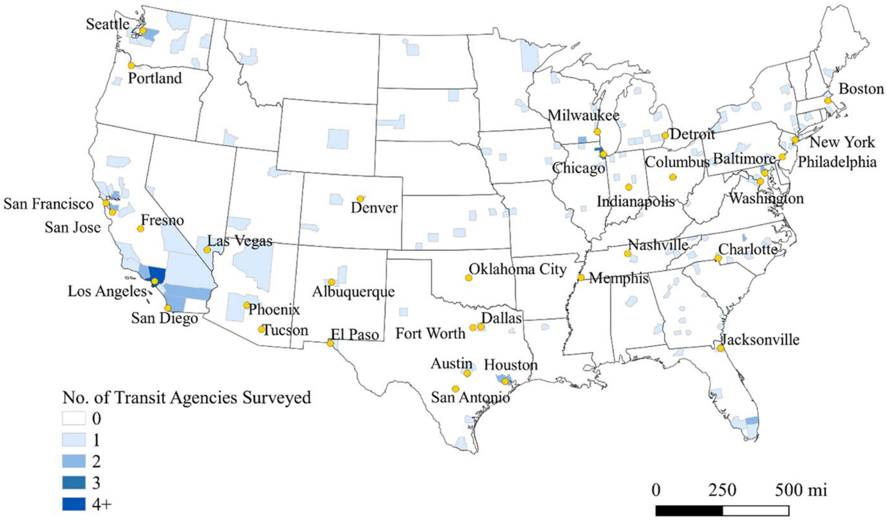


Fig. 2 Spatial distribution of the 200 agencies surveyed

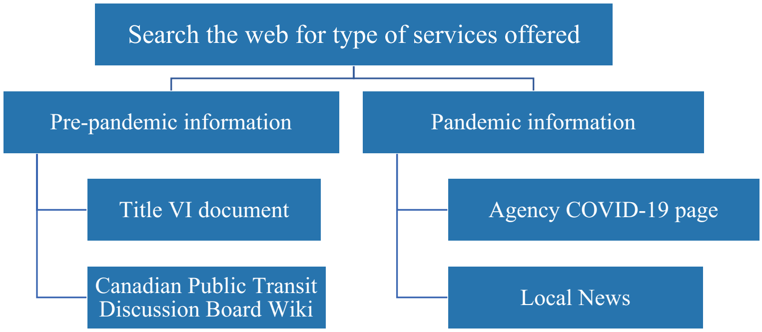


Fig. 3 Investigation flow chart

For agencies that defined either their pre-pandemic or pandemic crowding standards in terms of load factors, we calculated the maximum passenger capacity as the product of maximum load factor and the number of seats on a given vehicle. Those agencies for which our investigation revealed no public pre-pandemic and/or pandemic crowding standards were coded as either operating the vehicle type, but publishing no crowding standard for it, or not operating that vehicle type.

We used these data to generate statistics as well as the dependent variables in our regression models. The independent variables in our models include various characteristics of the 200 transit agencies as well as the counties within which they are located. We also relied on various administrative datasets, including the National Transit Database (NTD) maintained by the U.S. Federal Transit Administration (National Transit Database 2020) and the American Community

Survey (ACS) maintained by the U.S. Bureau of the Census (American Community Survey 2020). We also used data from GitHub, an open-source database (McGovern 2016; NYTimes COVID-19 data bot and Sun 2020). Using data drawn from widely varying sources in order to analyze transit crowding standards is an increasingly common transportation research method (Ge et al. 2021).

We estimated logistic regression models to investigate an array of factors associated with transit agencies publishing or not publishing crowding standards before and during the COVID-19 pandemic. We also estimated a linear regression model to examine the factors associated with changes to agency crowding standards during the pandemic. In Table 3, we summarize our independent variables for both types of models and our hypothesized relationships between each of the independent variables and the publication of pre-pandemic and pandemic crowding standards.

The number of pre-pandemic unlinked passenger trips (UPT) is perhaps the most direct measure of transit agency size. Dividing UPT by vehicle revenue hours (VRH) yields an aggregate measure of vehicle occupancy. While crowding on an individual vehicle depends on the time, direction, and location of travel, in addition to vehicle capacity, we assume in this analysis that the higher the system-wide UPT/VRH measure, the more likely peak-period crowding occurs. The county population measure indicates the scale of the cities or metropolitan areas within which the transit system operates. The transit commute-mode share directly measures the relative role played by public transit in the primary county (and not just our sampled system); it is typically highest in older, larger, more densely developed cities with long histories of transit use. The percentage of Republican vote margin in the 2016 presidential election measures the general political orientation of counties, which may account for both local financial support of transit prior to the pandemic, and the degree of public sector adoption of public health regulations during the pandemic. Finally, the county-based reported COVID-19 infection density (the ratio of reported COVID-19 cases to population) measures publicly available information on the spread of the virus in December 2020, from which the data for this study were gathered. We converted all these variables, except the partisan political lean and COVID-19 density measures, to natural log form to better fit the distributions of the data.

Many of the transit agencies examined did not publish crowding standards before (N = 85) and/or during (N = 104) the pandemic. Some, and perhaps most, of these agencies may monitor load factors and crowding on their vehicles and may have unpublished crowding standards that they use for service planning and deployment, and Title VI reporting requirements. But such unpublished internal load factor data or crowding standards are of little use to passengers in deciding whether, when, and where to ride in light of comfort or public health concerns. So with respect to the COVID-19 pandemic, we also investigated whether agencies communicated information about passenger control measures or social distancing guidelines to their riders.

Table 3 Input variables, data sources, and hypothesized relationships with crowding standards

Variable	Source	Expected association with pre-pandemic crowding standards	Expected association with pandemic crowding standards
Unlinked passenger trips (UPT)	FTA	+	+/-?
Passengers per vehicle revenue hour (UPT/VRH)	FTA	+	+
Population	American Community Survey (ACS)	+/-?	+/-?
Mode share of transit among commuters	ACS	+	+
% Republican vote margin	GitHub	–	–
COVID-19 density	GitHub, ACS	N.A.	–

+: Hypothesized positive relationship

–: Hypothesized negative relationship

+/-?: Unclear relationship

NA: Not applicable

4 Analysis and findings

The composition of the 192 agencies that offer fixed-route service in our initial sample of 200 is shown in Fig. 4 with respect to annual ridership. Note that "NYC" refers to the transit agency in New York City, which is a category by itself because it has more than three billion annual ridership.

Figures 5 and 6 show that, despite widespread concerns about social distancing on transit during the early months of the pandemic, the transit agencies surveyed were more likely to publish pre-pandemic crowding standards than modified crowding standards during the COVID-19 pandemic, regardless of the type of vehicles operated. The likelihood of an agency publishing pre-pandemic crowding standards increases as the size of the transit vehicles operated by that agency increases. This likely reflects that transit agencies operating heavy and light rail, along with articulated buses, are more likely to do so in high-transit-demand environments where standees and crowding are more common. Conversely, because the pandemic significantly lowered the numbers of passengers that constituted crowding in order to comply with social distancing guidelines on all systems, not just the heavily patronized ones, the lack of any relationship between types of operated vehicles and published pandemic crowding standards was expected as well.

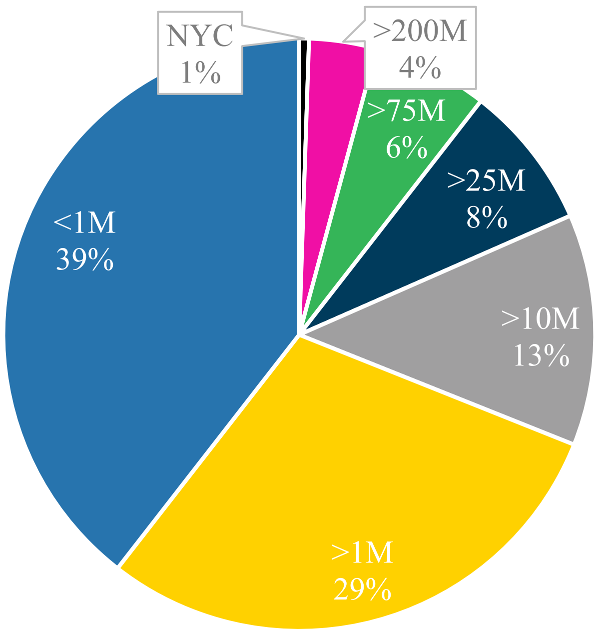
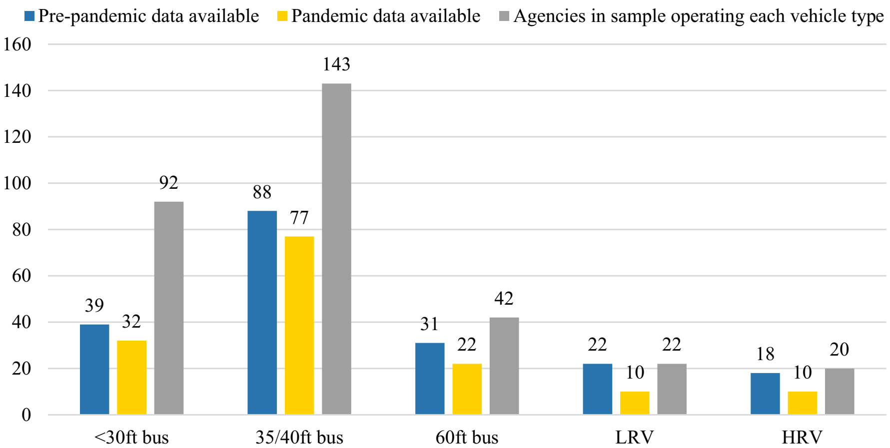


Fig. 4 Composition of transit agencies surveyed in terms of annual patronage



Note: The total number of agencies in this figure exceeds the 192 in our sample because many systems operate more than one type of vehicle.

Fig. 5 Transit agencies with pre-pandemic and pandemic crowding standards by the type of operated vehicles

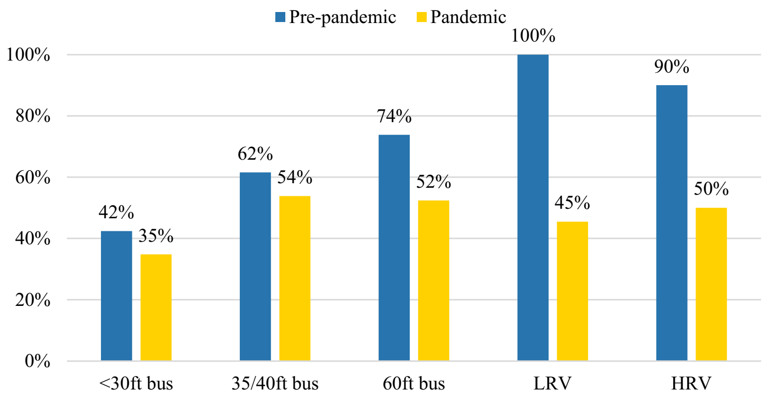


Fig. 6 Percentage of agencies with published crowding standards by operated vehicle type

4.1 Crowding standards before the COVID-19 pandemic

Because most transit agencies operate more than one vehicle type, we analyzed the incidence of crowding standards using the agency as the unit of analysis rather than the types of vehicles operated. Overall, 56% of the investigated agencies publicized some form of pre-pandemic crowding standard and/or associated data. To simultaneously account for an array of factors we hypothesized were associated with an agency publishing pre-pandemic crowding standards, we estimated a logistic regression model of the likelihood of an agency publishing such standards.

A correlation matrix of the variables revealed that several of the independent variables were not so independent. Specifically, county population, county transit mode share, partisan political lean, and UPT/VRH all had 0.50 or greater correlations with one another, and three pairs of variables had correlations of 0.70 or greater (ln(UPT) & ln(UPT/VRH), ln(UPT) & ln(Countywide Transit Mode Share), and % Republican vote margin vs. ln(Countywide Transit Mode Share). Indeed, in our initial model (see Table 4) both total ridership (ln(UPT)) and service effectiveness (ln(UPT/VRH)) were statistically significant, but the negative sign for ln(UPT/VRH) suggesting that the likelihood of publishing a pre-pandemic crowding standard went *down* as the system-wide average vehicle occupancy went *up* was the opposite of what we hypothesized. (Though it is conceivable that while larger systems are more likely to publish crowding standards, the large systems with the highest average passenger loads are *less likely* to publish them than large systems with lower passenger loads.) However, since re-running the model by omitting ln(UPT) flipped the sign of ln(UPT/VRH) to be positive, this (and the high correlation between the two variables of 0.83), suggests that the two variables were excessively collinear. Because the model omitting ln(UPT/VRH) performed better than the one that omitted ln(UPT), we dropped ln(UPT/VRH) in our revised model (Table 4).

None of the other variables in our revised model – ln(Population), ln(Countywide Transit Mode Share), and % Republican presidential vote margin were statistically

Table 4 Logistic regression models of the factors associated with transit agencies publishing pre-pandemic crowding standards

N = 192	Std. coef.	Std. error	p Value
Initial model including all variables			
(Intercept)	0.32	0.17	0.059*
Ln (UPT)	1.75	0.40	< 0.001***
Ln (Population)	− 0.04	0.23	0.852
Ln (Transit Mode Share)	0.20	0.32	0.523
% Republican vote margin	0.06	0.28	0.836
Ln (UPT/VRH)	− 0.77	0.31	0.011**
McFadden's Pseudo $R^2 = 0.19$			
Revised model omitting UPT/VRH			
(Intercept)	0.29	0.16	0.077*
Ln (UPT)	1.09	0.28	< 0.001***
Ln (Population)	0.00	0.23	0.996
Ln (Transit Mode Share)	0.11	0.31	0.733
% Republican vote margin	0.07	0.27	0.802
McFadden's Pseudo $R^2 = 0.17$			
Parsimonious one-variable model			
(Intercept)	0.29	0.16	0.075*
Ln (UPT)	1.12	0.19	< 0.001***
McFadden's Pseudo $R^2 = 0.17$			

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$

Table 5 Logistic regression of the factors associated with transit agencies publishing pandemic crowding standards

N = 192	Std. coef.	Std. error	p Value
Initial model including all variables			
(Intercept)	− 0.20	0.16	0.198
Ln (UPT)	0.52	0.36	0.149
Ln (Population)	0.12	0.22	0.591
Ln (Transit Mode Share)	− 0.62	0.31	0.046**
% Republican vote margin	− 0.13	0.27	0.620
COVID-19 density	− 0.34	0.17	0.047**
Ln (UPT/VRH)	0.26	0.31	0.399
Pre-pandemic data	0.36	0.18	0.043**
McFadden's Pseudo $R^2 = 0.104$			
Revised model omitting Ln(UPT/VRH) and % Republican vote margin			
(Intercept)	− 0.20	0.16	0.200
Ln (UPT)	0.74	0.27	0.007***
Ln (Population)	0.13	0.22	0.548
Ln (Transit Mode Share)	− 0.50	0.25	0.050**
COVID-19 density	− 0.33	0.17	0.052*
Pre-pandemic data	0.33	0.17	0.057*
McFadden's Pseudo $R^2 = 0.101$			

*p < 0.10, **p < 0.05, ***p < 0.01

significantly related to whether transit agencies published crowding standards before the pandemic. In fact, a simple one-variable (ln(UPT)) model (see Table 5) performed the same as the four-variable model (Pseudo $R^2 = 0.17$ for both). Since we are trying to link the general characteristics of transit agencies and counties within which they operate to a particular phenomenon (whether agencies publish crowding standards), the relatively modest pseudo R^2 of 0.17 is expected. In fact, McFadden considers an R^2 of 0.2 to 0.4 in a logistic regression model to be an excellent fit (1977).

These regression results suggest, simply and intuitively, that the larger the agency in terms of annual passengers, the more likely it published pre-pandemic crowding standards. For example, the Chicago Transit Authority (CTA), which carries the second-most passengers annually in the U.S., adopted a crowding reduction plan in 2013 to address passenger discomfort with crowding on its busiest rail and bus lines (Chicago Transit Authority 2013). Indeed, most of the large rail transit agencies in the U.S. publish detailed crowding-related information, such as seating plans and standing capacities, for the rail vehicle models they operate (Berkovich et al. 2013).

4.2 Crowding standards during the COVID-19 pandemic

We employed the same approach described above to examine the factors associated with adopting new or revised crowding standards during the pandemic. Forty-six percent (88 of 192) of the transit agencies in our sample adopted pandemic-specific crowding standards. These agencies variously published crowding standards in terms of passenger limits, percentage of pre-pandemic standards, or percentage of seats on vehicles. In these latter cases, we used these measures to calculate passenger limits for each vehicle type operated to create continuity across our sample.

In addition, we found references to pandemic crowding limits for some agencies, but these were described in only the most general of terms, such as, "limit the number of passengers on board" (Shoemaker 2020), ride in "designated seats" (Grant Transit 2021) or "drivers may enforce reduced capacity" (Soltrans 2020). While most of the agencies in our sample posted or published some information on pandemic-specific policies, such as mask requirements or asking their patrons to socially distance while riding, 26 (14%) of the agencies in our sample either provided no publicly available information about COVID-19 public health requirements or precautions, or they specifically offered that they had no pandemic crowding standards because they were not able to add more service to satisfy socially-distanced rider demand. Because we were not able to convert absent or vague information on pandemic crowding standards into our standard maximum-passengers-per-vehicle-type metric, we count these agencies as not publishing pandemic-specific crowding standards.

Unlike the pre-pandemic model, the signs of the independent variables in our initial logistic regression model on pandemic crowding standards adoption (Table 5) all performed as expected, including the two additional variables in this model: (1) COVID-19 infection density reported in December 2020 when our data were collected, and (2) a dummy variable for whether the agency published pre-pandemic crowding standards. Both of the newly added variables have relatively little correlation (<0.50) with other independent variables. In this initial model, the county-wide transit commute-mode share (ln(Transit Mode Share)), COVID-19 infection density (COVID-19 Density) and an agency having published a pre-pandemic crowding standard were statistically significant.

However, because of the high levels of correlation among several of the variables noted in the discussion above, we re-ran the initial model omitting two of the variables in pairs with correlations greater than 0.75: ln(UPT/VRH) – which had a 0.83 correlation with ln(UPT) – and % Republican vote margin – which had a -0.82 correlation with ln(Transit Mode Share). In this revised model (Table 5), the size of the transit agency (measured as ln(UPT)) became statistically significant and positive, meaning that, all else equal, agencies with more riders were more likely to adopt a pandemic crowding standard. The county-wide transit commute-mode share (ln(Transit Mode Share)) variable was statistically significant and negative, meaning that as the share of workers commuting to work on transit before the pandemic increased, the odds of an agency operating in that county adopting a pandemic crowding standard decreased. This suggests that while larger *agencies* are more likely to adopt such standards, all else equal, agencies *operating areas* with high levels of transit use are less likely to do so. The county-wide COVID-19 infection density (COVID-19 Density) was statistically significant and negative, meaning that areas with (at the time) high COVID-19 infection rates were less likely to adopt pandemic crowding standards. This suggests perhaps that places suffering with higher infection rates, where safer-at-home orders and travel restrictions would be expected to be most stringent during the infection surge of December 2020, were likely to have especially depressed transit travel demand, which would obviate the need for pandemic standards. Finally, an agency having published a pre-pandemic crowding standard was statistically significant and positively related to adopting pandemic-specific standards, as expected.

The initial (Pseudo $R^2=0.104$) and final (Pseudo $R^2=0.101$) models performed similarly, though their explanatory power was lower than for the models explaining the publication of pre-pandemic crowding standards. Again, because we are using the characteristics of transit agencies and counties within which they operate to explain a particular phenomenon (whether agencies publish pandemic-specific crowding standards), the relatively modest Pseudo R^2 is to be expected (McFadden 1977).

The story here – that larger agencies and those with pre-pandemic crowding standards were more likely to adopt pandemic-specific standards, while agencies in counties with higher levels of pre-pandemic transit use and higher COVID-19 infection rates were less likely to adopt such standards – is a more complex one than we found regarding the publication of pre-pandemic crowding standards. This is perhaps to be expected, given the extraordinary uncertainty and variability surrounding transit operations during the first year of the pandemic.

4.3 Changes of crowding standards

While we observed very different factors associated with the adoption of pre-pandemic and pandemic crowding standards, what might explain the level of *change* in crowding standards for systems that published both pre-pandemic and pandemic standards? As expected, the drops in the maximum passenger load standards during

Table 6 Ordinary least squares regression of factors associated with scale of change in bus crowding standards in the pandemic

N = 56	Std. coef.	Std. error	p Value
(Intercept)	– 0.684	0.017	< 0.001***
Ln (UPT)	– 0.048	0.039	0.220
Ln (population)	– 0.040	0.021	0.058*
Ln (transit mode share)	0.019	0.027	0.489
% Republican vote margin	0.027	0.034	0.428
COVID-19 density	– 0.016	0.018	0.381
Ln (UPT/VRH)	0.072	0.038	0.061*
$R^2=0.171$			

*p < 0.10, **p < 0.05, ***p < 0.01

the pandemic were dramatic: 64% for small buses, 69.5% for full-sized buses, 70.9% for articulated buses, 76.1% for light-rail, and 74.5% for heavy rail, on average.

Among the 200 transit agencies in our sample, 62 published both pandemic and pre-pandemic crowding standards. We calculated the average reduction in bus crowding standards across the three types of buses (small, standard size, and articulated) for each of these 62 agencies and used this as the dependent variable in an ordinary least squares (OLS) regression analysis (Table 6). We excluded rail services because, while 56 of the 62 agencies operate buses, only 13 of the 62 operate rail and those that do are typically the largest transit systems. The input variables are the same as in the pandemic model described above, except that the pre-pandemic crowding standard dummy variable is excluded because it is endogenous to our outcome variable.

Given the relatively modest OLS R-square value of 0.171 and the fact that the constant term is the most statistically significant input with a standardized coefficient that has by far the largest magnitude, we suspect that the scale of crowding standard changes at transit agencies that published both pre-pandemic and pandemic crowding standards is explained largely by factors – such as state and local public health guidance, local perceptions among public officials and customers regarding the risks of infection, and so on – that are not adequately captured by our independent variables. While a higher county population (ln(population)) is statistically significant andassociated with smaller changes in crowding standards, and while higher average passenger loads (ln(UPT/VRH)) are statistically significantly associated with larger changes in crowding standards, the magnitudes of the standardized coefficients suggest that these relationships are relatively modest. The F-statistics for the model shown in Table 6 versus a constant-only model, which has a p-value of 0.1453, indicate that the model in Table 6 fits only modestly better than the constant-only model. Indeed, the intercept (− 68.4%) is close to the average percentage reduction of crowding standards discussed previously. So we interpret the results of this model as suggestive, but by no means conclusive.

5 Conclusion

The COVID-19 pandemic radically changed the perceptions of acceptable levels of crowding on public transit. Public transit excels at moving large numbers of people in the same direction at the same time, and standards for acceptable levels of crowding prior to the pandemic reflected that fundamental role. Indeed, a standard transit industry reference describes vehicles where all seats are occupied and at least 20% of the passengers are standing as "very productive service" (Kittelson & Associates, Inc. et al. 2013). The factors limiting how many pre-pandemic passengers, and standees, could reasonably be packed into transit vehicles were related to the degree to which (1) protracted passenger boarding and alighting increased vehicle dwell times at stops or stations, (2) passengers were willing to tolerate discomfort associated with standing in close proximity to others, and having to push their way onto and off of vehicles, and (3) opportunities for inappropriate touching among passengers could be reduced.

Such considerations largely went out of the proverbial window in March of 2020. Ridership levels plummeted to previously unimaginable depths in a matter of days. Public health moved to the forefront of transit operations in order to reduce the spread of the SARS-CoV-2 virus and assuage vehicle operators' and passengers' safety concerns. In addition to mask requirements, calls for social distancing of up to two meters (or about six feet) radically transformed the definition of crowding on transit during the first year of the pandemic.

While research has previously examined passenger loads and crowding on public transit, as well as the bases by which standards for reasonable maximum passenger loads might be set, there has been little examination of *why* some transit operators set and publicize crowding standards and others do not – either before or amidst the COVID-19 pandemic. We set out to address this gap in the literature through an investigation of a stratified random sample of 200 U.S. transit agencies.

We find that, prior to the pandemic, larger transit agencies (measured in terms of annual pre-pandemic ridership) were more likely to publish crowding standards than smaller ones. Agencies with high annual ridership are more likely to experience periods of passenger crowding, all things equal, and may well be more likely to publicize standards and performance metrics of all types.

However, that simple story did not carry over to the pandemic. We again found that higher ridership agencies were more likely to adopt pandemic-specific standards, *ceteris paribus*. But we also found that agencies with pre-pandemic crowding standards were likely to do so as well, all things equal. In addition, we found that agencies operating in counties with higher levels of pre-pandemic transit commuting (across all transit systems in that county) and counties with higher COVID-19 infection rates in December 2020 were *less likely* to adopt pandemic crowding standards.

With respect to the level of change in crowding standards at agencies in our sample that published both pre-pandemic and pandemic standards, we find that the level of crowding standard reduction was largely consistent across agencies. Although we do observe that counties with a larger population are associated with smaller changes in crowding standards, while higher average passenger loads are associated with larger changes in crowding standards.

So, in contrast to the clear, simple story behind which agencies published pre-pandemic crowding standards, the factors associated with adopting pandemic standards or the changes to pre-pandemic standards in the pandemic paint a varied picture. This is perhaps to be expected, given the extraordinary uncertainty and variability surrounding transit operations during the first year of the pandemic.

Our research focuses on U.S. transit agency crowding standards, and how they differ across agencies before and during the pandemic, so our results may not be generalizable to other countries where public transit plays a more substantial role in metropolitan mobility, and where COVID-19 public health guidance varied as well. Similar research in other regions and countries may well find, as Gkiotsalitis and Cats (2021) suggest, that the effect of public health guidance on transit system capacities varied widely from place to place around the world. Moreover, since many transit agencies are now able to monitor and predict real-time transit demand, they could implement, labor and rolling stock permitting, demand-responsive dispatch schedules to reduce waiting times and crowding during peak hours (Peled et al. 2021). As with perceptions of crowding, perceptions of safety on transit are very much in the eye of the beholder, with important implications for patronage. Accordingly, research on passengers' perspectives on public health safety during the pandemic, and whether such perceptions are discouraging some from returning to transit late in the pandemic, are needed lines of future research. On that account, Parker et al. (2021) and Palm et al. (2021) have investigated the characteristics of passengers who stopped riding public transit during the COVID-19 pandemic due to fear of infection, but whether this has a significant relation with the changed notion of crowding during the pandemic remains unknown and is worth investigating.

While it appears that the global recovery from the COVID-19 pandemic is proceeding, the return of riders to public transit has (as of 2022) proven slow and at times halting. The future of late- and post-pandemic transit use will surely relate to the density of activities in downtowns and large centers of employment and education in the years ahead, but it will also relate to travelers' comfort levels with increasingly populated trains and buses as well. The evidence suggests that bars, restaurants, and sporting venues are filling back up with revelers eager to be free from two years of masking and the isolation of remote work and schooling, but new waves of infection, particularly if new virus variants begin to cause serious illness among the vaccinated, could quickly change things. If masking and social distancing return, wariness toward crowded buses and trains may return, and endure, as well. If so, the gap between "very productive service" and the levels of crowding riders will tolerate, might remain far apart for months, or even years, to come.

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Data availability The unlinked passenger trips (UPT) and passenger-per-vehicle revenue hour (UPT/VRH) data are available to the public (in the public domain) in the National Transit Database under Federal Transit Administration: https://www.transit.dot.gov/ntd/data-product/monthly-module-raw-data-release.

The Population and Commute-mode share data are available to the public (in the public domain) on the US Census Bureau website: https://data.census.gov/cedsci/table?q=commuting%20mode&g=0100000US%240500000&tid=ACSST5Y2019.S0801&hidePreview=true&moe=false.

The 2016 election results data are available to the public (in the public domain) and summarized by GitHub user tonmcg: https://github.com/tonmcg/US_County_Level_Election_Results_08-20.

The COVID-19 total confirmed case by county data are available to the public (in the public domain) and summarized by GitHub user nyt-covid-19-bot: https://github.com/nytimes/covid-19-data/blob/master/us-counties.csv.

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