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Effects of COVID-19 on rail passengers’ crowding perceptions

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A R T I C L E   I N F O

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A B S T R A C T

Understanding changes in travel behavior during the spread of pandemic diseases such as COVID-19 is important to develop a resilient transportation system. Since one of the most important ways to prevent the spread of this virus is to keep a safe distance from other people (i.e. social distancing), it has implications for the operations of public transportation as compared to other modes of transportation due to the confinement of a large number of passengers in enclosed space. This study investigated the effect of the spread of COVID-19 on crowding perception and crowding disutility in metro rail system of Tehran. Two surveys were conducted before and during the COVID-19. The stated preference data were analyzed by mixed logit models with the lognormal distribution. Results revealed that the value of crowding increased during the pandemic. Tracking the changes of crowding perception caused by COVID-19 shows that low comfort scores were observed at crowding levels where seats were taken, and the density of standees was high (i.e. not possible to maintain social distancing). During the outbreak of COVID-19, crowding has more disutility for rail passengers and the value of having a seat while traveling increased. Understanding passengers’ perceptions of crowding as examined in this study will assist transport operators, and planners maintain the critical functionality of public transport systems and manage risks of mass transportation during the pandemic and beyond.

1. Introduction

In December 2019, the first case of novel coronavirus (COVID-19) was reported in Wuhan, China, and three months later, in March 2020, the World Health Organization (WHO) declared COVID-19 as a pandemic disease (WHO, 2020). After quarantine was lifted in many countries, traffic was gradually resumed, but the overall number of trips decreased (Kanda and Kivimaa, 2020). Meanwhile, the reduced share of public transport (PT) is lower than other modes of urban transportation (De Vos, 2020; Gutiérrez et al., 2020; Kanda and Kivimaa, 2020). Fig. 1 shows the decline in metro ridership in some of the world’s major cities by the end of 2020. Opinions such as people’s perception of PT as a virus transmission agent (Gutiérrez et al., 2020) and the conflict between social distancing and the concept of PT (Musselwhite et al., 2020) made less-sustainable modes of transportation, such as private cars, the main mode of transportation for many people in society. The reason for this could be the protection of the car from the person against other road users (De Vos, 2020). Reduced PT ridership and people’s increased willingness to purchase and use private cars should not lead to a reduction in PT service during this period because it exacerbates inequality in society (De Vos, 2020; Gutiérrez et al., 2020). Since the working class does not have telework abilities compared to the more affluent classes of society and has to go to work in person, and it is

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also more difficult for them to access a private car, decreased PT service during this period can directly affect this group and increase inequality in society. Perceptions of crowding in PT compared to other attributes related to this service has received the greatest impact from the spread of COVID-19 as a contagious human-transmitted disease. Thus, researchers should recognize the changes in the travel behavior of individuals and offer their suggestions to policymakers to provide better and safer PT services in this period.

Congestion in car traffic increases travel time, while in PT and especially rail-based modes, congestion causes in-vehicle crowding (Haywood and Koning, 2015). Yap et al. (2020) also stated that the effect of crowding when traveling with PT is behavioral and increases the perception of travel time by passengers. Since travel time perception increases as congestion levels increase, crowding can be referred to as a generalized time component (Basu and Hunt, 2012). Crowding is displayed in various forms, the most common of which are load factor (LF) and density of standees (in pax/m²). Using LF to show crowding has the advantage of simplicity in calculation and the possibility of examining the effect of crowding before the seats are filled (Tirachini et al., 2016), but its disadvantage is the strong dependence on vehicle’s interior layout (Horcher et al., 2017), which makes the results not generalizable to other trains with different designs. For this reason, Wardman and Whelan (2011) consider the superiority of density of standees to represent crowding. To measure the value of crowding (VOC), in addition to the trade-off between crowding and travel time (Horcher et al., 2017; Kroes et al., 2014; Tirachini et al., 2017; Whelan and Crockett, 2009; Yap et al., 2020), the effect of willingness to pay (WTP) for reducing crowding was also assessed in monetary units (Basu and Hunt, 2012; Batarce et al., 2015; Douglas and Karpouzis, 2006; Haywood and Koning, 2015; Hensher et al., 2011; Prudhomme et al., 2012). However, Whelan and Crockett (2009) preferred the time-dependent aspect of VOC evaluation, stating that crowding evaluation is more tangible as an incremental effect on travel time perception.

Li and Hensher (2013) recommended assessing VOC with both subjective and objective measures. Subjective measurement of crowding means examining the psychological aspects of crowding and how it is perceived by travelers. In contrast, objective measures of VOC are the products of discrete choice models, such as WTP for reducing crowding, value of travel time savings (VTTS) in crowded situations, crowding multiplier (CM) and standing multiplier (SM). WTP is the ratio of crowding marginal disutility to price/cost marginal disutility. VTTS is the ratio of the in-vehicle travel time coefficient to the monetary unit coefficient used in the model, which is usually calculated in both crowded and uncrowded situations. Crowding multiplier (CM) or time multiplier is the ratio of VTTS in the crowded situation to VTTS in the uncrowded situation. In other words, this coefficient is multiplied by VTTS of the uncrowded situation to achieve the VTTS of the crowded situation (Tirachini et al., 2013). The CM is usually expressed in two forms, sitting CM and standing CM, which indicate how much the travel time perception changes at different crowding levels for sitting and standing passengers. Finally, the standing multiplier (SM) (i.e. standing penalty or value of having a seat) is the ratio of standing CM to sitting CM, which shows how much unavailability of seats and standing increases the VTTS in the same crowd. This parameter usually increases for longer trips such as sub-urban and interurban trips (Tirachini et al., 2017).

After the arrival of COVID-19 disease in Iran, various lockdown measures were taken to control the disease and to break its transmission chain. One of the major measures is the classification of cities into 4 groups of red, orange, yellow and blue (based on the number of COVID-19 patients), and enact laws for prohibitions of travelling to and from red and orange cities. Jobs were also divided into four groups, and some of these groups were forced to shut down during certain periods. In addition, the use of masks is mandatory for people in public places. Also, in stage 4 of lockdown, the traffic ban has been established from 9 pm to 4 am. In the case of the PT system, however, the solutions adopted do not seem appropriate as the enforcement measures are not adequately followed during peak hours. For example, in the Metro, although the seats are marked with a cross sign alternately to prevent passengers from sitting on them, it is not strictly followed as the volume of passengers increases during peak hours.

The contributions of the study are twofold. First, this study assesses VOC and provide CMs in the metro system of a developing country like Iran.
country, Iran, as there are fewer studies on passengers’ crowding perceptions in developing cities or countries. Second, it examines the changes in the crowding perception and travel behavior of metro rail passengers before COVID-19 and during COVID-19. The contribution of this study is that it is one of the rare studies that tracked the changes in the crowding perception and travel behavior of metro passengers in a pandemic. The findings from this study will inform policymakers of these changes so that a better and safer metro service may be achieved in COVID-19 and post COVID-19 period. This article is organized into 7 sections. Section 2 provides comprehensive literature on measured VOC in the PT system of different cities around the world. Section 3 describes the case study, data collection and sample characteristics before and during COVID-19 pandemic. Section 4 introduces the discrete choice models used in the analysis of the stated preference (SP) data to measure crowding disutility and related parameters. Section 5 presents the results related to passenger crowding and the measurement of crowding disutility and compares these results before and during COVID-19 pandemic. Section 6 discusses the results by providing a comparison between the obtained results in Section 5 and measured VOC in the literature before and during COVID-19 and proposes policy implications for PT administrators to better serve the metro system during the COVID-19 pandemic. Finally, in Section 7, the conclusions are stated.

2. Literature on value of crowding (VOC)

This section reviews objective and subjective measurements of VOC along with the effect of COVID-19 on VOC under different subsections as presented below:

2.1. Objective measurements

The UK Rail system has been the subject of many studies for assessing VOC. Wardman and Whelan (2011), in their meta-analysis, reviewed 17 articles from 20 years of UK rail industry and stated that the average of sitting CMs is 1.19 and the average of standing CMs is 2.32. Whelan and Crockett (2009) showed that at crowding of 6 pax/m² the sitting and standing CMs for London SE rail system are 1.54 and 2.21, respectively. By dividing these two values, the SM can be expressed as 1.44.

Douglas and Karpouzis (2006), Hensher et al. (2011) and Tirachini et al. (2013) measured VOC for the Sydney PT system. Douglas and Karpouzis (2006) by conducting a SP survey for the rail system showed that CM for crowded seats is 1.17 and standing for 10, 15, and 20 min have CMs of 1.34, 1.57 and 1.81, respectively. Also, CM for 10 min of standing in the crowded condition is equal to 2.04. This article also showed that crowding adds $1.01/hr ($AUD in 2003) to the VTTS of uncrowded condition. Furthermore, VTTS at uncrowded condition, 100% LF and 200% LF are $8.45, $8.84 and $12.05, respectively ($AUD in 2003). Finally, it was concluded that women have higher VOC when standing in a crushed condition. Hensher et al. (2011) also conducted a SP survey for the metro and bus system. They showed that WTP for a 30 min trip with a 50% probability of having a seat is $2.97 ($AUD in 2009); while this parameter increases to $6.08 ($AUD in 2009) for a 75% probability of having a seat. Finally, Tirachini et al. (2013), by conducting a SP survey for metro and bus systems, showed that increasing crowding by 1 pax/m² increases the CM by approximately 0.3; so at a density of standees of 6 pax/m², the CM equals to 2.8. The average VTTS also shows an increase of approximately $2/h ($AUD in 2009) for adding one passenger per m².

Prud’homme et al. (2012), Kroes et al. (2014) and Haywood and Koning (2015) measured VOC in the Paris Metro system. Prud’homme et al. (2012), by conducting a SP survey, showed that more congestion and longer trips increase the WTP for non-congestion trips. Also, an increase of 1 pax/m² of crowding increases the cost of travel (i.e. welfare loss) by €0.68/trip (€EUR in 2009). Kroes et al. (2014), by conducting both SP survey and RP survey (for verification of results), stated that the sitting and standing CMs at 4 pax/m² (i.e. 250% LF) are 1.39 and 1.55, respectively. The SM was also estimated at 1.12 at this crowding level. Finally, Haywood and Koning (2015), by conducting a SP survey showed that CM at 6 pax/m² is equal to 1.57. They also calculated WTP for crowding, showing that the external cost of increasing a passenger on the Paris Metro is €0.63 (€EUR in 2011).

Batarce et al. (2015), Batarce et al. (2016) and Tirachini et al. (2017) measured VOC in PT system in Santiago, Chile. Batarce et al. (2015), with mixed data analysis (RP and SP) of bus and train systems showed that the marginal disutility of travel time at 6 pax/m² is almost two times the marginal disutility of travel time at 1 pax/m². Furthermore, VTTS at 6 pax/m² is equivalent to 5.894 CLP (Chilean pesos) (2015$USD10.40) per hour, which is almost twice as much as VTTS at 1 pax/m². Batarce et al. (2016) also showed that the disutility of travel time at 6 pax/m² is 2.5 times that of the seats are available (i.e. CM = 2.5). Finally, Tirachini et al. (2017), using SP survey results in the metro system, obtained a sitting CM of 1.67 and a standing CM of 1.98 at 6 pax/m² density of standees. The SM was also calculated to be 1.18 at this crowding.

Björklund and Swärdh (2017) measured VOC in PT system by conducting SP survey in Stockholm, Gothenburg and Malmo in Sweden. The sitting and standing CMs for pooled data at a density of standees of 4 pax/m² were 1.13 and 2.15, respectively. At the crowding level of 8 pax/m², the sitting and standing CMs were 1.48 and 2.94, respectively. Finally, they showed that despite the less perception of VTTS for older passengers (+40) and passengers with the trip purpose other than working, they significantly experienced more standing CM.

Although the majority of researches on VOC assessment have been done with SP data, few studies (Hörcher et al., 2017; Tirachini et al., 2016; Yap et al., 2020) measured VOC using RP data. These studies typically used data from automatic fare collection (AFC) and automatic vehicle location (AVL), and the trade-offs between the attributes influencing PT route choice such as travel time, waiting time, transfers and crowding are obtained through smart card transactions. Tirachini et al. (2016) performed a RP survey using smart card transactions data to measure VOC in Singapore metro system. The results showed that the SM for the average crowding of the Singapore metro is 1.18–1.24, and with a crowding level of 3 pax/m², this parameter is 1.55. Hörcher et al. (2017) used AFC and AVL data to examine the revealed behavior of rail transit passengers in Hong Kong. A passenger-to-train assignment model was also
designed for this data. The results showed that the standing penalty for metro passengers is 26.5% (i.e. $SM = 1.265$), and adding one passenger per $m^2$ adds 11.9% to the travel time multiplier. Thus, the sitting and standing CMs at the density of standees of 6 pax/$m^2$ are 1.71 and 2.17, respectively. Yap et al. (2020) conducted a RP survey to measure the CMs for trams and buses in the Netherlands. 28-day AFC and AVL data and smart card transactions were used for this purpose. The results showed that the CM is 1.16 when all seats are occupied (0 standing passengers per $m^2$), and adding one passenger per $m^2$ causes to a linear increase of 0.06 in CM. Thus the CM at the density of standees of 6 pax/$m^2$ is equal to 1.52.

The review of articles in the literature illustrates that almost all the VOC assessment surveys have been conducted in developed cities. The only developing city for which the VOC has been measured is Mumbai, India. Basu and Hunt (2012) and Sahu et al. (2018), by conducting SP surveys for the rail transit system of this city, calculated the crowding disutility, both in terms of monetary and time-dependent units. Basu and Hunt (2012) examined the effect of headway and travel time on sub-urban train mode choice at different levels of crowding. The results showed that the passenger WTP for a decrease of 1 pax/$m^2$ equals 0.70–0.80 Rupee (2012$USD0.02). Furthermore, passengers with lower incomes have more WTP for reducing headway and crowding. Sahu et al. (2018), by conducting a SP survey, showed that crowded seating (seats fully occupied with free space for standing) adds 0.81 min to each minute of travel time perception (i.e. $CM = 1.81$). Also, when standing for 10 min at density of standees of 7–9 pax/$m^2$ and at super dense crush crowding (13–15 pax/$m^2$), the travel time perception increases by 94% (i.e. $CM = 1.94$) and 282% (i.e. $CM = 3.82$), respectively. Finally, they concluded that female passengers have more disutility for crowding.

### 2.2. Subjective measurements

Cox et al. (2006), by introducing a model for subjective measurement of crowding, stated that factors such as lack of control and unpredictability of events moderately affect the relationship between high passenger density and perception of the situation as crowded. Ultimately, this perception leads to stress in the person and subsequent health problems. Mohd Mahudin et al. (2012) showed that the psychological aspects of crowding, crowding environment, and passenger density have a direct effect on passenger reaction to a crowded situation, and this reaction eventually leads to feelings of stress and exhaustion in the passengers. Finally, Haywood et al. (2017) investigated the effect of eight causes of crowding discomfort on reducing comfort satisfaction. They categorized these eight dimensions into five categories: stress and lack of control due to closeness to others (psychological category), fatigue and pain due to standing up as the seats are taken (physical category), noise and odor caused by crowding (sensory category), time loss upon slower boarding and alighting (friction effect), and waste of time due to the inability of the passenger to perform his/her tasks (temporal category), and ultimately, increased likelihood of crime or falling down in a crowded vehicle (risky category). Finally, it was concluded that the three most common causes of crowding discomfort are dissatisfaction with standing and not finding a seat, less opportunity to make better use of travel time and physical closeness to other passengers.

![Fig. 2. Public transport network in Tehran. (Derived from Esmailpour et al. (2020)).](image-url)
2.3. Effect of COVID-19 on VOC

Only few articles have examined the effect of an epidemic on VOC and the perception of crowding (Cho and Park, 2021; Shelat et al., 2021). With the start of the COVID-19 pandemic, it is expected that the studies investigating the effect of the pandemic on VOC to grow in future. Shelat et al. (2021) by conducting a SP survey for train passengers in Netherlands after the end of the first infection wave (when the initial restrictions were lifted); investigated the behavioral effects of COVID-19 on passengers and their perception of crowding. By analyzing the data with latent class models, two classes named COVID conscious and infection indifferent were produced. In the COVID conscious class, the average VOC is 8.75 min/person, while for the indifferent infection class average VOC is 1.04 min/person. In other words, passengers in the COVID conscious class are about 8.5 times more likely to wait to reduce one person on-board. Membership model showed that women and the elderly have more chance of being in the COVID conscious class, while in the infection indifferent class, frequent users have significant membership. Cho and Park (2021) conducted two SP surveys before and after the COVID-19 to investigate the effect of this pandemic on VOC in PT system of Seoul, South Korea. The results revealed that during the COVID-19 pandemic, the CMs for metro and bus relatively increased 1.23 and 1.04 times, respectively. In other words, CMs before and after COVID-19 for those who had no experience of crowding are 1.58 and 1.95, respectively, and these values for those who experienced crowding in their previous trips are 1.99 and 2.41, respectively (at 200% LF).

3. Case study, data collection and descriptive statistics

The construction of metro rail system in Tehran began in 1978 and finished in 1999. Metro system in Tehran, which is considered the most important mode of transportation in this city, provides services in seven main lines, six of which are urban and one is suburban (Fig. 2). According to the annual report of the Tehran Traffic and Transportation Organization in 2018 (TTTO, 2018), the operated metro lines are 205 km with 109 stations, and there are 1364 operating rail wagons and 66 locomotives with transit speed of 35 km/h. Tehran Metro transports an average of more than 2.5 million passengers on a daily basis, which also achieved a record of 3 million trips per day. Hassannayebi et al. (2014) stated that one of the features of Tehran metro system is a stochastic variation of its passengers’ demand, which causes disruption for the system. Also, unexpected changes in demand for this system will eventually lead to severe congestion in this system. Thus, the crowding of metro system in Tehran is a part of the daily commute for passengers. According to a report by the operating company of Tehran metro and suburbs (Temrah, 2020), with the outbreak of COVID-19, the use of the metro service in this city was reduced by 30%, but over time, the number of passengers is increasing, and now during the COVID-19 pandemic, the ridership of metro system is about 800,000 passengers per day. Due to the increasing trend of metro passengers, it is important to study crowding and measure its disutility and identify changes in the travel behavior of metro passengers in this period.

Table 1
Demographic and trip characteristics of the survey samples.

| Categories | Variables |
|------------|-----------|
| N (%) | Gender |
| During COVID-19 | Before COVID-19 |
| 271 (45.9) | 297 (47.7) | Female |
| 319 (54.1) | 325 (52.3) | Male |
| 19 (3.2) | 13 (2.1) | Adolescent (<18) |
| 318 (53.9) | 355 (57.1) | Young (18-35) |
| 208 (35.3) | 190 (30.5) | Middle-age (36-55) |
| 45 (7.6) | 64 (10.3) | Old (<55) |
| 341 (57.8) | 360 (57.9) | Single |
| 249 (42.2) | 262 (42.1) | Married |
| 117 (19.8) | 72 (11.6) | Diploma or lower*** |
| 76 (12.9) | 68 (11.0) | Associate degree**** |
| 289 (49.0) | 328 (52.7) | Bachelor’s degree |
| 108 (18.3) | 154 (24.7) | Master’s degree or higher |
| 464 (78.6) | 460 (74.0) | Yes |
| 126 (21.4) | 162 (26.0) | No |
| 261 (44.2) | 188 (30.2) | Work |
| 78 (13.2) | 157 (25.2) | Education |
| 45 (7.6) | 77 (12.4) | Shopping |
| 87 (14.8) | 65 (10.5) | Administrative tasks |
| 48 (8.2) | 85 (13.7) | Leisure or social activities |
| 71 (12.0) | 50 (8.0) | Other |
| 302 (51.2) | 176 (28.3) | –4 |
| 135 (22.9) | 123 (19.8) | 4–8 |
| 87 (14.7) | 161 (25.9) | 8–12 |
| 50 (8.5) | 97 (15.6) | 12–16 |
| 16 (2.7) | 65 (10.4) | +16 |
| 90 | 622 | Total |

* Diploma is the name of a degree in the Iranian educational system that students succeed in receiving after graduating from high school.
** Associate degree awarded after a course of higher education that requires a diploma, which usually takes two to three years.
*** The average number of metro trips per week for respondents, in which the round trips were counted as two.
In this study, the Tirachini et al. (2017) questionnaire was used to collect data on crowding perceptions and travel behavior. The reason for using this questionnaire is that it was designed for Santiago, Chile, whose metro system is similar to the Tehran metro system in many ways. The Santiago Metro system operates on 6 lines, which according to Batarce et al. (2015), has an average transit speed of 33.4 km/h and an average travel time of 28.5 min per passenger. The system also transports an average of 2.3 million passengers a day.

In other words, for metro users in both cities, crowding is an acceptable phenomenon. The questionnaire was received by the authors of the article in October 2019 via email, and it was distributed among metro passengers immediately after translating it from Spanish into Persian. The data was gathered as a part of a comprehensive study on the crowding perception of Tehran metro users. After a few months, when COVID-19 was officially confirmed in Iran in February 2020, it was decided to collect new data with the same questionnaire during the pandemic to compare it with the previous data. In order to minimize the impact of seasonal and other background factors on the results, during COVID-19, data were collected in the same months as the before COVID-19 data, i.e., in October and November 2020. In the before COVID-19 survey, 622 valid questionnaires were collected face-to-face and online. The number of valid questionnaires collected online during COVID-19 was 590. It is to be noted that the data collection is not longitudinal, i.e., both surveys are cross-sectional in two different time periods, and hence the participants are different. As there is no official information about the population of Tehran metro users, to ensure the representativeness of the sample, the physical data collection was performed by simple random sampling in all 6 urban metro lines. At the beginning of the questionnaire, participants were asked whether they have used the metro, and if the answer to this question was “yes”, the rest of the questions were made available to them. The similarity of our sample with the sample of (Soltanpour et al., 2020), which was also collected randomly in Tehran metro system, gives some confidence about the representativeness of the sample. The similarities between the two samples are that the number of men is slightly higher than women, about 70% of the participants are under 40 years old, and the majority of people have an academic education, especially with Bachelor’s degree. Also, examining trip frequency shows that half of the respondents have 8 trips per week or less and the other half have more than 8 trips per week. However, during the COVID-19, this ratio changed from 50/50 to 70/30. The questionnaire provided to metro passengers had 7 parts. In this article, the results of 3 parts before and during COVID-19 are compared. These 3 parts are as follows:

1. **Demographic characteristics and trip purposes**: Table 1 shows the demographic characteristics (such as gender, age, marital status, education, and car ownership) and the trip characteristics (trip purpose and frequency) of the sample participants before and during COVID-19. The demographic characteristics of the two samples were almost identical, and it can be inferred that the difference in the results for the two samples is not due to differences in demographic characteristics, and these differences can be due to COVID-19 pandemic conditions in PT and its effect on passenger crowding perception and its disutility. It should be noted that the income was removed from the questionnaire due to the reluctance of respondents to answer. Furthermore, a comparison of travel purposes in two surveys showed that the use of the metro to get to school after the outbreak of COVID-19 decreased significantly, which could be due to the online classes. Purposes such as shopping and leisure and participating in social activities also decreased. In other words, after the outbreak of the disease, people were less likely to shop in areas far from their residential area. Leisure and participation in social activities, where there was a possibility of spreading the virus, also decreased. In contrast, the use of the metro to get to work and to do administrative tasks in offices and organizations slightly increased. Despite these differences, the percentage of compulsory trips in the two surveys before (65.9%) and during COVID-19 (72.2%) has remained almost identical. Compulsory trips are trips where the traveler must reach their destination at a certain amount of time (Allen et al., 2018). In this study, the trips to work, education, and administrative tasks were considered compulsory trips.

2. **Subjective measurement of VOC**: In this section, in order to measure the passengers’ perception of crowding in Tehran Metro, security and comfort at different levels of crowding (low, medium, and high) were considered. Because of the similarity of meaning that these two terms may have for some passengers, a further explanation was provided for each question in parentheses. Thus, such cases as assaults, mugging and pickpocketing were considered as security criteria, and the feeling of physical and psychological discomfort caused by the crowding and closeness of other people to the passengers were considered as comfort criteria. Comparing the crowding classification in Haywood et al. (2017) article, it can be stated that here, security is equivalent to robbery and crime aspect of the “risky category” and comfort is equivalent to the “physical” and “psychological” categories of crowding.

3. **Objective measurement of VOC**: In this section, a SP survey with a D-efficient design was provided to the participants to select one out of two choice scenarios in 6 binary choice tasks. Efficient designs aim to maximize the information gained from choices by minimizing the correlation among the differences between attributes (i.e. orthogonal in differences) (Batarce et al., 2016). D-efficient design is one of the efficient designs which uses the determinant of the design matrix as a metric for minimizing the covariance matrix of estimated parameters. Three attributes of travel time, crowding, and standing or sitting position were used to determine the characteristics of each choice scenario. Unlike the metro system in Santiago (the city where the Tirachini et al. (2017) questionnaire was collected) in which the cost of travel was independent of the distance of the route; in the Tehran Metro, ticket costs are calculated based on the distance traveled. However, since the cost of a metro ticket in Tehran is very low and is not an important factor for the passenger, the Tirachini et al. (2017) questionnaire, in which the cost of travel is not used as an attribute for the choice scenarios, deemed appropriate. In the main questionnaire, the base travel time was specified as the travel time of passengers’ last trip, and accordingly, 5 levels of travel time were considered as −25%, −12.5%, 0, +12.5%, and +25% around this base travel. Since it is possible that some participants may have difficulty calculating these numbers, in the questionnaire used in this article, the base travel time was considered to be 20 min and 5 levels of travel time were calculated accordingly. The crowding was also specified in 6 levels in the questionnaire (see Appendix). In the main questionnaire, text, 2D diagram, and real photo from inside the metro were used to show the crowding levels, and a specific format was considered for each participant. Since in Tirachini et al. (2017) article, the comparison of the results obtained by these 3 formats did not reveal any significant difference, in the questionnaire used in this article, crowding levels were shown with pictorial format (the 2D diagram next to the real photo) to participants, and the text format was not used to
avoid complicating the choice tasks. Furthermore, in each choice scenario profile, the travel time and the passenger’s standing or sitting position were specified with sentences under the pictures of crowding levels. Fig. 3 represents an example of a choice task translated to English.

4. Data analysis and methods

In the SP section of the questionnaire, participants were faced with two choice scenarios in each six choice tasks. The utility of choice scenario $j=(1,2)$ for individual $i$ in choice task $t$ $(1,...,6)$ can be expressed as follows:

$$U_{ijt} = x_{ijt} \beta_i + \epsilon_{ijt}$$

where $x_{ijt}$ represents the attributes of SP survey, $\beta_i$ denotes the coefficients and $\epsilon_{ijt}$ represents the random error term. The estimated utility function in this study is:

$$U_{ijt} = \beta_{TT} TT_{ijt} + \beta_{CR} CR_{ijt} + \beta_{ST} ST_{ijt} + \epsilon_{ijt}$$

where $TT$ represents travel time, $CR$ denotes crowding, and $ST$ is a dummy variable for standing. The reason for using the interaction terms between travel time, crowding and standing is that the travel time has more disutility in higher crowding levels and in standing condition of passengers (Wardman and Whelan, 2011).

Since the data collected in the SP section includes repeated measurements for every subject, it is necessary to take account of the intra-individual correlation in estimating the coefficients. Intra-individual correlation can be modeled by entering the variability pattern from two sources of variability in the data: between-subject variability and within-subject variability (Liu, 2016). Variance component models or mixed models are models that have the ability to model within-subject and between-subject variance by splitting the residual into two uncorrelated components (Rabe-Hesketh and Skrondal, 2012). Thereby, mixed logit (ML) models, which are the generalized form of linear mixed models, are increasingly being used by researchers for analyzing discrete choice data. ML models allow one or more parameters to be distributed continuously and randomly. In this case, the probability of the observed sequence of choices is given by:

$$P_{ML}(\beta) = \int \prod_{t=1}^{T} \prod_{j=1}^{J} \left( \frac{\exp(x_{ijt})}{\sum_{k=1}^{J} \exp(x_{ikt})} \right)^{\gamma_{ijt}} f(\beta|\theta) d\beta$$

where $f(\beta|\theta)$ is density function for $\beta$.

It is worth to note that, the intercepts were not entered the utility function for two main reasons. First, the purpose of interpreting the models in this section is to examine the effect of attributes on passenger preferences and to use the estimated coefficients of these attributes to calculate crowding multipliers. Additionally, the choice scenarios were different states of the metro trip with a predefined combination of attributes (based on the design of choice tasks). Thus, these choice scenarios do not have any utility beyond the characteristics attributed to them (i.e. unlabeled choice experiments) (Hole, 2007), and considering intercept to measure the passengers’ inherent tendency to choose choice scenarios and considering preference heterogeneity in ML models may not have any interpretation value. Second, in ML models which estimate multiple random variables, this simplification significantly improves the computational speed of the estimations.

Since the attributes used in the models have disutility for all individuals, the use of lognormal mixing density in ML models is
desirable to limit the sign of the coefficients to negative. Because of the fat upper tail of the lognormal distribution, using the mean to calculate crowding multipliers causes these values to be irrationally high and behaviorally implausible (Basu and Hunt, 2012). For this reason, Tirachini et al. (2017) and Björklund and Swärdh (2017) used the median to calculate crowding multipliers. In this study, the median of the lognormal distribution was used to report the outcomes of ML models and to calculate CMs. Since the coefficients with lognormal distribution must be estimated positively, attributes values were multiplied by $-1$. Then, exponential of coefficients multiplied by $-1$ (to compensate for $-1$ multiplication of attributes values in the estimation process) were used as the median (Hole, 2007) to calculate the crowding multipliers. It should be noted that in the ML models, 500 Halton draws were used to estimate the coefficients.

Crowding multipliers (CM) in passengers’ sitting and standing conditions, as the main outcome of discrete choice models, are obtained by dividing the marginal disutility of travel time under crowding conditions by the marginal disutility of travel time under uncrowded conditions.

$$\text{SittingCM} = \frac{\beta_{TT} + \beta_{CR}}{\beta_{TT}}$$  \hspace{1cm} (4)

$$\text{StandingCM} = \frac{\beta_{TT} + \beta_{ST} + CR(\beta_{CR} + CR_{ST})}{\beta_{TT}}$$  \hspace{1cm} (5)

The ratio between standing and sitting crowding multiplier, denotes the value of having a seat or standing multiplier (SM) (Eq. (6)). This coefficient indicates how much travel time is valued more for passengers when they are standing compared to when they are sitting.

$$\text{SM} = \frac{\text{StandingCM}}{\text{SittingCM}}$$  \hspace{1cm} (6)

In this article, STATA 16.0 and mixlogit syntax (Hole, 2007) was used to estimate ML models. It should be noted that mixlogit syntax maximize the log-likelihood function indirectly using simulation methods.

![Fig. 4. Average security and comfort scores at different crowding levels.](image-url)
5. Results

5.1. Subjective measurement of VOC

The 7-point Likert scale was used to record the security and comfort scores of each crowding level. Thus, 1 indicated very unsafe/very uncomfortable and 7 indicated very safe/very comfortable. Passengers recorded their security and comfort scores of 3 levels of crowding: low crowding (crowding level 1), medium crowding (crowding level 3), and high crowding (crowding level 5) (see Appendix). At level 1, only 35% of train seats are taken, and no one is standing; while in levels 3 and 5, all the seats are taken and the density of standees are 1 and 6 pax/m², respectively. In order to show the crowding levels, 2 image formats (2D diagram and real photo) were used in the questionnaire.

To investigate the effect of heterogeneity on crowding perception, the mean of comfort and security scores at different crowding levels were evaluated for 8 variables. Thus, using two sample Z test, it was calculated whether there is a significant difference between the mean scores of comfort and security across groups. To better reveal this difference, all 8 variables were tested in two categories: survey variable in two categories of before COVID-19 and during COVID-19, gender variable in two categories of male and female, age variable in two categories of under 35 years old (adolescent and young) and above 35 years old (middle-age and old), marital status variable in two categories of single and married, educational status variable in two categories of with and without academic degree, car ownership variable in two categories of choice and captive users trip purpose variable in two categories of compulsory and non-compulsory trips and trip frequency variable in two categories of frequent users (≥8 trips per week) and infrequent users (<8 trips per week).

Fig. 4 shows the average comfort and security scores at crowding levels for survey, gender, age and trip frequency variables that revealed at least one significant difference between their means. Accordingly, for all situations, the average security and comfort scores decrease as the crowding level increases. Furthermore, at low crowding levels, security scores were slightly lower than comfort scores. The reason for this could be the possibility of assaults in almost empty trains (Cox et al., 2006). In contrast, at high crowding levels, the average passenger comfort score was slightly lower than their security.

By assessing the effect of heterogeneity on the results, it can be concluded that at low crowding the women’s perception of security (5.13) is significantly lower than men (5.91), and at high crowding women’s perception of comfort (1.59) is significantly lower than men (2.24). Also, the perception of comfort and security at high crowding for the elderly and middle-aged people (comfort: 1.28 and security: 2.32) is significantly less than youths and adolescents (comfort: 2.41 and security: 3.10). The effect of trip frequency on comfort perception is such that at a high crowding level, frequent users (1.39) perceive significantly less comfort than infrequent users (2.29). The reason for this may be that occasional passenger may not have an accurate perception of comfort at high crowding levels due to their less travel by metro service (Allen et al., 2019). Also, at a high crowding level, security perception for infrequent users (2.21) is significantly lower than frequent users (3.64). In other words, infrequent users have a pessimistic perspective of the security inside the metro, which may be one of the reasons why they use metro system occasionally. In contrast, frequent users have a more realistic understanding of the security within the metro, because of their higher level of knowledge about the network (Yap et al., 2020).

Table 2
Mixed logit model results for before and during COVID-19.

| Survey               | Variable | Coef. | Std. Err. | z-value | Median |
|----------------------|----------|-------|-----------|---------|--------|
| Before COVID-19      | $\beta^{CR}$ | -1.817*** | 1.089* | -9.343 | -0.163 |
|                      | $\beta^{ST}$ | -4.243*** | 1.245* | -13.493 | -0.014 |
|                      | $\beta^{TT}$ | -3.656*** | 1.116* | -10.484 | -0.026 |
|                      | $\beta^{CR*ST}$ | -4.968*** | 1.415* | -10.356 | -0.007 |
|                      | LL       | -997.19 |          |         |        |
|                      | Pseudo R-square* | 0.209 |          |         |        |
|                      | Observations | 3732 |          |         |        |
|                      | Clusters    | 622   |          |         |        |
| During COVID-19      | $\beta^{CR}$ | -1.710*** | 1.148* | -9.448 | -0.181 |
|                      | $\beta^{ST}$ | -3.576*** | 1.545* | -9.797 | -0.028 |
|                      | $\beta^{TT}$ | -3.244*** | 1.512* | -8.192 | -0.039 |
|                      | $\beta^{CR*ST}$ | -3.963*** | 1.673* | -9.481 | -0.019 |
|                      | LL       | -824.51 |          |         |        |
|                      | Pseudo R-square* | 0.223 |          |         |        |
|                      | Observations | 3540 |          |         |        |
|                      | Clusters    | 590   |          |         |        |

*p < .05.

* Mc Fadden’s $R^2 = 1 - \frac{\ln L(\text{Model})}{\ln L(\text{Model base})}$, where the numerator represents the log-likelihood of the model with predictors and the denominator represents the log-likelihood of the model without predictors.

** p < .01.

*** p < .001.
During COVID-19, compared to the period before COVID-19, the mean comfort scores of medium (2.95 compared to 4.53) and high crowding (1.48 compared to 2.37) levels significantly decreased. In fact, at these crowding levels, all the seats were taken, and the social distancing was not explicitly observed. It was also more contingent for the passengers to physically collide with other people or the interior parts of the train. Interestingly, at the medium crowding level, the average comfort scores during COVID-19 showed a drastic decline compared with before COVID-19 (1.58), which was more than the reduction in comfort scores related to the high crowding level (0.89). In other words, the medium crowding level where all the seats are taken and density of standees is 1 pax/m², in the pre-COVID-19 period had above-average comfort for passengers, while during COVID-19 had low comfort.

5.2. Objective measurement of VOC

In this section, the results of discrete choice models are described. The results of ML for before and during COVID-19 surveys are given in Tables 2. The median of the derived parameters from models is then used to calculate CMs and SMs. Table 3 and Fig. 5 compare the sitting CMs before and during COVID-19. Similar results are provided in Table 4 and Fig. 6 for standing CMs. Additionally, a comparison of SMs before and during COVID-19 is shown in Table 5 and Fig. 7. It is worth noting that the standard error of CMs, which was used in calculating the confidence intervals and significance test for difference between the mean of two parameters, was calculated using the delta method formulae introduced by Daly et al. (2012).

By examining the CMs it can be concluded that in both before and during COVID-19 periods, the CMs increase with increasing crowding levels and changing conditions from sitting to standing. Furthermore, during the COVID-19 period compared to the before COVID-19 period, sitting CMs significantly increased at all crowding levels. So that at the 6 pax/m² density of standees, this coefficient has changed from 1.52 to 1.92 (27% relative increase). In other words, for the same crowding in the two periods before and during COVID-19, VTTS for passengers increased.

Standing CMs also increased significantly during COVID-19 compared to the before COVID-19 period. At the density of standees of 6 pax/m², this coefficient changed from 1.93 to 2.77 (44% relative increase). Comparing the average relative increases in sitting and standing CMs, it can be concluded that the average relative increase of standing CM (27%) is greater than that of sitting CMs (15%). In other words, for passengers during COVID-19 compared to the before COVID-19 period, the rate of increase of crowding disutility in the standing condition is greater than the rate of increase of crowding disutility in the sitting condition. The comparison of standing multipliers in the two periods before and during COVID-19 also showed a significant increase in this coefficient. At the 6 pax/m² density of standees, this coefficient changed, from 1.28 to 1.34 (13% relative increase). In other words, the value of having a seat on the train during COVID-19 increased compared to the before COVID-19 period.

To investigate the effect of observed heterogeneity on CMs, the other seven variables (see Section 5.1) in the study were evaluated. In this paper, the interaction between demographic variables and the attribute terms in the utility function was not used to investigate the effect of the observed heterogeneity. This is because the number of interaction terms in the utility function is high and adding more interactions caused the model to face convergence problems. This case was also reported by Björklund and Swärd (2017). For this reason, similar to examining the effect of the survey (before and during COVID-19), sample segmentation by groups of these variables and separate modeling in each of these segments have been used. Results revealed that the three variables of gender, age and trip frequency have significantly different CMs between their groups. So, women, middle-aged and elderly people and frequent users have more CMs at different crowding levels. The results of this section somehow confirm the results obtained in the subjective measurement of crowding in which these three groups had less comfort perception at high crowding levels. Furthermore, other studies have concluded that women (Douglas and Karpouzis, 2006; Sahu et al., 2018; Shelat et al., 2021) and the elderly (Björklund and Swärd, 2017; Shelat et al., 2021) have higher perception of crowding disutility. Another noteworthy point is that the dependence of VTTS on personal characteristics (Mackie et al., 2001) is almost an accepted norm in the literature, and as such, increasing income (Prud’homme et al., 2012) and trips with working purpose (Björklund and Swärd, 2017) are associated with increased VTTS. In contrast, Björklund and Swärd (2017) showed that the standing CM is significantly lower for working trip while Sahu et al. (2018) also stated that high-income people have less WTP for reducing the crowding. Thus, it can be inferred that for high-income passengers and passengers with working purpose, time is more important than crowding. So these passengers are willing to endure more crowding in the PT fleet to have less travel time. In this article, the declining trend of CMs for compulsory trips compared to non-compulsory trips provides an evidence to this observation. Table 6 shows the CMs values for these four variables at the crowding levels of 3 and 6 pax/m².

| Density of standees (pax/m²) | Before COVID-19 | 95% CI | During COVID-19 | 95% CI | Relative increase |
|-----------------------------|----------------|--------|-----------------|--------|-------------------|
| 0                           | 1.00           | –      | 1.00            | –      | 0                 |
| 1                           | 1.09           | [1.07-1.11] | 1.15 | [1.12-1.19] | 0.06 |
| 2                           | 1.17           | [1.13-1.21] | 1.31 | [1.25-1.37] | 0.12 |
| 3                           | 1.26           | [1.20-1.32] | 1.46 | [1.39-1.54] | 0.16 |
| 4                           | 1.34           | [1.27-1.42] | 1.62 | [1.52-1.72] | 0.20 |
| 5                           | 1.43           | [1.33-1.53] | 1.77 | [1.66-1.89] | 0.24 |
| 6                           | 1.52           | [1.40-1.63] | 1.92 | [1.77-2.08] | 0.27 |
Table 4
Standing CMs for before and during COVID-19.

| Density of standees (pax/m²) | Before COVID-19 | 95% CI       | During COVID-19 | 95% CI       | Relative increase |
|------------------------------|-----------------|--------------|-----------------|--------------|-----------------|
| 0                            | 1.16            | [1.12-1.20]  | 1.22            | [1.18-1.25]  | 0.05            |
| 1                            | 1.29            | [1.23-1.35]  | 1.48            | [1.40-1.55]  | 0.14            |
| 2                            | 1.42            | [1.32-1.52]  | 1.73            | [1.62-1.85]  | 0.22            |
| 3                            | 1.55            | [1.43-1.66]  | 1.99            | [1.84-2.15]  | 0.29            |
| 4                            | 1.67            | [1.52-1.83]  | 2.25            | [2.04-2.47]  | 0.35            |
| 5                            | 1.80            | [1.61-2.00]  | 2.51            | [2.26-2.77]  | 0.39            |
| 6                            | 1.93            | [1.70-2.17]  | 2.77            | [2.48-3.07]  | 0.44            |

Fig. 5. Comparison of sitting CMs for before and during COVID-19.

Fig. 6. Comparison of standing CMs for before and during COVID-19.
6. Discussions and policy implications

Despite the great variety in crowding disutility perception, Tirachini et al. (2017) stated that the appropriate value of sitting CM at crowding level of 6 pax/m$^2$ is 1.5–1.6. The sitting CM obtained from this study at crowding of 6 pax/m$^2$ is equal to 1.52, which is in the aforementioned range. Also, a comparison of this sitting CM with the sitting CMs reviewed in the literature section shows that the estimated sitting CM for Tehran is very close to London, Paris and Santiago, is higher than the cities of Sweden and is less than Hong Kong. In contrast, the standing CM obtained from this study at 6 pax/m$^2$ for the Tehran metro system (1.93) is less than the range introduced by Tirachini et al. (2017) (2–2.3) and other developed cities in the world. Similarly, Sahu et al. (2018) stated that the

| Density of standees (pax/m$^2$) | Before COVID-19       | 95% CI          | During COVID-19  | 95% CI           | Relative increase |
|---------------------------------|-----------------------|-----------------|------------------|------------------|-------------------|
| 0                               | 1.16 [1.14–1.18]      | 1.22 [1.19–1.24]|
| 1                               | 1.19 [1.16–1.21]      | 1.28 [1.25–1.31]|
| 2                               | 1.21 [1.18–1.23]      | 1.32 [1.29–1.36]|
| 3                               | 1.23 [1.20–1.26]      | 1.36 [1.32–1.40]|
| 4                               | 1.25 [1.21–1.28]      | 1.39 [1.35–1.44]|
| 5                               | 1.26 [1.22–1.30]      | 1.42 [1.37–1.47]|
| 6                               | 1.28 [1.23–1.32]      | 1.44 [1.38–1.49]|

Fig. 7. Comparison of SMs for before and during COVID-19.

Table 6

Results of assessing observed heterogeneity on CMs.

| Gender                  | Standing CM at 3 pax/m$^2$ | Sitting CM at 6 pax/m$^2$ | Standing CM at 6 pax/m$^2$ | No. observations |
|-------------------------|----------------------------|---------------------------|----------------------------|------------------|
| Female                  | 1.96 [1.81–2.11]           | 1.89 [1.74–2.04]          | 2.68 [2.43–2.93]           | 568              |
| Male                    | 1.58 [1.45–1.71]           | 1.53 [1.41–1.65]          | 2.15 [1.96–2.34]           | 644              |
| Age                     |                            |                           |                            |                  |
| Under 35 years old      | 1.52 [1.39–1.65]           | 1.49 [1.37–1.61]          | 2.17 [1.98–2.36]           | 705              |
| Above 35 years old      | 1.92 [1.76–2.08]           | 1.87 [1.72–2.02]          | 2.69 [2.44–2.94]           | 507              |
| Trip frequency          |                            |                           |                            |                  |
| Frequent users (more than 8 trips per week)| 1.96 [1.80–2.12] | 1.93 [1.77–2.09] | 2.74 [2.49–2.99] | 476              |
| Infrequent users (less than 8 trips per week)| 1.61 [1.48–1.74] | 1.58 [1.45–1.71] | 2.20 [2.01–2.39] | 736              |
| Trip purpose            |                            |                           |                            |                  |
| Compulsory trips        | 1.76 [1.63–1.88]           | 1.67 [1.54–1.80]          | 2.25 [2.08–2.42]           | 836              |
| Non-compulsory trips    | 1.83 [1.69–1.98]           | 1.75 [1.61–1.89]          | 2.46 [2.22–2.70]           | 376              |
standing CM for the Mumbai metro system at 7–9 pax/m² is equal to 1.94, which is lower than the standing CM of the developed cities even at 6 pax/m². Therefore, it can be concluded that travelers in developed cities, compared to developing cities, perceive more penalties for standing in PT fleet. Also, this study showed that the relative increase in CM due to COVID-19 pandemic averaged 21% in both standing and sitting conditions. This relative increase is very close to the relative increase (23%) in CM due to the COVID-19 pandemic in PT system of Seoul, South Korea (Cho and Park, 2021).

One of the important findings of this study was the observation of the more relative increase of standing CM compared to sitting CM, and the increase in SMs during a pandemic outbreak such as COVID-19. It shows that having a seat for travelers while traveling during the COVID-19 period is of high importance. Shelat et al. (2021) also showed that people in the COVID conscious class were more likely to sit without anyone on the adjacent seats. The reason for this may be that in standing conditions, the probability of interaction with other people or the interior parts of the train is higher, each of which can be considered a factor for the transmission of the coronavirus. Kampf et al. (2020) reviewed 22 studies and found that coronavirus could persist on stationary surfaces such as metal, glass, or plastic for up to 9 days. Although (Goldman, 2020) stated the chance of transmission of the COVID-19 virus through inanimate surfaces is very small; there may be a perception among people not to touch external surfaces when they are outdoors. Passengers may also perceive that seats are cleaned regularly as compared to other interior parts of the train. Therefore, along with staff management and materials disinfection, information campaigns on the cleanliness (Shen et al., 2020) of rail may provide confidence to the public on safe public transport travel during COVID-19. The importance of internal cleaning and sanitation of public transportation vehicles have been emphasized by the researchers (Musselwhite et al., 2020). In indoor places like train carriages where a high level of aerosol production is anticipated, importance of minimizing crowding, improving ventilation conditions and maintaining safe physical proximity is important to prevent the spread of COVID-19 disease (Vuorinen et al., 2020). Since the PT system itself has never been a factor in transmitting coronaviruses (Gkiotsalitis and Cats, 2020), performing the above actions will lead COVID-19 conscious people to use this system. This may negate the people’s perception of PT as a tool of COVID-19 transmission and promote the positive perception of using PT (Shelat et al., 2021).

Since the specific conditions prevailing during the pandemic disease were the main reason for the difference of crowding multipliers in the two time periods studied in this paper, most likely, after this period, the coefficients may return to their original state or may stay for a short to medium period. However, it is necessary to consider the fact that adapting the conditions of public transportation, particularly the metro (as the main mode of PT in Tehran) during a pandemic disease and maintaining healthy and safe service in such conditions, can directly prevent the exacerbation of inequality in society and provide assurance to the passengers on safe public transport travel. At the time of writing this study, almost a year has passed since the official report of COVID-19 cases in Iran and the general vaccination roll-out program has also been announced with the end of 2021 as the final phase of Vaccination. The results of this article showed that during the outbreak of COVID-19, passengers seek to find a seat while traveling by metro and experience less crowding. Researchers have suggested increasing the frequency and decreasing the headway, increasing the number of carriages per train and increasing the capacity of the carriages (more space with more seats and a more comfortable space to stand) to reduce the crowding experience in the rail fleet (Basu and Hunt, 2012). What is clear is that these changes are long-term, and it is necessary to introduce short-term measures that PT administrators can implement in the midst of this pandemic. Shelat et al. (2021) suggest that if information about the crowding level of the PT fleets become available, COVID conscious passengers can adapt their trip to less crowded fleets. Gkiotsalitis (2021) proposed a dynamic service pattern model by using real-time data of passengers’ demand at each station and the capacity of each vehicle to suggest skipping stations in order to not exceed the pandemic-imposed capacity constraint of the vehicle. Having said that, it is expected that to maintain a safe physical distance of 1–2 m, many public transport service operators will have a major capacity drop of 60–90% (Gkiotsalitis and Cats, 2020). Thus, it is necessary to change the perspective on pre-COVID PT efficiency, which is primarily based on transporting the passengers with crowding and without maintaining social distancing. In other words, during the pandemic, the PT efficiency should be evaluated by other indicators that are designed based on reduction of crowding and transportation of people in accordance with health protocols (Cho and Park, 2021).

7. Conclusions

There is a dearth of knowledge regarding the potential impact of COVID-19 on public transport operations and models that can support service planning of public transport amid challenges posed by the pandemic (Gkiotsalitis and Cats, 2020). Considering the crowding of public transport as a factor to impose time and cost on passengers is very important in the planning phase of PT services and estimating the modal share of modes of transport. In other words, since passengers are willing to experience less crowding in exchange for more travel time or more cost, failure to consider crowding on public transportation can lead to overestimation of demand at high crowding levels (Tirachini et al., 2013). Lack of correct and rational decisions due to overlooking the effect of crowding on passengers can seriously impede the provision of transportation services.

In this study, the Tirachini et al. (2017) questionnaire was used to find out passengers’ perceptions of Tehran metro rail crowding and measure its dissatisfaction in the two periods before and during COVID-19. The questionnaire used in this article had two main separate sections. In the first section in order to subjective measurement the crowding, passengers were asked to express their perception of security and comfort at 3 levels of low, medium, and high crowding. The results showed that during the COVID 19 pandemic, crowding levels where seats were taken and passengers were standing in a way that was difficult or impossible to maintain social distancing, strongly affected passenger comfort scores. This change was the largest on the medium crowding level with the density of standees of 1 pax/m². It is to be noted that before the outbreak of COVID-19, this crowding level had a moderate to high comfort score, but during the COVID-19, its score dropped sharply.

In the second section of the questionnaire, SP method was used to measure VOC objectively. The results showed that for the same
amount of crowding during COVID-19 compared to the before COVID-19 period, CMs increased both for sitting and standing conditions. In other words, passengers perceived more disutility for crowding during a pandemic outbreak compared to a time before the pandemic. Since the number of passengers decreased during COVID-19 period, this increase in VOC can be considered due to the psychological aspect of crowding (Haywood et al., 2017), namely stress and lack of control in social distance due to the nearness of other people.

Understanding passengers’ perceptions of crowding as examined in this study will assist transport operators and planners in maintaining the critical functionality of public transport systems and managing risks of mass transportation during the pandemic and beyond. Policymakers can use the results of this article to provide better metro rail services during the COVID-19 pandemic by observing health protocols. This is particularly beneficial for working-class commuters who have less access to telework and private vehicles.

CRediT authorship contribution statement

Kayvan Aghabayk: Conceptualization, Data curation, Investigation, Methodology, Writing – review & editing, Supervision. Javad Esmailpour: Investigation, Methodology, Conceptualization, Data curation, Writing – original draft. Nirajan Shiwakoti: Investigation, Writing – review & editing.

Declaration of Competing Interest

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

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Appendix A

| Crowding level | Crowding representation (shown to respondents) | Crowding characteristics (used in models) |
|----------------|-----------------------------------------------|------------------------------------------|
|               |                                               | Occupation of seats (%)                  |
|               |                                               | Density of standees (pax/m²)             |
| 1              | ![Crowded Bus](image1.png)                    | 35                                       |
|                | ![Crowded Bus](image2.png)                    | 0                                        |

(continued on next page)
| Crowding level | Crowding representation (shown to respondents) | Crowding characteristics (used in models) |
|---------------|-----------------------------------------------|-------------------------------------------|
|               | Occupation of seats (%) | Density of standees (pax/m²) |
| 2             | ![](image1) | 69 | 0 |
| 3             | ![](image2) | 100 | 1 |
| 4             | ![](image3) | 100 | 2 |
| 5             | ![](image4) | 100 | 4 |

(continued on next page)
Crowding level | Crowding representation (shown to respondents) | Crowding characteristics (used in models) |
---|---|---|
6 | | Occupation of seats (%) | Density of standees (pax/m²) |
100 | 6 | |

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