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Passenger Perceptions, Information Preferences, and Usability of Crowding Visualizations on Public Displays in Transit Stations and Vehicles

Leah Zhang-Kennedy
University of Waterloo
Waterloo, Canada
lzhangke@uwaterloo.ca

Saira Aziz
University of Waterloo
Waterloo, Canada
saira.aziz@uwaterloo.ca

Oluwafunminitemi (Temi) Oluwadare
University of Waterloo
Waterloo, Canada
oioluwadare@uwaterloo.ca

Lyndon Pan
University of Waterloo
Waterloo, Canada
yizhou.pan@uwaterloo.ca

Zeyu Wu
University of Waterloo
Waterloo, Canada
anthony.wu@uwaterloo.ca

Sydney E.C. Lamorea
University of Waterloo
Waterloo, Canada
slamorea@uwaterloo.ca

Soda Li
University of Waterloo
Waterloo, Canada
y2773li@uwaterloo.ca

Michael Sun
University of Waterloo
Waterloo, Canada
z249sun@uwaterloo.ca

Ville Mäkelä
University of Waterloo
Waterloo, Canada
ville.makela@uwaterloo.ca

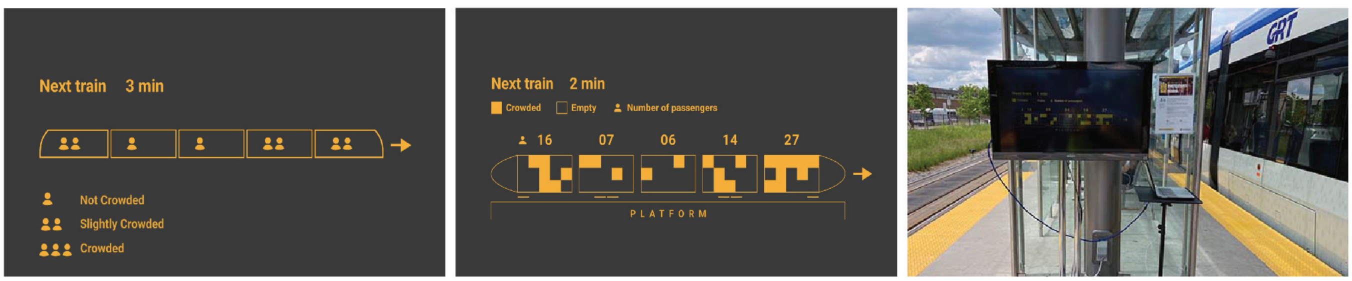

Figure 1: We first investigated crowding perceptions and information and visualization preferences in an online survey, and then deployed two visualization prototypes (left, middle) using historical passenger data in a field user study at three light rail stations (right). The Fullness concept focusing on overall crowd levels (left) was the easiest to understand, but the Occupancy concept visualizing occupied seating and standing spaces (middle) was the most useful to help passengers avoid crowded areas on the train.

ABSTRACT

Large crowds in public transit stations and vehicles introduce obstacles for wayfinding, hygiene, and physical distancing. Public displays that currently provide on-site transit information could also provide critical crowdedness information. Therefore, we examined people's crowd perceptions and information preferences before and during the pandemic, and designs for visualizing crowdedness to passengers. We first report survey results with public transit users (n = 303), including the usability results of three crowdedness visualization concepts. Then, we present two animated crowd simulations on public displays that we evaluated in a field study (n = 44). We found that passengers react very positively to crowding information, especially before boarding a vehicle. Visualizing the exact physical spaces occupied on transit vehicles was most useful for avoiding crowded areas. However, visualizing the overall fullness of vehicles was the easiest to understand. We discuss design implications for communicating crowding information to support decision-making and promote a sense of safety.

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CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; • **Applied computing → Transportation**.

KEYWORDS

crowding, public transit, public displays, visualization, covid-19

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1 INTRODUCTION

Large crowds are common in public transit stations and vehicles, which presents challenges for wayfinding and public health. Crowds can block pathways and doors, and occupy all seats and standing areas in public transit vehicles. While crowds have and always will present certain health risks (e.g., many diseases spread via air or touch), the COVID-19 pandemic and the related policies gave rise to unprecedented safety concerns about sharing public transportation with other passengers [8], because it could increase the risk of catching and transmitting the virus [9].

People need crowding information to make informed decisions about travel options. Crowding on public transport has been previously investigated primarily as an indicator of passenger comfort rather than safety [42]. While some prior research has explored crowding information during the pandemic [33], we currently lack detailed knowledge about how the pandemic has affected crowd tolerances and preferences for crowding information at different parts of the passenger journey. Similarly, some visualizations for crowding information have been proposed (e.g., [28, 31, 70]); however, prior explorations have been limited, for example, by focusing only on communicating overall crowding levels. As such, we lack a comprehensive investigation into what kind of crowding information is suitable and desired for public transit, and how such information could be visualized.

Therefore, our research goal is to explore visual methods to communicate crowding as well as current crowding perceptions and needs for crowding information, to help public transit riders make informed boarding decisions, find vacant pathways and vehicles, and address their safety concerns. Our research questions are:

- ***RQ1****: How has the COVID-19 pandemic affected people's perception of risks and crowding in public transport?*
- ***RQ2****: What kind of crowding and safety information do people want to see and when do they want to see it?*
- ***RQ3****: What is the preferred visualization design for conveying crowdness information?*

To address the first two research questions, we conducted an online survey with 303 public transit riders in North America. To address our third RQ, we first created three crowding information visualization concepts and evaluated them as part of the survey. Next, we implemented two visualization prototypes based on historical passenger data to simulate real-time crowding information and evaluated them on public displays at three light rail train stations with 44 passengers.

Our survey results showed a shift in crowding perception. Passengers more easily perceived transit vehicles as crowded during the pandemic than before. Although 1 passenger per m^2 is the "safe" physical distancing guideline provided in many countries, passengers may still perceive it as unsafe. In particular, the crowding threshold that deters most people from using public transport during the pandemic is 2 passengers per m^2. Generally, participants reported crowding information to be highly desirable for public transit use. This need was strong around the transit station and particularly on platforms prior to boarding a public transit vehicle.

Of our three visualization concepts (Figure 6), participants preferred a concept visualizing the overall *fullness* of a train, and a concept visualizing the exact spaces on the train *occupied* by passengers. A concept representing the average *distance* between passengers was found less intuitive. A field study of two animated prototypes that simulate real-time data (Figure 1) showed that visualizing the occupied physical space helps people avoid crowds, but visualizing the overall fullness of vehicles is easy to understand. This has implications for the transit context, such as placing glanceable information around transit stations, and more detailed information while passengers wait for the next vehicle.

We make three main contributions. First, we contribute to the understanding of passenger's crowding and risk perception and information needs. Second, we contribute to effective and accessible ways to present public crowding information in the context of public transit and find that crowding information can create actionable insights for passengers. For example, enabling passengers to determine which train car has the most room can help them make informed decisions about which door to enter the train from, which will help distribute passengers more evenly and reduce health risks associated with indoor crowding. Third, our survey and field study contributed to a set of empirically evaluated visualization concepts to communicate crowding. The results of this study help inform the design of crowd risk communications and advances the creative applications of user interface concepts for public transit vehicles [19].

2 BACKGROUND AND RELATED WORK

2.1 Transit Crowding and Safety Information on Public Displays and Signage

Public displays that show transit information, such as arrival and departure times and platforms, are a vital component in transportation hubs and public transit stops [7, 47]. Despite the convenience of personal navigation on smartphones, public displays and signage are still used to access information [52] because it is a natural way to navigate a physical space [17]. People also often carry items that makes accessing smartphones inconvenient [36, 37], particularly in the transit context as passengers may carry heavy luggage.

Crowding on train and subway platforms while passengers wait and board vehicles can cause dramatic differences in the fullness and comfort of cars along the vehicle [22]. Meghana et al. [42] proposed an automated system using machine learning and IoT technologies for displaying five levels of passenger density information on LCD screens at bus stops. Zhang et al. [70] found that real-time crowding information on a public display had a positive impact on the boarding distribution between cars and incidentally reduced downstream in-vehicle crowding on the trains. A study in the Netherlands [17] showed that LED signage displaying train fullness hanging above the length of the train platform promoted more efficient boarding. A study by the New York Metropolitan Transportation Authority [12] found that the front of subway cars is the most crowded compared to the middle and the rear car is the least crowded. The London Underground faces similar problems, and a user interface mockup was proposed that indicates the volumes of passenger cars using color signals (e.g., red, yellow, green) to indicate crowding levels [28]. Another design by a Brussels-based design studio proposed a display showing a train's arrival time using coloured bulbs that dim when more passengers are traveling in a particular car [28]. However, neither solution was implemented nor tested. Hadas et al. [22] proposed a monetary approach that dynamically changes the fare based on the level of crowdedness in the vehicle and compensates passengers for the additional waiting time when they choose to wait for the next, less crowded vehicle.

As the COVID-19 pandemic changed people's perceptions of hygiene and safety in public spaces (e.g., using touchscreens [39]), crowding could further raise concerns about public health and passenger safety. People are turning to alternative modes of transportation after the COVID-19 pandemic, which is problematic, as increased use of private vehicles increases traffic-related air pollutants associated with global warming and health-related issues [65]. Therefore, it is important to investigate the information preferences following the pandemic and its effect on transport behavior. During the pandemic, for example, a study in the Netherlands [59] found that certain groups of people can be motivated to change their departure time if real-time crowding information is provided to them. In the UK, researchers [33] developed public transport messaging about crowding to provide guidance on a platform to travellers.

2.2 Transit Crowd Management

Prior research on transit crowding focuses primarily on perceptions and measurements of passenger comfort (e.g., [6, 15, 58]) and how high passenger density affects travel time, service reliability, and passengers' well being (e.g. [53, 63]). When passenger distribution among cars is not taken into account, there is a non-negligible cost to passengers, such as a perceived increase in travel time [53], an increase in stress, anxiety, and feelings of exhaustion, and a possible loss of productivity working while riding [63]. It could also increase perceptions of risk to personal safety and security and feelings of invasion of privacy [63]. Researchers [53] have evaluated the effective use of the transit vehicle considering the distribution of passengers. Passengers experience less discomfort when crowds are more evenly distributed across the transit vehicle [53]. Alternative crowd management strategies have been proposed, such as controlling passenger flow to platforms through different gates [53, 69].

Various existing and emerging data sources are available for obtaining passenger data [10, 34], such as automatic passenger counting (APC) [54] and automatic fare collection systems (AFC) [48] for counting the number of passengers boarding a transit vehicle, and IoT camera and sensing technologies for crowd analysis [10, 34]. Passenger data collected by the systems is commonly used to optimize and plan strategies for public transit systems, such as providing information on trips to passengers and for the management and monitoring of the transit service [10]. Making real-time passenger information available to passengers can improve their user experience (UX) [18]. We focus on transit passengers' user experience towards crowding information on public displays, and use existing historical passenger counter data to simulate real-time information.

2.3 Passenger behavior Due to Crowding

Passengers crowding on the platforms and trains can be highly unevenly distributed [22, 23, 53, 64, 70]. Research shows that passengers make calculated trade-offs to avoid crowding on board [32, 55], such as choosing alternative travel paths, boarding a less crowded car on multi-car vehicles (e.g., trains), adapting their travel schedule to crowding conditions, such as choosing to wait for the next transit vehicle when there are no seats available. However, other intrinsic factors, such as minimizing walking distance at destination stations, may also affect boarding choices [30]. Efforts to reduce uneven passenger distribution have been made primarily through tactical planning methods, such as optimizing the location of train stops along a platform [60], installing one-way gates on platforms to control passenger flow [46], and using predictive transit assignment models [20]. Another study [5] found that crowding affected people's travel decisions to a greater extent during the COVID-19 pandemic; other factors such as face mask enforcement, vehicle disinfection and cleanliness, health risk perception, and safety were also relevant considerations for passengers.

Social distancing strategies and strict hygiene mandates during the pandemic have added an additional dimension to transit safety requirements. Therefore, the effect of altered safety perceptions on public transit behavior needs to be assessed for effective policy decisions post-pandemic [40]. Indeed, Cho and Park [9] found differences in behavior in passengers' crowding impedance before and after the COVID-19 pandemic. Shelat et al. [57] assessed transit-related behaviors of travellers who where conscious or indifferent about the risk of COVID-19 found that while indifferent travellers' risk perceptions towards crowding are only slightly higher, risk-conscious passengers have a strong desire to sit where neighbouring seat are unoccupied. Bansal et al. [4] investigated factors that influence the preferences of pre-pandemic passengers for the London Underground during the pandemic and provided estimates of the impact of crowding on reducing or improving the effectiveness of interventions, such as that the positive effect of vaccine adoption reduces substantially with increasing crowding levels. Kim et al. [31] reported the majority of their participants said they were willing to move to board a less occupied carriage if they had assess to crowding information. A preliminary survey on hygiene in public transport reported the interest of passengers in knowing where in the vehicle it is safe to touch (e.g., unused handrail [25]). Therefore, we believe that it is similarly valuable to explore ways to provide crowding information for passengers to help them avoid crowded areas during public transit, thus increasing public safety and improving passenger traffic flow.

2.4 Summary and Research Gap

Our work addresses two important research gaps. First, existing research shows that the pandemic has affected the preferences and behavior of public transit riders [4, 5, 9, 40, 57]; however, we currently lack a detailed understanding of how crowd tolerances since the pandemic have affected the current demand for crowding information. We investigate perceived thresholds for transit riders (e.g., when they would no longer board a vehicle due to crowding), as well as demand for different crowding information in different situations (e.g., information about crowds on board vs. crowds on

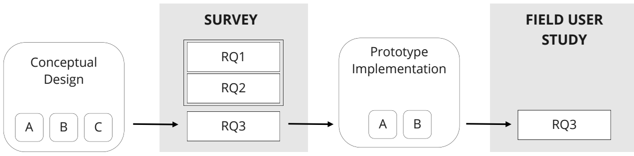

Figure 2: Flowchart of the study procedure.

the platform, information offered when entering the transit station vs. when boarding the vehicle). Our results can inform the design of crowding communication at large.

Second, we conduct a comprehensive evaluation of crowding visualizations by exploring three different approaches with varying levels of detail. Some existing designs have not been evaluated at all [28]. More importantly, existing crowding visualizations have focused on communicating only the *overall fullness* of the vehicles using various symbols. For example, Zhang et al. [70] used a 10-point scale of human figures to communicate crowd levels, and Kim et al. [31] used a 4-point scale of empty, partially, and fully filled boxes to communicate how full train cars were. Hence, there is need to study other approaches to crowding, especially now that concepts such as *social distancing* have been brought to the public's attention. Other visualizations might be more effective at helping passengers avoid crowds, keep their distance to other passengers, and assess the situation and take appropriate action. Therefore, our work compares three visualizations each with a different focus and level of detail: the overall *fullness* of the vehicle, the average *distance* that can be kept between passengers on board, and the *occupancy* of seats and standing spaces on board.

In addition, some existing solutions rely on colours to communicate crowding [28], which can create accessibility barriers for people with visual impairments (e.g., color blindness). Multi-colour displays are also more expensive and are not compatible with single-coloured LED or LCD displays commonly found in public transit stations and vehicles worldwide. Similarly, some existing designs use quantitative metrics for conveying crowding, such as passengers per square meter, percentages, and physical distancing recommendations, and may not fully capture and convey the ways in which passengers experience crowded situations [62]. All of our proposed visualizations factor in these considerations.

Mobile applications can conveniently provide transit crowding information (e.g., Google maps) and details like exit and transfer point locations [29]. Mobile apps have also been proposed to encourage people to board less crowded vehicles by providing them with crowding information [31]. However, prior studies [17] suggest that many passengers prefer public displays and signage over an app when more precise and time-sensitive information is required (e.g., which areas of a platform or a vehicle are crowded). It is also worth noting that public display infrastructures already exist in these settings, and people are actively using them to, e.g., check for information about platforms and arrival and departure times. Therefore, our work focuses on communicating information about transit crowding on public displays.

3 RESEARCH APPROACH

We conducted an online survey and a field user study to answer our research questions. Our high-level research approach is presented in Figure 2. The online survey (n = 303) investigated differences in people's perceptions of crowding on public transit before and during the COVID-19 pandemic (RQ1) and their crowding and safety information preferences (RQ2). Participants' preferred visualization to convey crowd information (RQ3) was first explored in the survey to evaluate the usability of three visualization concepts. We selected and refined the design of two crowd visualization concepts based on the survey feedback, and implemented animated information visualization prototypes of the concepts using historical passenger count data to simulate real-time crowding information. Finally, we deployed and evaluated the prototypes in a field user study with 44 participants at three light rail train stations. The field study addressed the limitations of the survey by allowing users to view the visualizations in their natural context and respond to contextual questions, which is a more ecologically valid evaluation [1].

Section 4 describes our survey methodology. In Section 5, we present the survey results and discuss our conceptual designs and the preliminary usability results. In Section 6, we describe the prototype implementation for the field user study, the methodology, and the findings.

4 CROWDING PERCEPTION SURVEY

We first summarize our survey methodology and results regarding passenger crowding perceptions and information preferences and then discuss our preliminary crowding information visualization concepts and feedback.

4.1 Survey Methodology

Our REB-approved survey focused on collecting feedback about participants' safety perceptions and practices, their perceptions of levels of crowding, and their preferences for visualizing crowdedness information. We set up the survey using Qualtrics and collected 303 responses from Prolific[1] during February 2022. The participants were remunerated 2 GDP ($3.40 CAD) and completed a five-part questionnaire that took on average 21 minutes (Md = 17).

We screened the eligibility of Prolific participants as public transportation riders in Canada (n = 201) and the US (n = 102) who took public transportation at least once in the last 12 months, so they have experience taking public transit before and during the pandemic. Furthermore, we selected participants from North America because the pandemic "began" for most people around the same time in March 2020. The contents of the questionnaire were:

(1) *Demographics:* We collected basic demographic questions such as age, sex, education, employment status, and purpose for taking public transit.
(2) *Perceptions of crowding:* The participants indicated their perceived crowdedness of a transit vehicle *before* and *during* the pandemic on seven-point Likert scales from "not at all crowded" to "extremely crowded." They assessed seven crowding levels in random order with visual aids adapted from Batarce et al. [6] (see Figure 3). The figures were shown

[1] https://www.prolific.co

Table 1: Summary of the survey demographics.

Country & Gender		Age Group		Level of education		Household Income		Employment status	
Canada	102 (34%)	18 to 19 years	18 (6%)	High school	75 (25%)	<$19k	37 (12%)	Employed for wages	158 (52%)
USA	201 (66%)	20 to 29 years	157 (52%)	College	40 (13%)	$20k-$39k	39 (13%)	Student	73 (24%)
		30 to 39 years	81 (27%)	Bachelor's	139 (46%)	$40k-$59k	55 (18%)	Self-employed	32 (11%)
Male	106 (63%)	40 to 49 years	21 (7%)	Master's	36 (12%)	$60k-$79k	55 (18%)	Out of / Looking for work	20 (7%)
Female	190 (35%)	50 to 59 years	16 (5%)	Doctoral	7 (2%)	$80k-$99k	36 (12%)	Homemaker	8 (3%)
Non-binary	5 (2%)	60+	9 (3%)	Other	5 (2%)	$100k-$149k	48 (16%)	Unable to work / not looking	5 (2%)
Prefer not to say	2 (1%)	Prefer not to say	1 (0.3%)	Prefer not to say	1 (o.3%)	>$150k	22 (7%)	Retired	3 (1%)
						Prefer not to say	11 (4%)	Prefer not to say	4 (1%)

with metric and imperial measurements ranging from one passenger per two metres (six feet) to six passengers per metre (three feet). The least crowded level is based on our country's physical distancing guidelines (two metres or six feet). Participants also indicated the degree of crowding that would discourage them from entering public transit vehicles *before* and *during* the pandemic according to the figures.

(3) *Information preferences:* The participants indicated their preferences for 11 types of information related to crowding, safety, sanitation, and other transit-relevant information (see Figure 5) that passengers would like to know on public displays at three points in the user journey: 1) arriving at a transit station; 2) on the platform waiting for the next transit vehicle; 3) onboard the transit vehicle. We clarified that the information is for digital public displays around transit stations, platforms, and inside transit vehicles. Participants indicated their preferences based on a Likert scale from "Strongly agree" to "Strongly disagree".

(4) *Information visualization feedback:* Participants provided their opinion about our three visualization concepts (Figure 6). They viewed one concept at a time in randomized order and responded to three usability questions on a five-point Likert scale regarding the understandability, usefulness, and appropriateness of visualizations to communicate crowd information. Participatns could also provide qualitative feedback on each concept via an open-ended question.

(5) *Risk perceptions and practices:* Questions about risk perceptions were asked at the end of the survey to avoid bias in the previous questions. We adapted six questions from the COVID-19 Risk Perception index [14] about the perceived severity of the COVID-19 pandemic, perceived likelihood of contracting the virus over the next six months, the perceived likelihood of family and friends catching the virus, and their current level of concern about the virus. Participants also indicated whether their frequency of using public transit had changed during the pandemic. They also reported how they stay informed about public transit, the accessibility features they regularly use, and their safety practices.

5 SURVEY RESULTS

This section summarizes the self-reported attitudes and behaviors of the participants. Quantitative analysis assumed a significant level of $p < .05$ unless the Bonferroni correction was applied. Qualitative analysis of open-ended questions used affinity diagramming to cluster participants' feedback into thematic groups.

5.1 Demographics and Risk Perception

Demographics: Table 1 summarizes the demographics of the participants. More than half (63%) of the participants self-identified as female, 35% as male, and 2% as non-binary. Most (85%) were between 20 and 49 years of age, of various levels of education and household income, and of employment status.

Frequency riding public transit: 40% of the participants said that they took public transport at least once a week in the previous year, 43% took it at least once in the last one to three months, and 26% took it at least once in the last six to twelve months. Half (50%) used public transport primarily for social and recreational purposes, 36% for work, 34% for irregular trips, 23% for school, 13% for groceries, 10% for medical-related trips (e.g., hospital, pharmacy), and 1% for caregiving purposes (e.g., taking children to school). 44% said that their frequency of taking public transport has decreased dramatically during the pandemic and another 33% said that it has somewhat decreased. Only 18% said that there was no change and 6% said that it increased.

Risk perception and safety measures toward COVID-19: We measured risk perception as an index covering the cognitive dimensions (likelihood), emotional dimensions (worry), and temporal-spatial dimensions to provide a holistic measure of risk [14]. The Mean risk perception of our participants ranged from 1.50 to 4.33 on a five-point Likert scale and was neither high nor low on average ($M = 3.07$, $SD = 0.52$). We did not find statistically significant differences in risk perception between participants from Canada ($M = 3.09$) and the United States ($M = 3.04$).

Almost all participants (96%) stated that they wear a mask in transit vehicles, probably due to the mandatory requirements for masks indoors at the time of the survey. Most (79%) also reported that they use hand sanitizer or wash their hands after taking public transit. 71% said that they practice physical distancing whenever possible. 66% avoid touching public surfaces such as doors and handles in vehicles and in transit stations. Approximately half of the participants (54%) said that they use alternative modes of transportation such as biking or driving when possible. 35% said they stand behind physical barriers such as plexiglass partition barriers at check-in counters, ticket booths and service desks. Only 21% currently check the crowdedness of public transportation before riding, possibly because the information is only available on Google Maps in metropolitan areas. Only 2% of the participants said that they do not take any safety measures on public transit.

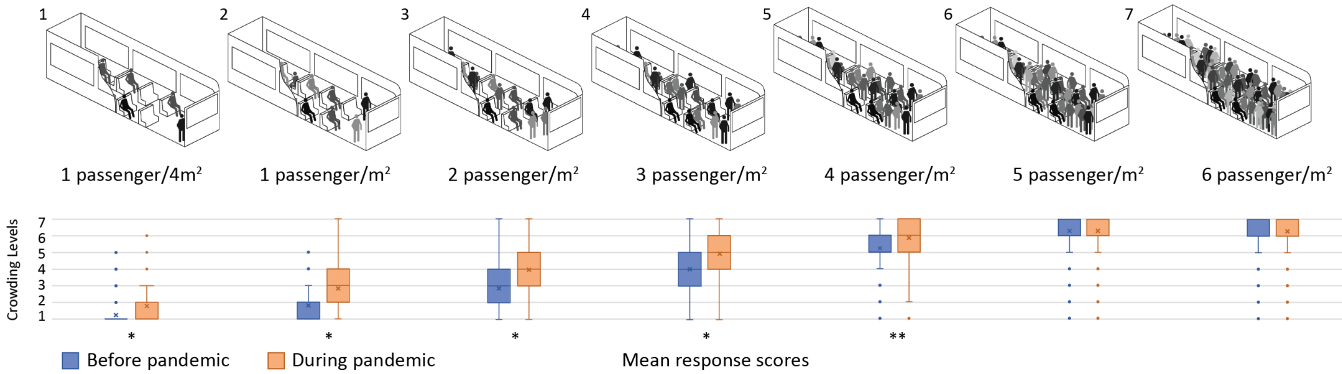

Figure 3: Participant's mean scores for how crowded it is onboard based on passenger density and figures to represent level of crowding: 1 = Not at all crowded, 7 = Extremely crowded. Significant difference between before and during the pandemic is denoted with $*: p < .0005$, $**: p < .001$.

5.2 Perceptions Towards Crowding Density

Figure 3 summarizes the participants' scores on how crowded it is onboard for seven crowd density levels. We defined the number of passengers per square meter along with figures to help participants visualize the passenger density. A Wilcoxon Signed-Rank test showed a statistically significant difference in *five* of the seven crowd density levels between the two time periods: Participants perceived that transit vehicles were significantly more crowded during the pandemic than before.

Crowd density perceptions increased in 34% ($n = 117$) of participants for *1 passenger/4m*^{2} ($z = 8.28, p < .0005$), 63% ($n = 191$) for *1 passenger/m*^{2} ($z = 10.08, p < .0005$), 68% ($n = 205$) for *2 passengers/m*^{2} ($z = 10.66, p < .0005$), 61% ($n = 186$) for *3 passengers/m*^{2} ($z = 9.20, p < .0005$), and 52% ($n = 157$) for *4 passengers/m*^{2} ($z = 6.35, p < .001$). There were no statistically significant changes in crowding perceptions for *5 passengers/m*^{2} and *6 passengers/m*^{2}, as they were generally perceived as very or extremely crowded in both contexts.

Figure 4 compares the crowding levels that could prevent our participants from boarding a public transit vehicle during and before the pandemic. The crowding threshold during the pandemic appears to be around *2 passengers/m*^{2} compared to a much higher crowding threshold of *4 passengers/m*^{2} before the pandemic. Only 3% said that none of the crowding levels would deter them during the pandemic compared to 19% before the pandemic. 86% of the participants agree that having access to information about transit crowds will make them feel safer taking public transit, and 59% agree that having access to crowding information will motivate them to take public transit more often.

These results highlighted that during the pandemic, most passengers perceived the crowding levels to be crowded or very crowded from 3 passengers/m^2 and some passengers may choose not to board a transit vehicle when there are only 2 passengers/m^2 onboard. The results suggest that communicating the crowd density beyond 3 passengers/m^2 (e.g., level 5 to 7 on our scale) could be unnecessary because your boarding decisions are likely to be determined by a lower density threshold. Previous work has used three levels (e.g., [41]), four levels (e.g., [31]), five levels (e.g., [42, 61]), and ten levels

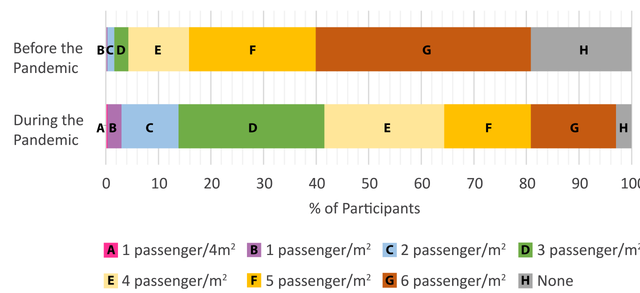

Figure 4: Percentage of participants not boarding public transit vehicles before and during the pandemic at various crowding levels.

(e.g., [70]) to indicate degrees of crowding. Our results suggest that a smaller density range with three levels (e.g., not crowded – partly crowded – crowded) may be sufficient to help passengers make boarding decisions, and would be quicker to understand at a glance.

5.3 Crowding and Safety Information

Participants indicated what information they would like to know on public displays during a one-way trip from arriving *at the station*, waiting on *on the platform*, riding *onboard*, and *getting off* the transit vehicle. They rated eleven types of information on a five-point Likert scale from Strongly Agree to Strongly Disagree:

- transit schedule (`schedule`)
- public health information (`public_health`)
- overall crowds on a train or bus (`onboard_crowds`)
- security monitoring (`security`)
- accessibility information (`accessibility`)
- car-by-car crowds onboard (`car_crowds`)
- when the facilities were last cleaned (`cleaned_facilities`)
- overall crowds on the platform (`platform_crowds`)
- car-by-car boarding area crowds on the platform (`boarding_crowds`)
- temperature onboard (`temperature`)
- humidity onboard (`humidity`)

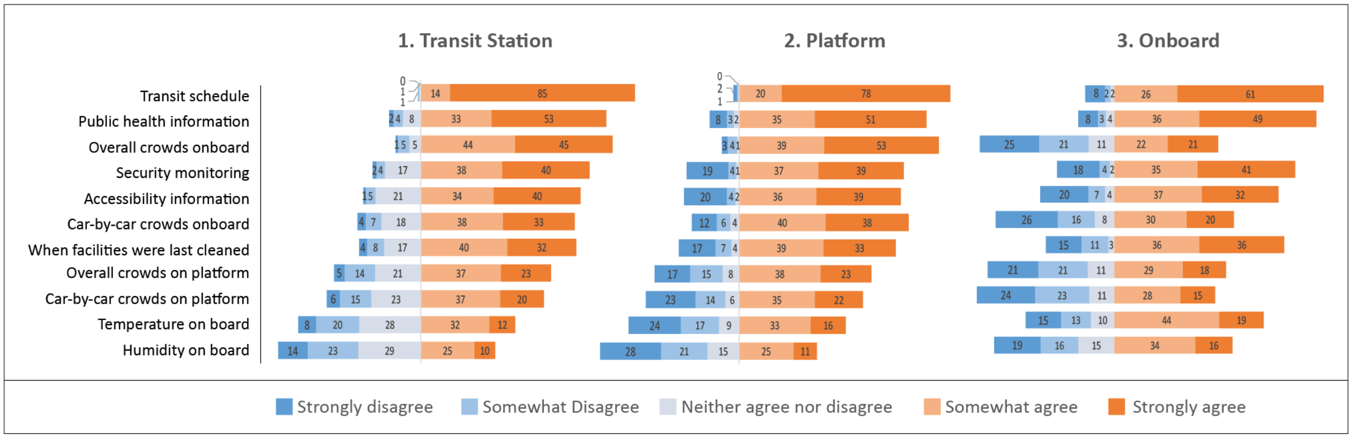

Figure 5: Preferences for various information on public displays at different stages in the user journey.

As shown in Figure 5, the top seven information that passengers would like to know is `schedule`, `public_health` information, `onboard_crowds`, `security`, `accessibility`, `car_crowds`, and `cleaned_facilities`. We used the Friedman test to determine how preferences for each type of information changes during the three points in the passenger journey. There were statistically significant differences between the passenger journey stages for all information types. Pairwise comparisons were made with a Bonferroni correction for multiple comparisons to follow up on the findings. The relevance of all information decreased after boarding the transit vehicle, particularly for crowding information. We summarize the results below for the eleven information types.

5.3.1 Crowding information: We found statistically significant differences between the three passenger journey points for the total `onboard_crowds` on the transit vehicle ($X^2(2) = 242.98, p < .0005$), `car_crowds` for multi-car transit vehicles (e.g., trains) ($X^2(2) = 82.23, p < .0005$), `platform_crowds` ($X^2(2) = 25.28, p < .001$), and car-by-car `boarding_crowds` on the platform ($X^2(2) = 31.84, p < .001$). Post hoc analysis revealed statistically significant differences in information preferences for `onboard_crowds` from *at-the-station* ($Md = 4$) and *onboard* ($Md = 4$) ($p < .0005$) and *on-the-platform* ($Md = 4$) to *onboard* ($p < .0005$), but not *at-the-station* and *on-the-platform*. We found similar results for `car_crowds` from *at-the-station* ($Md = 4$) and *onboard* ($Md = 4$) ($p < .0005$) and *on-the-platform* ($Md = 4$) to *onboard* ($p < .0005$) even though the median scores are the same and there are no statistically significant differences for *at-the-station* and *on-the-platform*. The results suggest that information about overall onboard crowds and car-by-car distribution of onboard crowds is most relevant early in the passenger journey when arriving at the transit station or waiting on the platforms. After boarding the transit vehicle, the desire to know crowding information significantly declines.

There were also statistically significant differences for `platform_crowds` between *at-the-station* ($Md = 4$) and *onboard* ($Md = 3$) ($p = .004$), and between *on-the-platform* ($Md = 4$) and *onboard* ($p = .003$), but not between *at-the-station* and *on-the-platform*. Similar results were observed for `boarding_crowds` from *at-the-station* ($Md = 4$) and *onboard* ($Md = 3$) ($p = .006$) and *on-the-platform* ($Md = 4$) to *onboard* ($p = .001$), but not *at-the-station* and *on-the-platform*. These results suggest that crowding information onboard and on platforms is preferred at the beginning of the journey before boarding.

5.3.2 Health-related information impacting COVID-19 transmissions: Preferences for `public_health` information *at-the-station* ($Md = 5$), *on-the-platform* ($Md = 5$), and *onboard* ($Md = 4$) were highly scored at all stages. `cleaned_facilities` received a mean score of 4 at all stages with no statistically significant differences.

Information preferences for `temperature` ($X^2(2) = 37.27, p < .001$) and `humidity` ($X^2(2) = 36.88, p < .001$) onboard were statistically significantly different at different points in the passenger journey. Post hoc analysis revealed significant differences in `temperature` information preferences between at-the-station ($Md = 3$) and onboard ($Md = 2$) ($p < .0005$), and between on-the-platform ($Md = 4$) and onboard ($p = .02$), but not between at-the-station and on-the-platform. We observed similar result for `humidity` information *at-the-station* ($Md = 3$) and *onboard* ($Md = 3$) ($p = .002$), and *on-the-platform* ($Md = 3$) and *onboard* ($p = .002$), but not *at-the-station* and *on-the-platform*.

The results suggest that passengers would like to be informed about the public health and facility cleaning information throughout the passenger journey. However, the temperature and humidity information scored the lowest compared to all other information and appeared more relevant to passengers on board.

5.3.3 Other transit information: Other transit-related information that our participants would like to know is `schedule`, `security`, and `accessibility`. Preferences for `schedule` ($X^2(2) = 87.16, p < .0005$) were statistically significantly different between three passenger journey points. Post hoc analysis found statistically significant differences between *on-the-platform* ($Md = 5$) and *onboard* ($Md = 5$) ($p = .003$), and *at-the-station* and *onboard* ($Md = 5$) ($p < .001$), but not *on-the-platform* and *onboard*. These results suggest that although a transit schedule is highly preferred at all stages, it is more relevant for passengers before boarding a transit vehicle. `Security` and `accessibility` information received nean scores of 4 at all stages, but the differences were also not statistically significant.

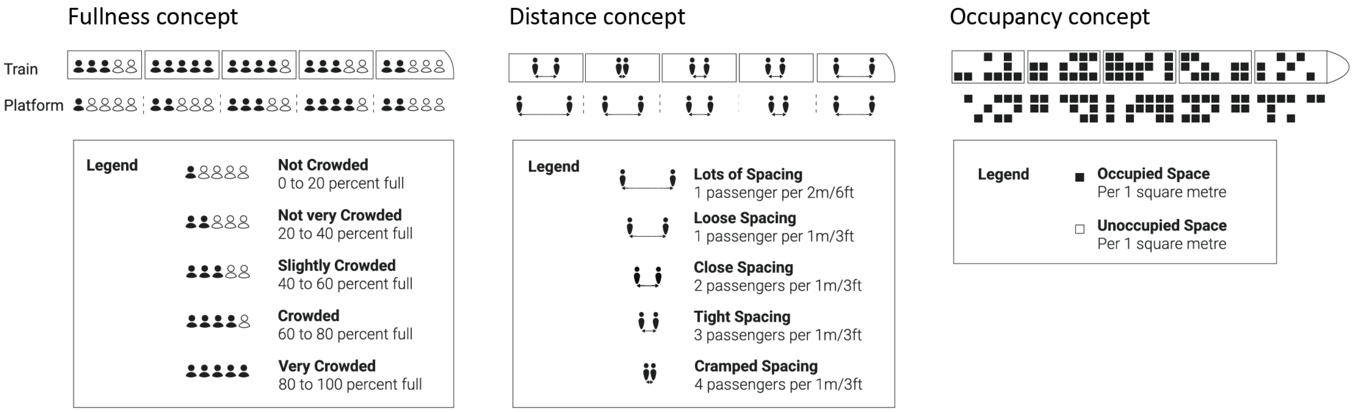

Figure 6: Three conceptual designs for public displays showing crowding information on a five-car passenger train and platforms.

5.4 Crowding Information Visualization on Public Displays

5.4.1 Concept Development Process. We created three crowding visualization concepts for public displays using the five-stage Design Thinking model [13] (Empathize, Define, Ideate, Prototype, and Test) in a collaborative process with the project team members and stakeholders. Most of the team members have a background in UX, user interface design, and human-computer interaction. In the *Empathize* phase, three researchers conducted auto-ethnography and observations of public transit riders. They rode public transit during rush and off-peak hours and documented their own riding experiences through notes, photographs, and observations of other passengers' behavior. The *Define* phase focused on creating user personas and user journey maps of public transit riders based on the information gathered. In the *Ideate* phase, we conducted collaborative ideation sessions with the project's team members and stakeholders to create various visualization concepts, and used established UX design methods and frameworks to critically assess them. For example, we used the value proposition canvas to identify how each idea will deliver value to passengers, Strength, Weakness, Opportunity, and Threat (SWOT) analysis framework to evaluate the solutions, and used scenarios and storyboards to map the user experience. Finally, the team discussed and voted on the three best concepts for *Prototype* to include in the survey for *Testing*.

The *Fullness* concept (Figure 6, *left*) uses a five-point figurative scale inspired by visual battery indicators to portray how full a space is in each passenger car. The *Distance* concept (Figure 6, *centre*) represents a safe physical distance of at least 2 metres between two persons according to physical distancing guidelines during the pandemic. We use arrows between simplified figure icons to communicate the distance between passengers. Finally, the *Occupancy* concept (Figure 6, *right*) is inspired by online seat selection maps (e.g., booking seats in commercial aircraft). The design resembles a heat map but without intensity dimensions. All visualizations were designed to support single-coloured LED or LCD displays commonly found in public transit worldwide. We chose to show minimalist designs in black and white, so that participants could focus on providing feedback on the design elements and usability.

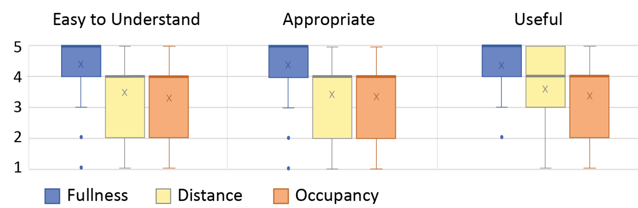

Figure 7: Usability comparisons of the three conceptual visualization designs.

5.4.2 Usability. The three concepts were included as part of the online survey described in the previous section. We clarified that the visualization is for public displays that are encountered around public transit stations and vehicles. The participants answered three statements on a five-point Likert scale from "Strongly agree" to "Strongly disagree" for each visualization concept: "The meaning of the visualization is easy to understand", "The visualization is appropriate for communicating the levels of crowding on public transit", and "The visualisation is useful for helping me avoid crowded areas on public transit". We used the Friedman test to determine if there were differences between conditions and followed up with post hoc pairwise comparisons with a Bonferroni correction for multiple comparisons.

Figure 7 shows participants' usability scores for the visualization concepts. We found a statistically significant difference for the three statements between conditions: easy to understand ($X^2(2) = 150.23, p < .0005$), appropriate ($X^2(2) = 147.63, p < .0005$), and *useful* ($X^2(2) = 128.01, p < .0005$). The *Fullness* concept scored a median value of 5 for all statements, suggesting that it is the easiest to understand, highly appropriate for communicating crowding, and very useful for helping passengers avoid crowded areas. *Occupancy* and *Distance* concepts were also understandable, appropriate, and useful, with a median value of 4 for all three statements. Pairwise comparisons further revealed a statistically significant difference for all three statements between *Fullness* and *Occupancy* ($p < .0005$) and *Fullness* and *Distance* ($p < .0005$), but not between *Occupancy* and *Distance* concepts.

5.4.3 Qualitative feedback. We followed the participants' usability ratings with qualitative feedback to gain further insight into their reasoning. Here, we summarize the most important points.

Fullness: Illustrating how full a train is using human figures appears to be intuitive to understand because "people generally understand human-like figures". The drawback of using human figures is that *"it may not be the most precise way of measuring the amount of people"* and *"the amount of people icons can give a false sense of low level of crowdedness if one doesn't read the legend..."*

Distance: The participants found that arrows representing the distance between passengers are *"an interesting and simplified way to explain crowdedness, but could be mistaken for how closely people are allowed to stand instead of how crowded a space is"*. As our intention, the visualization reminded the participants of physical distancing. However, the participants felt that physical distancing and crowdedness *"could mean the same thing, but it doesn't 'feel' the same."* The participant explained, the Distance concept *does not guarantee that that's how much space will be between you and another person given that it depends where everyone is located and if everyone is trying to maintain an even amount of space between one another.* Further, the actual spacing between passengers depends on whether people adhere to physical distancing guidelines, which could be different across regions and countries, and change overtime.

Occupancy: Using coloured square symbols to represent occupied physical space provided a more detailed *"sense of how crowded the spaces are and where there is space." "I like that you can choose a spot that could possibly be away from others,"* said another. Depicting where a space is occupied helped the participants think about where they want to stand or sit: *"I like that at a glance, I can see where to plan to stand based on the least crowded areas of the image."* In particular, *"you can see exact available spaces, you can plan if you want to get the vacant window seat or a seat closer to a door."* However, the participants found *"The squares are a little hard to decipher and the black and white makes it a bit harder to read."* The participants suggested adding the location of the doors and *"numerical counts of how many passengers are currently in each car..."* to give a general sense of crowdedness.

Other Considerations: Simple and quick to read information appears to be an important factor for users of public transit when in a hurry to get to their destination. *"I'm in a hurry or absent minded... while catching a bus,"* another explained, *"I would rather take a quick look at the visualization and be able to tell right away which train has the most empty space."* Several participants recommended reducing the number of crowding levels from five to three to make the differences more obvious, because *"the amount of time is limited to view the legend in that fast paced environment."*

Many participants disliked the quantification of space using numerical measurements, such as percentages, metres, and feet in the legends to describe crowding levels because it requires literacy in math and a higher cognitive load. *"So many people are already functionally illiterate and scared of anything that resembles math"* explained one participant. Even percentages can be difficult for some to discern; *"For those who hate math. me included, calculating the 'percent' full (Fullness) will be frustrating and too inconvenient and time consuming."* For the Distance concept, the participants *"dislike this visualization for emphasizing upon the idea of distance [because] not everyone is capable of digesting the meaning behind... the measurement of 1m or 3ft."* Further, the visualization should be considerate of persons with reading disabilities. *"I have dyslexia,"* said one participant, *"so visualizations like [Occupancy] are hard for me to grasp, but having the contrast between an open space and filled space is helpful to gauge overall crowdedness."*

Overall, the Fullness concept ranked high in usability. The Distance and Occupancy concepts also scored reasonably well. However, qualitative feedback suggested that Distance concept would not scale beyond the pandemic context as physical distancing guidelines change overtime and become obsolete.

6 FIELD USER STUDY

Based on the feedback from the survey, we improved the *Fullness* and *Occupancy* concepts, based on which we created two public display prototypes, and conducted a field study at three light rail train stations to explore how the prototypes influence public transit riders. Transit riders viewed the prototypes on train platforms before boarding, reported their subsequent behavioral intentions based on crowd levels, and provided their feedback about the visualizations.

6.1 Concept Improvement

We improved and tested the *Occupancy* and *Fullness* concepts from the survey. We removed the *Distance* concept because participant feedback indicated that physical distancing guidelines change over time and may be irrelevant post-pandemic. For both tested concepts, we removed the quantitative metrics because our results indicated that they are difficult to comprehend. The colour choices (orange on black background) were adapted from existing LED displays at the stations where the study was conducted to integrate our design into the transit environment.

For the *Occupancy* concept, we simplified the square symbols to reduce visual complexity, and added the locations of the doors and platform. Our survey results suggest that passengers perceive a space to be crowded or very crowded from approximately 2 passengers/m^2 to 3 passengers/m^2. Since our field study was conducted in June, 2022, we selected the upper threshold of 3 passengers/m^2 to reflect an increase in public transit ridership since the height of the pandemic. In our revised design, we divide the occupancy of the train into 3 by 5 squares; a square symbol is highlighted when there are three or more passengers occupying the space. To keep the design simple, it does not visually distinguish between seating and standing space. However, the row of squares along the windows suggests seating areas, and the row in the center of the vehicle suggests standing space. The design can be adapted to different types of passenger trains as the approximate configuration of seating space (along the windows) and standing space (in the middle aisle) are the same between different types of passenger train (e.g., light rail, subway, long-distance train), even though the exact seating configurations vary.

For the *Fullness* concept, our survey results suggested that communicating the crowd density beyond 3 passengers/m^2 could be unnecessary because all levels above the threshold would be perceived as crowded. Therefore, we reduced the level of crowding from a five-point scale to a three-point scale to communicate when each train car is "not crowded", "slightly crowded", or "crowded" to help passengers make boarding decisions. The "crowded" level represents around 3 passengers/m^2; "slightly crowded" represents around 2 passengers/m^2; and the "not crowded" level represents 1 passenger/m^2 or less.

6.2 Prototype Implementation

We acquired and processed a subset of sensor data from the local transit authority that tracks the number of passengers who get on and off the train at each door on the local trains. The dataset contained the vehicle number, sensor ID, arrival and departure times, total number of passengers in/out at each door, and latitude and longitude from November 2019 (i.e., before the pandemic) and November 2020 (i.e., during the pandemic).

To map the crowding levels in our visualizations, we used the dataset to estimate the total number of passengers on the train and the number of passengers in each car. We processed a subset of the dataset during local rush hour between 3 pm and 5 pm (both before and during the pandemic) using a customized Python script. Next, we animated the visualizations based on timestamps in the data to simulate real-time crowding information. The visualizations were displayed in orange colour on a black background to match the existing designs of public displays at the stations.

We separated segments to cover three crowding scenarios: S1) *uncrowded train* showing reduced capacity, S2) *slightly crowded train* showing "regular" crowding levels during peak hours, and S3) *very crowded train* based on S2 crowding levels increased by 50% to simulate over-crowding.

6.3 Field Deployment and Recruitment

We obtained a work permit and completed safety awareness training through local transit authorities, and obtained ethics approval from our academic institution. We set up our information visualization displays at three light trail train stations that serve as local transit in the city centres with 19 stations between two connected mid-sized cities that serve a population of approximately 600,000 people. All tested stations are above ground. Two of our test stations connect to the main bus system in the region and the largest shopping centres, and a third station is at a university. Especially because public deployments are prone to errors and other issues [38, 49], we first conducted a pilot study with three participants to test our study protocol and equipment. Based on the pilot, we made minor adjustments to our equipment (e.g., brightness and contrast of the display, recorder audio settings), and found that no changes were required to our study protocol. We collected data for five days during the first week of June 2022.

We set up a flatscreen display mounted on a portable stand showcasing our prototypes on the train platforms for a few hours each day during peak hours. In addition, we placed recruitment posters near the study area. Passengers indicated their interest in participating by giving their informed consent. Using a within-subject design, the participants viewed both visualization concepts one at a time in randomized order on the display and participated in a contextual interview for each visualization. They described how they would interpret and use the visualizations to avoid crowded areas, what they liked or disliked about each visualization, and answered three usability questions on a five-point Likert scale on the understandability, usefulness, and appropriateness of the visualizations for crowding information communication. The participants then compared the two visualizations and explained which one they preferred. Additionally, we inquired about the best location to display crowding information on a public display. Lastly, the participants answered basic demographic questions (gender, age, and frequency and reasons for taking public transit). Each study session took approximately 10 minutes, and participants were remunerated $5 cash. The sessions were audio-recorded with timestamps and transcribed to accurately document the responses to the questions.

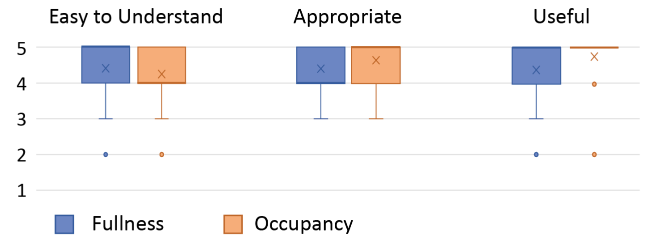

Figure 8: Usability comparisons of the Fullness and Occupancy visualizations.

6.4 Demographics

A total of 44 participants (20 men, 24 women) recruited on site at the three stations participated in our study. Most participants (n = 32, 72%) were between the ages of 18 and 29, but five (11%) middle-aged individuals ages 30-49, five (11%) youths ages 13-17, and two (4%) older adults ages 60-74 also participated. Almost half (n = 21, 48%) of the young adults and the older youth had a high school degree or equivalent. Eight (18%) participants had a Master's degree, another eight (18%) had a Bachelor's degree, and three (7%) had a college degree. As expected, younger youth (n = 3, 7%) had less than a high school degree. One participant had an unspecified "other" professional degree.

Most of the participants were frequent riders of public transit, with 57% (n = 25) using it at least once a day and another 39% (n = 17) using it at least once a week. Only 5% (n = 2) used it at least once a month. More than half took public transport to get to work (n = 26, 59%) and school (n = 24, 55%). More than a third used it to buy groceries (n = 17, 39%) and for social and recreational purposes (n = 16, 36%). A quarter said that they use public transport for irregular trips (n = 11, 24%), and a few for medical-related trips (n = 3, 7%), such as to the hospital.

6.5 Results

For both visualizations, participants answered three statements on a five-point Likert scale from "Strongly agree" to "Strongly disagree" related to three usability dimensions from Section 5.4.2: Easy to understand, appropriate, and useful. We conducted Wilcoxon Signed-Ranked tests to determine if there were differences between the conditions in any of the dimensions. Difference scores between the two conditions were assessed by a histogram showing an approximately symmetrically distributed curve. Data are median unless otherwise noted.

Both visualizations were rated highly in all dimensions (Figure 8). The *Fullness* concept received a median score of 5 for understandability, while *Occupancy* was rated 4. Conversely, the *Fullness* concept received a median score of 4 for appropriateness, while *Occupancy* was rated 5. For usefulness, both conditions scored 5. No statistically significant differences were observed for understandability or appropriateness, however, there was a statistically significant median increase in usefulness scores for *Occupancy* compared to *Fullness* ($z = 2.43, p < .05$).

When asked which visualization is preferred to help avoid crowding, 64% ($n = 28$) preferred the *Occupancy* visualization and 36% ($n = 17$) preferred the *Fullness* visualization. Feedback from participants found both visualizations useful for making decisions about whether they should wait for the next train due to crowding. However, the *Occupancy* visualization was more useful to support passengers' boarding decisions. For example, a participant said:

> *I like the fact that the visualization is using blocks. It's an easier way to represent the capacity or more so the space. I can have a better understanding of the spatial awareness I'll have when I'm on the train.*

Most people interpreted the visual representation as *"The yellow boxes represent crowded spaces, while empty represents vacant spaces in between…"* To improve the *Occupancy* visualization, participants suggested visually differentiating between the available seats and the standing space, as some interpreted the square symbols to represent the available seating on the train. Echoing the feedback from our survey for the *Fullness* visualization, some participants expressed concern that descriptors such as "crowded" can be subjective compared to communicating the actual space occupied. A participant made further comparisons between the visualizations:

> *I can't plan out where I'm going to sit in advance, which is I feel like a nice thing to do, especially while you're waiting for a train every 10 minutes. I feel like the [Occupancy visualization] allows me to do that, whereas [in the Fullness visualization] I have to figure that out while I'm on the train, which is just inconvenient…I feel like that's an important part, especially in European countries where LRT is more utilized…I feel like incorporating aspects that would allow users to do things that they could do on the train while being on the platform would be a better way.*

Although the *Occupancy* visualization conveyed more information to inform passengers' boarding decisions, some felt the visualization required more cognitive load and time to read and understand it. The *Fullness* visualization, on the other hand, is "simple" and "straightforward" and requires only "a passing glance" to understand. This suggests trade-offs between information simplicity and degree of accuracy.

7 DISCUSSION

Our research focused on investigating passenger perceptions of crowding, and information preferences and crowding information visualization on public displays at transit stations. In this section, we consolidate the results from our online survey and field study to draw design implications for communicating crowding information to support decision making and promote a sense of safety.

7.1 Design Implications for Public Transit

7.1.1 Access to crowding information makes passengers feel safer. To create a pleasurable and safe travel experience, it is critical to investigate elements of the user experience associated passenger needs [24]. Overall, we found that there is a demand for crowding information, partly due to changes in people's perception of public transit safety since the onset of the pandemic. Specifically, commuters are more sensitive to crowding and want information on vehicle density. The majority (86%) of our participants said that having access to crowding information will make them feel safer taking public transit, and more than half (59%) said that the information will motivate them to take public transit more often.

Our survey showed that providing simple information visualizations showing occupied space on the vehicle is a promising approach to crowding communication. Our field study provided encouraging feedback from passengers that having access to the information will allow them to decide what sections of the arriving vehicle to board and where to sit. The information can significantly reduce congestion in the vehicle experienced by passengers [66] and promote a safer environment for public transit riders. Previous studies [57] suggest that passengers who are more conscious of risks relating to COVID-19 have strong preferences to sit where neighbouring seats are unoccupied, while passengers who are indifferent to those risks only slightly prefer unoccupied seats around them compared to pre-pandemic. Hence, we believe that crowding information will be particularly useful in reducing safety concerns for risk-conscious passengers.

7.1.2 Crowd density communications should be based on passenger perceptions. Although a light rail train can carry around 200 passengers [21] (approximately 40 passengers per car on a five-car train), our results suggest that passengers' tolerance for crowding is lower. Capacity information is important for operational procedures, but may not fully capture and convey the ways in which passengers experience crowded situations [62]. Research on passenger crowding usually involves measurement of crowding based on density (i.e., space limitations) but rarely considers the role of psychological factors in crowding metrics [35, 67]. Our survey results that informed our designs found that most passengers perceived a train to be crowded at around *3 passengers/*m^2 and some are deterred from boarding at around *2 passengers/*m^2, which is approximately 25% lower in density (around 30 passengers per car) than the recommended optimal passenger density of a light rail train [21]. The results suggest that crowd density communications should be based on passenger perceptions and crowd tolerance, which could change over time, and not on train metrics that define optimal rail passenger capacity.

7.1.3 Provide crowding information varying in detail at different stages of the trip. Previous studies of public displays in the transit context identified challenges in their design due to users ignoring them [27, 43, 44]. Therefore, the visibility, position, content, and functionality of the display need to be carefully considered [26, 50]. Based on our survey, our participants preferred various information on public displays at different stages in the user journey (see Figure 5). In particular, they preferred to receive information about crowds at the beginning of the passenger journey when they arrive at the transit station and wait on the platforms for the next train. Hence, the optimal location to display crowd information on public displays is outside of the transit stations and on the vehicle platforms. Similar technology applications [17] have demonstrated passenger preference to view up-to-date transit information on public signage over mobile applications to navigate physical spaces like transit stations. We recommend communicating general crowds on trains when passengers first arrive at the station and providing information about car-by-car crowds on the platforms, as users' needs change depending on context [51]. Travelers on the move through the transit station may not pay close attention to detailed crowd information, so easy-to-understand information at a glance is essential [27, 44]. Passengers have more time waiting on the platforms, so more detailed information about the distributions of car-by-car crowds in the next train, such as our *Occupancy* concept, will be more useful in informing boarding decisions.

After boarding the transit vehicle, the desire to know crowding information quickly declined. Only 42% of the participants would like to know about overall crowds on board at this stage, compared to 92% before boarding. Similarly, car-by-car crowds were less relevant after boarding, as approximately half of the participants indicated that they would like to know the information compared to 78% before boarding. This decline is likely because passengers can physically see and experience how crowded it is on board. The crowdedness of other train cars may be irrelevant since passengers rarely change cars after boarding. However, other information like schedules, accessibility and security information, public health information, and when the facilities were last cleaned remained desirable onboard the train.

From a user interface design perspective, simple visual presentations showing how full the vehicle is and showing occupied seats onboard were the easiest for passengers to understand. We found that quantitative metrics (e.g. percentages, distance) are more difficult to interpret and less accessible, which may also link to the lower socioeconomic and education status of some transit riders [2]. Previous research supports our findings, which hypothesize that quantitative metrics like passengers per square meter do not fully capture and convey the ways in which passengers experience crowded situations. Furthermore, our participants indicated that vague linguistic descriptors like "crowded" are subjective. For example, what one passenger perceives as "slightly crowded" might feel "very crowded" to another passenger. Therefore, we recommend pairing text descriptions with visual representations of the density of the crowd to communicate the information.

7.1.4 Use public displays and signage for crowd navigation. In addition to addressing passengers' safety concerns, providing accessible crowding information on public displays can guide travelers through complex transit environments and enhance their understanding of the space, thus creating a positive arrival, navigation, and boarding experience. Our information visualizations interface can be expanded into a crowd navigation and wayfinding system to help people reach their destination quickly and safely. For example, our visualizations can be paired with adaptive directional arrows in large metro stations and train platforms that dynamically change to diverge traffic flow and prevent crowding.

Our study focused on studying crowding visualizations in public displays. However, a mobile app interface can also be developed with our visualizations. Similar technology applications like Google Maps [61] are expanding features that show live crowdedness information on train lines and down to the general level of the car. We show that visualizing the physical occupied space onboard could be a more precise alternative to help passengers navigate crowdness on trains. We emphasize that although passengers often use their own mobile devices to receive real-time information related to their travel [3, 16], accessible digital public displays that show travel information on site are still critical to passengers. For example, a study [17] found that digital signage in a transit station is easier to use than similar information in a companion mobile app because it is a more natural way to navigate physical spaces. Another study found that despite smartphones, public displays are still used to access information [52]. Furthermore, people also often carry items when moving in urban spaces [36, 37], and this is especially true in transit settings where people may carry heavy items like luggage, limiting their ability to access their smartphones. Other technical issues, such as the loss of connectivity in underground metros, can also degrade the performance of mobile applications. Therefore, we propose that mobile applications for crowd prediction are optimal during trip planning, and public displays and signage are more suitable for crowd navigation on site.

7.2 Limitations and Future Work

Our in-person field user study was conducted at local light rails stations, so our study was limited to the metropolitan areas on the local light rail line. Due to deployment limitations of the field study, we could not study the effect of real-time crowding information on passengers' behavior. As an alternative, we used historical passenger counter data to create visualization simulations of crowds to elicit passengers' reported behavior in response to the information. The information visualizations were tested over one week at three train stations in a mid-size city. Therefore, the longitudinal impact of real-time crowding information on passenger travel behavior will need to be studied under different locations and settings, and in major metro stations with various passenger traffic and density.

Participants' behaviors are self-reported and hence may not always reflect their real behavior. Since our field study recruited participants on site through posters that attracted interested volunteers, participants in our sample are more likely to be transit enthusiasts or optimists. Participants in our survey were recruited from North America to control reasonably consistent perceptions about when the pandemic began. However, the decline in transit ridership during the pandemic is a worldwide phenomenon [45, 56, 68], and therefore, we are confident that the insights from this work will contribute to a deeper understanding of crowd perceptions and information preferences in the transit context.

Advances in digitization and the Internet of Things (IoT) in public transportation create opportunities for both travellers and transit operators [11]. Crowd visualizations supported by real-time data could help transit operators and planners manage and monitor traffic flow in public transit, particularly during rush hour. It could enable proper allocation of resources for service delivery, and inform emergency planning and law enforcement, such as allocating more trains to serve crowded routes, dispatching security personnel and planning fire safety responses. Outside the public transit context, event organizers, municipalities, and other organizations can use crowd visualizations to control crowds during events or large traffic periods, for example, to detect overcrowding under capacity limits and inform the allocation of resources for service delivery, personnel management, emergency response, and security.

Our paper showed that there is a need to study *how* and *when* crowding information should be provided to maximize its utility. The key is to provide real-time data designed with privacy in mind that can be translated into usable insights to inform travel decisions. For example, we are currently developing an infrared camera-based crowd detection system powered by 5G wireless networks to provide real-time crowd density tracking on transit vehicles and relaying information on public displays at transit stations. Any crowd detection and prediction system should apply anonymization technology; if identifiable information such as location history data is collected, differential privacy techniques should be applied to ensure that the data remain secure and private.

8 CONCLUSION

Our research studied the public transit passengers' experience with crowding and crowding information. Using a survey and field user study, we researched the public perception of crowding during public commutes and explored what types of information would be useful to support decision-making and promote a sense of safety. Although commuters will return to public transportation post-pandemic, we suspect changes in public perception of transit safety relating to crowding will be everlasting. Transit crowding information encourages and empowers hesitant riders to anticipate crowds, allowing them to navigate fewer crowds while they take public transit. When combined with other critical travel information like transit schedules, our proposed crowding visualization concepts can translate passenger density data into real insights, which could benefit both passengers and transit operators to provide a safer, comfortable, and more enjoyable mode of public transportation.

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