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Impacts of COVID-19 on individuals’ mobility behavior in Pakistan based on self-reported responses

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ABSTRACT

Introduction: The COVID-19 pandemic has been extremely disturbing mobility behavior due to travel restrictions and perceived COVID-19 threats. Recently, researchers from developed countries have shown interest in quantifying the impacts of the COVID-19 on individuals’ mobility; however, similar research themes in lower income developing countries like Pakistan have not been sufficiently explored. Therefore, the objectives of the study are; 1) to explore the changes in self-reported individual’s mobility behavior—trip frequencies by mode and by purpose in three COVID-19 severity periods; 2) to quantify the effects of respondents’ personal (i.e., age, gender, education, and living place), and perceived details (i.e., safety perceptions, the COVID-19 threat perceptions) on the change in mobility behavior in the COVID-19 severity change; 3) to analyze the willingness to use public transportation in the post-pandemic period. Methods: A web-based questionnaire survey was conducted from September 2020 to November 2020, resulting in 565 responses. Descriptive analysis, random parameter bivariate probit modeling, and structural equation modeling are adopted to achieve the objectives. Results: The results reflect the change in individuals’ mobility behavior in three severity periods of COVID-19, including before outbreak, during the most serious period, and after the most serious period. A substantial reduction in individuals’ mobility was observed during the most serious period, which is recovering back to normal. The results also indicate the relationship of individuals’ personal and perceived characteristics with the change in mobility in COVID-19 severity changes from before-to-serious and from the serious-to-after most serious period. Conclusion: The COVID-19 pandemic has been affecting individuals’ mobility behavior in Pakistan. The study’s findings provide insightful information for the transportation agencies to better prepare for sustainable transportation management in the post-pandemic era.

1. Introduction

The coronavirus disease 2019 (COVID-19) spread has been considered the most serious event of the early 21st century (Shakibaei et al., 2021). Over 131 million confirmed cases of COVID-19 and 2.85 million deaths were reported till the early April 2021 (World Health Organization, 2021). In response to the threats of the COVID-19 spread, countries have been taking measures, including social distancing, lockdown, and quarantines. Resultantly, it has abruptly affected the individual’s mobility patterns around the world.

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were almost equally active in taking measures against the COVID-19 pandemic, such as lockdowns, quarantines, and mobility restrictions (J. Zhang et al., 2021). Although the vaccines are available now in some countries and they are expected to control the COVID-19 pandemic. The world has experienced restrictions due to the COVID-19 for over a year, and it is still on-going (Gargoum and Gargoum, 2021). Thus, it is expected that the COVID-19 has long-term impacts on the transportation system of both developed and developing countries (Hensher, 2020).

Recently, many relevant studies have been conducted in China (Cui et al., 2021; Dong et al., 2021; Zhang and Lee, 2021), Australia (Hensher et al., 2021), Sweden (Kazemzadeh and Koglin, 2021), the United Kingdom (Vickerman, 2021), and Germany (Anke et al., 2021) to uncover the impacts of the COVID-19 on various modes of transportation and travel activities. During the COVID-19 pandemic period in South Asian countries, a few studies have been conducted in Pakistan to explore the factors contributing to putting pressure on the available health facilities (Habib and Abbas, 2021; Rehman et al., 2020; Waris et al., 2020) and community knowledge, attitudes, and practices, and awareness regarding the COVID-19 (Hussain et al., 2021; Nadeem and Khalil, 2021). However, the COVID-19 impacts on individuals’ mobility behavior and usage of public transportation remain unknown. Thus, this study aims to fill this gap to provide suggestions to the transportation authorities for the mobility policies in case of an epidemic in the future. The main objectives of the study are designed as enlightening the changes in self-reported individual’s mobility behavior (trip frequencies by mode and by purpose) in relation to the COVID-19 severity periods; determining the effects of respondents’ personal and perceived details on the change in mobility behavior in the COVID-19 severity change; and willingness to use public transportation in the post-pandemic period.

Considering the case of developing countries, the unavailability of country-wide observed or self-reported travel data encouraged us to conduct a questionnaire survey to collect data. A web-based questionnaire was designed, and a survey was conducted among Pakistani citizens to provide their valuable responses. Trip frequencies by modes (i.e., public transport, shared transport, paratransit transport (e.g., rickshaw, minibus, wagon), cars, two-wheelers, and walking) and trip frequencies by purpose (i.e., commute/education trips, leisure trips, buying necessities/hospital trips, and religious trips) are considered as self-reported individuals’ mobility behavior similar to a recent German study (Anke et al., 2021). According to the trend line of average reported new confirmed cases of the COVID-19 mentioned in the next section, we considered three periods (before the outbreak, during the most serious period, and after the most serious period) to reveal the self-reported individual’s mobility behavior. Thus, two types of severity change can be captured, one is before-to-most serious period, and the second is most serious-to-after most serious period. Descriptive analysis was used to explore the change in individuals’ mobility behavior with respect to three severity periods of the COVID-19. A random-parameter bivariate probit modeling approach was adopted to identify the relation of respondents’ personal and perceived details on the change in mobility behavior in the COVID-19 severity change (before-to-serious period; serious-to-after most serious period). A structural equation modeling approach was utilized to uncover the effects of attitudes and perceived the COVID-19 threat on willingness to use public transportation in the post-pandemic period.

1.1. Literature review

Many recent studies have been focusing on the impacts of the COVID-19 on the transportation system. After three months of the COVID-19 restrictions in Australia, Hensher et al. (2021) confirmed a 54% reduction in car and public transport commuters’ annual travel time costs than the pre-COVID-19 period in the Greater Sydney Metropolitan Area, associated with a decrease in congestion costs. However, ease in restrictions in Australia resulted in a 50% increase in aggregate travel, which remains less than two-third of individuals’ travel occurred in the pre-COVID-19 period (Beck and Hensher, 2020). Through the decomposition analysis approach, Cui et al. (2021) revealed the economic impacts of the COVID-19 pandemic on China’s transport sector, including a larger reduction in passenger transport’s output than freight transport. They argued that the COVID-19 had impacted the transport sector from both the demand and supply side, raising the protective costs and reducing the travel demand.

When the global curve of newly confirmed cases of the COVID-19 has flattened (J. Zhang et al., 2021), conducted a worldwide expert survey indicating a remarkable shift from public transport to the care, walking, and cycling, long term changes in individuals’ lifestyles, campaigns, and information dissemination as a useful tool against the COVID-19, and lack of readiness of public transport usage, and public health threats. On March 14, 2020, when the COVID-19 was declared to be under control in China, a survey among eight Chinese cities highlighted the increase in anxiety among passengers due to the recent occurrence of the pandemic event impacting negatively on perceived safety in public transport (Dong et al., 2021). Zhang and Lee (2021) found a considerable decrease in public transportation usage and increased car-usage due to the COVID-19 in China. Through the questionnaire survey, they have also explained that gender, occupation, and travel restriction were significantly affecting individuals’ travel behavior. Likewise, in Sweden, an empirical survey to reveal the COVID-19 impacts explored that the individuals see e-bikes as a substitute for public transport by ensuring social distancing and health concerns (Kazemzadeh and Koglin, 2021). From the UK, Vickerman (2021) revealed the impacts of the COVID-19 on the public transportation services and argued the slow speed of recovery of transportation to the pre-pandemic level. Through the analysis of survey responses in Germany, Anke et al. (2021) found the mobility behavior of shift away from public transportation and increased private transportation such as car-usage, cycling, and walking.

From the above-mentioned studies, it is clear that the COVID-19 has impacted the world’s transportation system. However, the severity of impacts varies from country to country globally (Gargoum and Gargoum, 2021). Both developed and developing countries were almost equally active in taking measures against the COVID-19 pandemic, such as lockdowns, quarantines, and mobility restrictions (J. Zhang et al., 2021). However, the impacts of such measures on the individual’s mobility behavior in developing countries have been given less attention. Most of the relevant studies have been conducted in China (Dong et al., 2021; Kutela et al., 2021), providing suggestions for Chinese transportation systems to manage mobility in the post-pandemic world. However, little is known about the COVID-19 impacts on the South Asian countries’ transportation system.
Considering the insufficient attention on developing countries regarding the COVID-19 impacts on transportation, we considered exploring the changes in individuals’ mobility behavior in Pakistan with respect to the severity of the COVID-19 periods. The first confirmed case of the COVID-19 was reported on February 26, 2020, in Pakistan, triggering a sudden spread of this disease across the country (Waris et al., 2020). The government of Pakistan declared a nationwide locked down on March 22, 2020, leaded the public to stay home, disturbed mobility patterns across the country, and encouraged work from home (Habib and Abbas, 2021; Nadeem and Khaliq, 2021). In May 2020, the Government of Pakistan started to ease the locked down restrictions, which results in a sudden increase in the COVID-19 cases (Rehman et al., 2020). The trend of increase in the COVID-19 confirmed cases are presented in Fig. 1, illustrating the most serious period starting from the end of May 2020 to the mid of July 2020. From September 2020, the new confirmed cases were considerably under control (Nadeem and Khaliq, 2021). However, Pakistani authorities have been imposed a partial locked down throughout the year 2020 to prevent the mass gatherings in public places.

2. Methods

2.1. Questionnaire design

For the present study, a questionnaire was designed in three folds. First, the respondents’ sociodemographic details were asked, including gender, age, residence location, education level, income level, presence of travel restrictions, and the COVID-19 impacts on the occupation status.

Second, travel frequency-related close-ended questions were designed to reveal the trip frequencies by mode and trip frequencies by purpose in three COVID-19 severity periods (before the outbreak, during the most serious period, and after the most serious period). The travel modes considered for the present study include public transport, paratransit transport (e.g., rickshaw, minibus, wagon), cars, two-wheelers, walking, and shared transport. Travel purposes were commute and education, leisure, buy necessities, visiting religious places, and visiting hospitals.

Third, Likert scale-based questions were designed following reasoned action theory (Ajzen and Fishbein, 1980). According to the theory of reasoned action (Ajzen and Fishbein, 1980), behavioral intentions are the function of two factors, including attitude and subjective norms. In transportation literature, various extensions of the theory of reasoned action have been utilized to predict the intentions to adopt hybrid electric vehicles (Alzahrani et al., 2019), to explore the switching intentions towards public transit, and the usage of personal protective equipment while riding motorcycles (Norris and Myers, 2013). The attitude reflects the feelings of favorableness or unfavorableness towards performing a behavior (Hsiao and Yang, 2010). Thus, we hypothesized (H1) that the attitudes are directly and positively related to the intentions to use public transportation, as indicated in Fig. 2. Subjective norms refer to the perceived social pressure that significant others (parents, spouse, friends) desire the individual to perform or not perform a behavior (Zhang et al., 2016). Hypothesis (H2) emphasizes that subjective norms directly affect the intentions to use public transportation. For the present study, we extended the theory of reasoned action by adding the COVID-19 threat perceptions. Perceived COVID-19 threats refer to one’s feeling of fear from the COVID-19, which is also a reason for people to avoid public transportation during and after pandemics (Lamb et al., 2020). Hence, perceived COVID-19 threats are expected to negatively affect the willingness to use public transportation, constituting hypothesis (H3) as shown in Fig. 2.

Fig. 1. Average new confirmed cases in Pakistan (Dong et al., 2020; The Financial Times Ltd, 2021; World Health Organization, 2021).
Attitudes (Hsiao and Yang, 2010), subjective norms (Zhang et al., 2016), and intentions to use public transport (Borhan et al., 2019) in the post-pandemic period were measured with three items respectively (see Table 1) on a five-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. Perceived COVID-19 threats were measured with three items as illustrated in Table 1 on a seven-point Likert scale ranging from (1 = not true at all) to (7 = true at all) consistent with a previous study (Lamb et al., 2020). The percentage distributions of the responses to the items across the Likert scale can be seen in Appendix (Fig. A-1 and Fig. A-2).

2.2. Data collection

Considering the unavailability of nationwide data regarding travel behavior, we relied on the data collected through a questionnaire survey. Following COVID-19 standard operating procedures, it was difficult to collect a questionnaire survey with hard copies. Therefore, a questionnaire was prepared on Google forms and distributed randomly on various social media platforms (e.g., Facebook, WhatsApp, Twitter) to collect responses consistent with previous studies (Abdullah et al., 2020; Dingil and Esztergár-Kiss, 2021; Zhang and Lee, 2021). The data collection was started in early September when the new confirmed COVID-19 cases were under control. The weblink to collect the data was available from September 2020 to November 2020. A total of 565 responses were received from the respondents living in various Pakistani territories (Fig. 3), including Punjab, Khyber Pakhtunkhwa, Balochistan, Sindh, Gilgit Baltistan, and Islamabad. Most of the respondents were from Punjab province (42.89%), followed by Khyber Pakhtunkhwa (30.96%), Balochistan (9.62%), Sindh (7.53%), Gilgit Baltistan (2.1%) and Islamabad (6.9%). Data cleaning was performed to delete invalid responses, including the missing values and the ones which have similar responses for all the questions. Out of 565 responses, only 478 responses were found valid for further analysis. Following the simplified formula of Yamane (1967) mentioned in previous studies (Mihiretu et al., 2021; Munira and Santos, 2017), a valid sample size of 478 respondents were found statistically acceptable to conduct the analysis for the present study. According to the formula, when the precision level is (±5%) and the confidence level is 95%, the desired sample size is approximately 400 for the large population of more than two hundred million. The present study’s scope is to capture the changes in individuals’ self-reported mobility before the COVID-19 outbreak, during the most serious period, and after the most serious period. A longer time duration to collect questionnaire data for a recent pandemic situation may affect the responses as the memories evolve over time (Preston, 2009). Moreover, an increase in COVID-19 confirmed cases at the end of November 2020 was observed, as indicated in Fig. 1. Therefore, this study relied on the questionnaire data collected right after the peak of the new confirmed cases in Pakistan, as mentioned earlier in Fig. 1.

Table 1

| Items used to measure latent constructs | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 |
|----------------------------------------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| Perceived COVID-19 threat              | Thinking about the coronavirus (COVID-19) makes me feel threatened. | I am afraid of the coronavirus (COVID-19). | I am stressed around other people because I worry I will catch the coronavirus (COVID-19). | For me, taking public/shared transport is safe. | For me, taking public/shared transport is good. | For me, taking public/shared transport is convenient. | People who are important to me support me to use public/shared transport. | People who influence me, want me to take public/shared transport instead of any alternative means. | People whose opinions I value prefer that I should take public/shared transport to travel. | I am willing to use public/shared transport for my next travel. | I plan to take public/shared transport when I travel next time. | In the future, I intend to use public/shared transport to meet my travel needs. |
2.3. Analytical methods

Consistent with the objective, this study adopted three analytical methods. First, a descriptive analysis was conducted to explore the general trends of individuals’ trips in three severity periods of the COVID-19 in Pakistan, including before the outbreak, during the most serious period, and after the most serious period. Second, random parameter bivariate probit models were developed to identify the relation of respondents’ personal and perceived details on the change in mobility behavior in the COVID-19 severity change (before-to-serious period; serious-to-after most serious period). Third, the structural equation modeling approach was utilized to uncover the effects of attitudes and Perceived COVID-19 threats on willingness to use public/shared transportation in the post-pandemic period.

The random-parameter bivariate probit model has an advantage in capturing the unobserved heterogeneity by allowing the parameters to vary across observations. As this study deals with questionnaire survey-based data, models might have some unobserved correlations among error terms. A random-parameter bivariate probit model was adopted for this reason.

The first dependent variable in this study represents the change in the number of trips when the time changes from the before the outbreak (b) to the most serious period (d) and coded as: $b-d \rightarrow 0 \rightarrow 1$ (decrease in trips), $0 \rightarrow$ (no decrease in trips). The second dependent variable represents the change in the number of trips when the time changes from the phase of during the most serious period (d) to after most serious (a) and coded as: $a-d \rightarrow 0 \rightarrow 1$ (increase in trips), $0 \rightarrow$ (no increase in trips). Mathematically (Greene, 2012; Li et al., 2021; Sarwar et al., 2017), a general expression of the binary outcome of the model can be expressed as

$$Z_{i, 1} = \beta_{i, 1}X_{i, 1} + \epsilon_{i, 1}, \quad y_{i, 1} = \begin{cases} 1 & \text{if } Z_{i, 1} > 0, \\ 0 & \text{otherwise} \end{cases}$$

$$Z_{i, 2} = \beta_{i, 2}X_{i, 2} + \epsilon_{i, 2}, \quad y_{i, 2} = \begin{cases} 1 & \text{if } Z_{i, 2} > 0, \\ 0 & \text{otherwise} \end{cases}$$

with the cross-equation correlated error terms,

$$\begin{pmatrix} \epsilon_{i, 1} \\ \epsilon_{i, 2} \end{pmatrix} \sim N \left( \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix} \right)$$

where $X$ is a vector of explanatory variables that determine trip change (i.e., increase or decrease) based on characteristics of observation $i$, $\beta$ is a vector of estimable parameters, $y$ corresponds to integer binary outcome (zero or one for both dependent variables), $\epsilon$ is a random error (assumed to be normally distributed with zero mean and a variance of one), and $\rho$ refers to the cross-equation correlation coefficient of the error terms. To account for the unobserved heterogeneity with each group of observation generated by participants can be defined as

![Spatial distribution of the collected questionnaires.](image-url)

Fig. 3.
\[ \beta_j = \beta + u_j \]  

(4)

where \( \beta \) is the vector of estimable parameters and \( u_j \) is a randomly distributed term for each participant \( j \) with mean zero and variance \( \sigma^2 \). In such a bivariate random parameters modeling scheme, each \( \beta \) is defined for each participant \( j \), as opposed to the traditional random parameters scheme where each \( \beta \) is defined for each observation \( i \). In other words, Eq. (4) demonstrates that each of the participants will have their own \( \beta \). In this study, random parameters were assumed to follow a normal distribution. The mean and standard deviation of the normal distributed random parameters are presented in the modeling result.

This study developed bivariate random parameter probit models through NLogit software to capture the relationship among the changes in the number of trips by mode and purpose when the time has changed from before outbreak to most serious period and from most serious period to after most serious period. The change in the number of trips was considered as a dependent variable and coded as a binary variable; changes between the before the outbreak (b) and the most serious period (d); b-d>0 \( \rightarrow \) 1 (decrease), no decrease \( = 0 \); between the most serious period (d) and the after the most serious period (a): a-d>0 \( \rightarrow \) 1 (increase), no increase \( = 0 \).

The influence of perceived COVID-19 threats on intentions to use public transportation in the post-pandemic world was analyzed through structural equation modeling. Structural equation modeling (SEM) is suitable to capture the relationship among variables (latent constructs) that cannot be explained directly (Lee et al., 2021b). We used the partial least square path modeling (PLS-PM) approach of SEM (Lee et al, 2021a, 2021b; Sanchez et al., 2017). It consists of two models, including the inner model and the outer model. Mathematically, the inner model for relationships between latent variables can be written as (Henseler et al., 2009):

\[ \xi = B\xi + \zeta \]  

(5)

where \( \xi \) denotes the vector of latent variables, \( B \) is the matrix of coefficients of their relationships, and \( \zeta \) represents the inner model residuals. The basic PLS design assumes a recursive inner model that is subject to predictor specification. For this study, each manifest variable in a certain measurement model is assumed to be generated as a linear function of its latent variables and the residual \( \epsilon \):

\[ X_s = \Lambda_s \xi + \epsilon_s \]  

(6)

where \( \Lambda \) represents the loading (pattern) coefficients.

We used a package called “plspm” in R software to conduct structural equation modeling through the partial least square path modeling approach (Sanchez et al., 2017). A conceptual model was presented in the previous section in Fig. 2 with the items used to measure the constructs. In this section, we developed and validated the measurement model together with the formation of a structural model presenting the relationship among attitudes, subjective norms, perceived COVID-19 threats with the willingness to use public/shared transport.

Table 2

Respondent’s descriptive details.

| Variables                  | Frequencies | Percentages |
|----------------------------|-------------|-------------|
| Gender                     |             |             |
| Male                       | 411         | 86.0%       |
| Female                     | 67          | 14.0%       |
| Age                        |             |             |
| Minimum = 17, Maximum = 70, Mean = 27, S.D. = 7.01 | | |
| Education Level            |             |             |
| Lower than bachelor’s degree | 45        | 9.40%       |
| Bachelor’s degree          | 203         | 42.50%      |
| Master’s degree and above  | 230         | 48.10%      |
| Monthly Household Income   |             |             |
| Less than or 20,000 PKR    | 59          | 12.30%      |
| 21,000–60,000 PKR          | 246         | 51.50%      |
| 61, 000 PKR and above      | 173         | 36.20%      |
| Living Area                |             |             |
| Urban                      | 295         | 61.70%      |
| Non-urban                  | 183         | 38.30%      |
| Travel Restrictions        |             |             |
| Yes                        | 313         | 65.5%       |
| No                         | 165         | 34.5%       |
| Occupation                 |             |             |
| Self-employed              | 26          | 5.40%       |
| Office workers             | 130         | 27.20%      |
| Non-office workers         | 27          | 5.70%       |
| Jobless or retired         | 36          | 7.50%       |
| Student                    | 259         | 54.20%      |
| COVID-19 Impact            |             |             |
| Lost the Job               | 51          | 10.7%       |
| Shifted to part-time       | 42          | 8.8%        |
| Still working/studying full-time | 112   | 23.4%       |
| Still working full-time    | 33          | 6.9%        |
| Student shifted to study remotely | 190 | 39.7% |
| Temporary laid off (work/study) | 50   | 10.5% |

Note: 1 PKR = ~0.0065 USD (on April 1, 2021).
Average monthly household income in Pakistan = ~42,000 PKR (Pakistan Bureau of Statistics, 2019).
3. Results

3.1. Respondents’ details

The respondents’ details, including gender, age, education level, monthly household income, living area, travel restrictions, occupation, and perceptions of COVID-19 impacts, are presented in Table 2. Male participants (86%) were higher than the female participants, with an average age of 27 years. Furthermore, most respondents had a high education level (48.1%) and a monthly household income of 21000PKR-60000PKR. Most of the respondents were from urban areas (61.7%). Around (65.5%) of the total respondents reported facing travel restrictions during the COVID-19 spread. Students participated in this questionnaire survey more actively (54.2%), whereas office workers were 27.2%, as shown in Table 2. The COVID-19 spread has impacted all individuals; 39.7% of students were shifted to study remotely, whereas 23.4% of respondents indicated that they were still working or studying full time, as illustrated in Table 2. Some groups such as male, young, high income, and high education levels in the collected data may produce biased in the results and derived findings. However, it should be noted that the share of working women in Pakistan is relatively less than other population groups due to religious and cultural constraints (Abdullah et al., 2021; Javid et al., 2015). Therefore, females are less likely to commute or drive than males, constituting a low trip rate of approximately one-third of the males’ trip rate (Lee et al., 2021b). According to a provincial statistics report of Punjab Pakistan, only 5.2% of the total licenses were issued to women (Punjab Commission on the Status of Women, 2018). Given the gender inequality in Pakistan’s individuals’ mobility patterns, the share of the females in the collected responses makes an acceptable representation of the women population whose travel behavior was likely to be affected by the COVID-19 pandemic. According to Pakistan’s National Human Development Report 2017, the youth populations aged less than 30 years comprised 60% of the total nation’s population, which is one of the possible reasons for the young majority in the collected sample (Najam and Bari, 2017). Moreover, younger, more educated, and high-income people have greater access to the internet worldwide (Najam and Bari, 2017). Likewise, the high percentage of youth active on Pakistani social media is educated (Abdullah et al., 2021), resulting in many educated participants in this study.

Despite the limitations mentioned above, the results and findings derived from the collected responses would provide helpful information regarding changes in individuals’ mobility with the changes in the COVID-19 severity periods.

3.2. Descriptive analysis

3.2.1. Changes in trip frequencies

The results presented in Fig. 4 clearly show the variations in trip frequencies concerning the severity periods of the COVID-19 pandemic, including before the outbreak, during the most serious period, and after the most serious period. Fig. 4 explains the total weekly trip frequencies during three periods. Self-reported responses indicate that respondents had 6.5 total average trips in a week before the outbreak of COVID-19. During the most serious period of the COVID-19, respondents had reduced their trips to almost half (2.33 trips) of their total average trips per week, which has been recovered to 5.61 average trips per week after the most serious period.

3.2.2. Changes in mode choices

The variations in self-reported average individuals’ trips by mode in three severity periods of the COVID-19 are presented in Fig. 5. As indicated in Fig. 5, average trips by the public, paratransit (e.g., rickshaw, minibus, wagon), and shared transportation substantially decreased during the outbreak period, compared to the average trips by cars, two-wheelers, and walking. Considering the COVID-19 pandemic...

![Fig. 4. COVID-19 impacts on total trips/week.](image-url)
mass spread threats, it is reasonable for respondents to report the substantial reduction in public transportation usage.

3.2.3. Changes in trip purposes

Sufficient variation has been observed in the individuals’ self-reported trips by purpose with respect to the COVID-19 pandemic spread, as shown in Fig. 6. For better understanding, the self-reported trips mentioned by the respondents were considered a reference level to calculate the percentages of total trips by purpose during the most serious period and after the most serious period. Therefore, the percentages for trips before the outbreak were 100% depicting clearly an increase or decrease in trips by purpose in COVID-19 severity periods.

Except for the trips to buy necessities, all other trips substantially reduced during the most serious period and recovering to the normal level again after the most serious period. It is not surprising that the trips to buy necessities increased during the most serious period, as people were facing fully or partially locked down. The locked-down situation encouraged or forced people to stay at home, and people were only able to go out to buy necessary items resulting in an increase in these trips during the most serious period.

3.3. Random-parameter bivariate probit models

3.3.1. Change in self-reported trips by mode w.r.t change in pandemic severity

A series of random parameter bivariate probit models were developed considering the number of total trips by all modes, public transport trips, shared and paratransit mode trips, and bike/motorcycle/walking trips as binary dependent variables. Respondents’ personal and perceived details were considered as the independent variables, including age, gender, respondents with bachelor’s degree and lower, ownership of car, ownership of motorcycle, ownerships of bicycle, employed or retired, worker/self-employed/businessman, income of less than 30,000PKR, Agree with “I am threatened, afraid and stressed by COVID-19”, subjective norm, willingness to use public transport in future, safety perception of public transportation, Agree with “public transport is good and convenient” COVID-19 impact on flexible trips, trip restriction in area, and perception of COVID-19 severity.

According to Table 3, individuals with higher ages were found to decrease their trips when the time was changed from before-to-

![Fig. 5. COVID-19 impacts on average trips by modes/week.](image5)

![Fig. 6. COVID-19 impacts on average trips by purpose/week.](image6)
serious, as compared to people with lower age groups. Likewise, the elders were found to recover their total reduced trips faster than the other age groups when the time was changed from serious-to-after most serious. Males were found to have a significant reduction in their total trips when the time was changed from the before-to-serious period. However, the gender was not found significantly relevant to increase/decrease total trips in the time change of serious-to-after most serious period. Individuals having a bachelors' degree or lower education have significantly reduced their trips in a change of the COVID-19 severity from the before-to-serious period, whereas recovering faster in serious-to-after the most serious period. Those who were unemployed or retired respondents, those who own bicycles, and the ones who perceived public transport safe were more likely to reduce bike, motorbike, and walking trips in a change period as compared to other occupations. Similarly, people who feel threatened by the COVID-19 were more likely to reduce their trips, as compared to others with higher-income individuals, as indicated in Table 3. People who have a higher income of less than 30,000PKR, V10 = Agree with “I am threatened, afraid and stressed by COVID-19”, V11 = subjective norm, V12 = willingness to use public transport in future, V13 = safety perception of public transport, V14 = Agree with “public transport is good and convenient” V15 = COVID-19 impact on flexible trips, V16 = trip restriction in area, V17 = perception of COVID-19 severity.

For the public transport trips, individuals with lower-income people (having an income of lower or equal to 30,000 PKR) were not likely to reduce their trips, as compared to others with higher-income individuals, as indicated in Table 3. People who have a higher safety perception regarding public transportation were more likely to increase their public transport trips when the time changed from the serious-to-after most serious period. Those who were willing to use public transport were found to have an increase in total trips when the time changed from serious-to-after most serious, as compared to the ones who disagree to use public transport next time.

The results in Table 4 indicate that males were found to less likely to increase their shared/paratransit trips, as compared to females when the time changed from the serious-after the most serious period. In the change of before-to-serious period, the individuals with lower income level (lower or equal to 30000 PKR) were less likely to decrease their trips, as compared to higher income people. Unemployed or retired respondents, those who own bicycles, and the ones who perceived public transport safe were more likely recovering their shared/paratransit trips than respective others.

In Table 4, the change in total trips by bikes, motorbike, and walking was considered as the dependent variable. The individuals who perceived that the COVID-19 severely affected the flexible trips were more likely to reduce bike, motorbike, and walking trips in the before-to-serious period, whereas recovering faster than others in serious-to-after the most serious period. The individuals who faced the trip restrictions during the COVID-19 pandemic were recovering their bike, motorbike, and walking trips faster than those who did not face travel restrictions.

### Table 3
Change in number of trips by total trips/public transport trips.

| Variables                        | Model for change in total trips | Model for change in Public transport trips |
|----------------------------------|---------------------------------|-------------------------------------------|
|                                  | BS Coef. S.E.                  | SA Coef. S.E.                             | BS Coef. S.E.                  | SA Coef. S.E.                  |
| Intercept                        | -2.93974*** 0.36392            | -3.23018*** 0.38899                      | -1.77060*** 0.22938           | -1.92018*** 0.21054           |
| SD                               | .29294*** 0.04529              |                                          | .52169*** 0.06536             | .49623*** 0.06602             |
| V1                               | .03722*** 0.01166              | .05376*** 0.01137                        |                                          |                            |
| V2                               | .09325*** 0.00157              | .68104*** 0.07339                        |                                          |                            |
| V3                               | .36398*** 0.12245              |                                          |                                          |                            |
| V8                               | .31054*** 0.04436              |                                          |                                          |                            |
| V6                               | .29642*** 0.13337              | .70643*** 0.14822                       |                                          |                            |
| V9                               | .48128*** 0.14234              | .37235*** 0.15581                       |                                          |                            |
| V10                              | .19543*** 0.03627              | .16717*** 0.03938                       | .12128*** 0.02987             |                        |
| V11                              | .09453*** 0.00918              | .20922*** 0.00978                       | .32814*** 0.0669             |                        |
| V12                              | .177999*** 0.02583             |                                          |                                          |                            |
| V13                              | .11919** 0.0563                | .26850*** 0.07497                       | .16089** 0.06677             |                        |
| V14                              | .03722***                                   |                                          | -.21491*** 0.06216          |                        |
| Correlation between the errors   | .99839*** 0.00201               |                                          | .20488*** 0.0259             |                        |
| V15                              | .99839*** 0.00201               |                                          | .99975*** 0.00075            |                        |
| Log-likelihood                   | -.441.32447 1.77997***         | -.1.99218*** 1.77060***                 | -.326.51573 1.77997***      |                        |
| K (number of parameters)         | 21 13                             |                                          |                            |                        |
| Log-likelihood (UV/NRP)          | -.260.08006 142.45418          | -.227.62077 142.45418                  | -.217.14034 142.45418       |                        |
| K (number of parameters)         | 6 7 5 3                           |                                          |                            |                        |

Note: Only significant variables are presented in table.

BS= Before most serious outbreak-to-most serious period, SA = most serious period-to-after most serious period, SD = standard deviation, V1 = age, V2 = gender, V3 = respondents with bachelor’s degree and lower, V4 = ownership of car, V5 = ownership of motorcycle, V6 = ownership of bicycle, V7 = employed or retired, V8 = worker/self-employed/businessman, V9 = income of less than 30,000PKR, V10 = Agree with “I am threatened, afraid and stressed by COVID-19”, V11 = subjective norm, V12 = willingness to use public transport in future, V13 = safety perception of public transport, V14 = Agree with “public transport is good and convenient” V15 = COVID-19 impact on flexible trips, V16 = trip restriction in area, V17 = perception of COVID-19 severity.
In summary, the results from Tables 3 and 4 indicate that the reduction in mobility trips by all modes during the most serious period and recovery of the mobility trips by all modes was sensitive to the individuals’ characteristics as well as the COVID-19 threat perceptions. Males, respondents with high education levels, workers, self-employed, and business people have reduced their total trips during the most serious period of COVID-19. However, lower-income people were less likely to reduce their trips by public transportation. It is understandable as the lower-income people may work on daily wages and less likely to shift remotely due to their nature of work. The individuals who perceived COVID-19 severely affected the flexible travel have reduced their bike, motorbike, and walking trips in the most serious period and recovering faster than others after the most serious period. After the most serious period, a rapid recovery in the bike, motorbike, and walking trips was found for the respondents who faced travel restrictions in their areas. The findings indicate that the change in individuals’ mobility behavior is related to the mode of travel and the COVID-19 severity.

3.3.2. Changes in self-reported trips by purpose w.r.t change in pandemic severity

The results in Table 5 indicate that the individuals with higher age have reduced their commute trips in the before-to-serious period and also has been recovering faster than lower age groups in the serious-to-after most serious period. Likewise, individuals with bachelors’ degree or lower, worker or self-employed/business owners, living in an urban area, and afraid of the COVID-19 has been recovering faster than others in the change in the COVID-19 severity from serious-to-after most serious period. However, individuals who were workers or self-employed/business owners perceived the COVID-19 as severe, and perceived norms in favor of public transportation, willingness to use public transport in future, and safety perception of public transport were less likely to reduce their trips by public transport usage when the time changed as before-to-serious period.

Regarding the purchasing and hospital trips presented in Table 5, people with higher age, owned motorcycles, perceived public transport as safe and convenient mode, faced trip restrictions, and threatened by the COVID-19 severity were more likely to reduce their trips when time has changed from the before-serious period. However, male respondents indicated to have less reduction in their purchasing and hospital trips, as compared to females. When the time changed from the serious-to-after the most serious period, individuals with car ownership recovered their purchasing and hospital trips faster than those who own other vehicles.

Individuals with higher age, education level of bachelor’s degree or lower, owns the car, and perceive high severity of COVID-19 have reduced their leisure and visiting trips (see Table 6) compared to the respective others during the change before-serious pandemic period. Unlikely, when the time was changed from the before-serious period, the individuals with low income were reluctant to reduce their trips compared to high-income people. During the time change of serious-to-after most serious period, individuals who own cars, living in an urban area, and faced trip restrictions were recovering their leisure and visiting trips faster than other respective ones. However, individuals who perceived public transport safety were not likely to increase their leisure and visiting trips.

### Table 4

| Variables                              | Model for change in shared and paratransit | Model for change in Bike, motorbike, walking trips total trips |
|----------------------------------------|--------------------------------------------|---------------------------------------------------------------|
|                                        | BS                                         | SA                                            | BS                                         | SA                                           |
|                                       | Coef. S.E.                                 | Coef. S.E.                                     | Coef. S.E.                                 | Coef. S.E.                                    |
| Intercept                              | −1.3484*** 0.09612                        | −1.69605*** 0.15777                             | −1.38419*** 0.17044                       | −1.76617*** 0.18818                          |
| SD                                     | .65404*** 0.09065                         | .65317*** 0.14609                               | .54851*** 0.05457                        | .61538*** 0.02348                            |
| V2                                     | .59068*** 0.10711                         | .61925*** 0.05532                              | .44851*** 0.05457                        | .61538*** 0.02348                            |
| V6                                     | .63644*** 0.05532                         | .55177*** 0.16634                              | .44851*** 0.05457                        | .61538*** 0.02348                            |
| V7                                     | .61925*** 0.05532                         | .55177*** 0.16634                              | .44851*** 0.05457                        | .61538*** 0.02348                            |
| V9                                     | .88954*** 0.18485                         | .317215*** 0.19362                             | .46273*** 0.09317                        | .2048863* 0.03997                            |
| V10                                    | .15465*** 0.0399                           | .15465*** 0.0399                               | .21535*** 0.0099                         | .2048863* 0.03997                            |
| V11                                    | .97770*** 0.04849                         | .97770*** 0.04849                              | .99973*** 0.00042                        | .2048863* 0.03997                            |
| V12                                    | .09040*** 0.01444                         | .09040*** 0.01444                              | .2048863* 0.03997                        | .2048863* 0.03997                            |
| V13                                    | .42492*** 0.09773                         | .42492*** 0.09773                              | .42492*** 0.09773                        | .42492*** 0.09773                            |
| SD                                     | .77829*** 0.07533                         | .77829*** 0.07533                              | .77829*** 0.07533                        | .77829*** 0.07533                            |
| V15                                    |                                     | .33728* 0.18536                                | .33728* 0.18536                         | .33728* 0.18536                                |
| V16                                    |                                     | .1850988432 0.3005043                          | .1850988432 0.3005043                   | .1850988432 0.3005043                        |
| SD                                     |                                     | .20975*** 0.00288                              | .20975*** 0.00288                        | .20975*** 0.00288                            |
| Correlation between the errors R(1,2)  | .99973*** 0.00042                         | .99973*** 0.00042                              | .99973*** 0.00042                        | .99973*** 0.00042                            |
| Log-likelihood                         | −297.39027 115                           | −297.39027 115                                 | −300.5043 11                           | −300.5043 11                          |
| K (number of parameters)               | 15                                         | 15                                             | 2                                         | 2                                         |
| Log-likelihood (UV/NRP)                | −139.6388 7                              | −139.6388 7                                   | −204.8863 3                              | −204.8863 3                                |
| K (number of parameters)               | 26                                         | 26                                             | 3                                         | 3                                         |

Note: Only significant variables are presented in table.

BS = Before most serious outbreak-to-most serious period, SA = most serious period-to-after most serious period, SD = standard deviation, V1 = age, V2 = gender, V3 = respondents with bachelor’s degree and lower, V4 = ownership of car, V5 = ownership of motorcycle, V6 = ownerships of bicycle, V7 = employed or retired, V8 = worker/self-employed/businessman, V9 = income of less than 30,000PKR, V10 = Agree with “I am threatened, afraid and stressed by COVID-19”, V11 = subjective norm, V12 = willingness to use public transport in future, V13 = safety perception of public transportation, V14 = Agree with “public transport is good and convenient” V15 = COVID-19 impact on flexible trips, V16 = trip restriction in area, V17 = perception of COVID-19 severity.
Interestingly, results indicated that individuals with low income (lower than 30,000 PKR) were not likely to reduce their religious trips when the time changed from before-to-serious-period, as presented in Table 6. Those who feel threatened by the COVID-19 have reduced their religious trips in a time change from the before-to-serious period.

In summary, the results from Table 6 illustrate that the individuals with higher age have reduced almost all types of trips by purpose when the time has changed before most serious period to during the most serious period. However, males were less likely to reduce their purchasing and hospital trips during the most serious time period. The possible reason is that the population of working women is less than other population groups in Pakistan due to cultural and religious constraints (Abdullah et al., 2021; Javid et al., 2015; Lee et al., 2021b). The leisure trips and visits to relatives have been reduced when the time changed from the before-to-serious period. However, lower-income people were less likely to recover their leisure trips in the serious-to-after the most serious period. Individuals with lower income were less likely to reduce their trips before-to-serious period. In general, findings indicate that the travel frequencies by purpose did not have similar trends to the factors affecting the change in travel frequencies. These findings are helpful to understand the COVID-19 impacts and the relation of the individuals' characteristics with the change in travel frequencies by purpose.

### 3.4. Structural equation modeling

#### 3.4.1. Measurement model

The measurement model was developed to check the adequacy of items through reliability and validity tests. To meet the reliability and validity criteria, Cronbach alpha and composite reliability should be greater than 0.5, and 0.7 respectively (Dong et al., 2021; Sanchez, 2013). Further, Fornell-Larcker criterion was used to test validity (Fornell and Larcker, 1981; Henseler et al., 2015). To achieve Fornell-Larcker criterion, the square root of average variance extracted (AVE) arranged in off-diagonals should be larger than the correlations of constructs arranged in off-diagonals, as shown in Table 7.

Further, factor loadings were also calculated to check that the items appropriately load on their respective construct as suggested by Table 5.
### Table 6
Change in number of trips by in leisure and visiting trips/in religious trips.

| Variables | BS Coef. | S.E. | SA Coef. | S.E. | BS Coef. | S.E. | SA Coef. | S.E. |
|-----------|----------|------|----------|------|----------|------|----------|------|
| Intercept | -3.04649*** | 0.33097 | -2.16782*** | 0.23416 | -2.13375*** | 0.24119 | -1.60207*** | 0.22461 |
| SD V1     | .04199***  | 0.00911 | .42153*** | 0.0622 | .71394*** | 0.01202 | .20612*** | 0.01386 |
| V3        | .07240***  | 0.00432 | .09729    |      | .27190*** | 0.05657 | .03864    |      |
| SD V4     | .56495***  | 0.07214 | .15913    |      | .31169*** | 0.03864 | .08364    |      |
| V9        | -.49106*** | 0.17953 | .13316    |      | .14412*** | 0.05052 | .05121    |      |
| SD V10    | -.23188*** | 0.08266 | .11820*** | 0.01047 | .08502*  | 0.05121 | .05121    |      |
| V13       | -.56869    | 0.2926  | .35755**  | 0.16851 | .56495*** | 0.07214 | .08364    |      |
| V16       | .47557***  | 0.17804 | .47716*** | 0.1723 | .56495*** | 0.07214 | .08364    |      |
| V17       | -.49106*** | 0.17953 | .13316    |      | .14412*** | 0.05052 | .05121    |      |
| SD V18    | -.23188*** | 0.08266 | .11820*** | 0.01047 | .08502*  | 0.05121 | .05121    |      |
| V19       | -.56869    | 0.2926  | .35755**  | 0.16851 | .56495*** | 0.07214 | .08364    |      |
| V20       | .47557***  | 0.17804 | .47716*** | 0.1723 | .56495*** | 0.07214 | .08364    |      |

Note: Only significant variables are presented in table.

BS = Before most serious outbreak-to-most serious period, SA = most serious period-to-after most serious period, SD = standard deviation, V1 = age, V2 = gender, V3 = respondents with bachelor’s degree and lower, V4 = ownership of car, V5 = ownership of motorcycle, V6 = ownerships of bicycle, V7 = employed or retired, V8 = worker/self-employed/businessman, V9 = income of less than 30,000PKR, V10 = Agree with “I am threatened, afraid and stressed by COVID-19”, V11 = subjective norm, V12 = willingness to use public transport in future, V13 = perception of COVID-19 severity.

### Table 7
Reliability and validity of models’ constructs.

| Latent Constructs | Reliability of constructs | Formel-larcker criterion (diagonals = correlations, off-diagonals = √AVE) |
|-------------------|---------------------------|--------------------------------------------------------------------------|
|                   | Cronbach alpha | Composite reliability | AVE | COVID | SN | ATT | INT |
| COVID             | 0.909          | 0.943                   | 0.845 | 0.919 |    |     |     |
| SN                | 0.833          | 0.900                   | 0.749 |      | -0.105 | 0.865 |     |
| ATT               | 0.867          | 0.919                   | 0.790 |      | -0.141 | 0.649 | 0.889 |
| INT               | 0.911          | 0.944                   | 0.849 |      | -0.201 | 0.534 | 0.762 | 0.921 |

COVID= Perceived COVID-19 threats; SN= Subjective norms; ATT = Attitudes; INT = willingness to use public/shared transportation.

### Table 8
Factor loading of items used to measure constructs.

| Items | Question numbers | weight | Factor loading | communality |
|-------|------------------|--------|----------------|-------------|
| COVID | Q1               | 0.308  | 0.887          | 0.787       |
| COVID | Q2               | 0.345  | 0.938          | 0.88        |
| COVID | Q3               | 0.433  | 0.932          | 0.869       |
| SN    | Q4               | 0.395  | 0.866          | 0.75        |
| SN    | Q5               | 0.356  | 0.847          | 0.717       |
| SN    | Q6               | 0.404  | 0.883          | 0.78        |
| ATT   | Q7               | 0.384  | 0.914          | 0.835       |
| ATT   | Q8               | 0.374  | 0.882          | 0.777       |
| ATT   | Q9               | 0.367  | 0.871          | 0.758       |
| INT   | Q10              | 0.37   | 0.933          | 0.87        |
| INT   | Q11              | 0.369  | 0.936          | 0.875       |
| INT   | Q12              | 0.346  | 0.896          | 0.802       |

COVID= Perceived COVID-19 threats; SN= Subjective norms; ATT = Attitudes; INT = willingness to use public/shared transportation.
Sanchez (2013) (Table 8). According to the criteria of the factor loading greater than 0.5, all items were accepted for further analysis.

3.4.2. Structural model

The structural model was developed to explore the relationship among the individuals’ attitude, subjective norms, and perceived COVID-19 threats with the intentions to use public transport (Fig. 7). Results indicate that attitude has a positive relationship ($\beta = 0.706, p < 0.001$) with intentions to use public transport, leading to accepting hypothesis (H1). However, subjective norms ($\beta = 0.066, p = 0.086$) were not found to have a significant relationship with intentions to public transport at 0.05 significance level. Thus, hypothesis (H2) is not supported in this study. Hypothesis (H3) indicating the negative relationship of the perceived COVID-19 threat with the intentions to use public/shared transport is supported by the results ($\beta = -0.094, p = 0.002$). In the post-pandemic period, individuals who perceived higher COVID-19 threats are less willing to use public/shared transport, as a negative relationship exists between these two constructs.

To validate the structural model, we conducted the bootstrapping test with 1000 subsamples, as suggested in (Sanchez, 2013). Results validated the structural model presented in Table 9.

4. Discussions

This paper aimed to present the changes in individuals’ mobility behavior with respect to COVID-19 pandemic severity periods. It is well-known that COVID-19 adversely affected the transportation system. Still, a better understanding was required to explore the relationship of COVID-19 severity with individuals’ mobility behavior (trips by modes/trips by purpose), individuals’ characteristics (age, gender, education), and perceived details (safety perceptions, COVID-19 threat perceptions). To fill this knowledge gap, the study results shed light on the change in trips by mode and trips by purpose with respect to the change in COVID-19 pandemic periods, including before-to-serious period and serious-to-after most serious period. Using the reasoned action theory, the study also explains the negative effects of perceived COVID-19 threats on the willingness to use public/shared transport in the post-pandemic period. Thus, this study will help in understanding the change in individuals’ mobility behavior with respect to change in COVID-19 severity and provide insightful details to transportation agencies for the pandemic resilient policies and plans in the future.

The findings of the descriptive analysis presented in this study indicate a sudden decrease in individuals’ trips in the most serious period of the COVID-19 outbreak, consistent with the findings from the United States (Hu and Chen, 2021), Australia (Beck and Hensher, 2020), Poland (Borkowski et al., 2021), and Turkey (Shakibaei et al., 2021). Additionally, a comparison of self-reported trips by modes in three periods before the outbreak, most serious period, and after the most serious period indicated a slow recovery of trips by public/shared/paratransit transportation. However, trips by cars were alarmingly increased in the COVID-19 after the most serious period, more than the car trips that happened before the outbreak. These findings are also consistent with previous studies, including (Vickerman, 2021) from the UK (Anke et al., 2021), from Germany, and (Beck and Hensher, 2020) from Australia. Except buying necessities, all trips regardless of the purpose (commute/education, leisure, religion, hospital) were found to have a sudden decrease in the most serious COVID-19 pandemic, consistent with Germany, Turkey and China (Beck and Hensher, 2020; Shakibaei et al., 2021; Zhang and Lee, 2021). The increase in trips to buy necessities during the most serious period can be explained under the light of panic buying in the COVID-19 pandemic, as explained by Yuen et al. (2020).

The findings of the present study are also inconsistent with some previous studies. For example, a study from Spain indicated the willingness to use public transport in post-pandemic periods (Awad-Núñez et al., 2021). The possible reason for this is a well-equipped public transportation system in Spain. In developing countries like Pakistan, public transportation is not well equipped with preventive measures to reduce COVID-19 spread. Therefore, the study’s finding indicating slow recovery of individuals’ trips by public transportation after the most serious period in Pakistan is understandable. The rise in shared and personal bikes had been observed after the most serious period in New York and Seattle (Bian et al., 2021). Likewise, the average duration of trips on bike has been increased in Chicago and Boston (Padmanabhan et al., 2021). On the other hand, the active modes of transportation, including bicycles, walking

![Fig. 7. Structural model to explain the willingness to use public/shared transport in the post-pandemic period.](image-url)
remains less attractive due to the limited availability of facilitating conditions (e.g., public shared bicycle programs, infrastructure, and pedestrians’ facilities) in developing countries like Pakistan. During the COVID-19 peak in Taipei, Taiwan, a decrease in metro ridership was associated with the metro stations connected to night markets, shopping centers, or colleges (Chang et al., 2021). The local travel volumes in Hong Kong was also decreased for shopping (Zhang et al., 2021). However, the findings indicated the increase in the trips for buying necessities in Pakistan in the most serious period. Unlike the previous studies, this study included religious trips, which were found to reduce less and recover faster than commute/education and leisure trips when the time changed from the before-to-serious period and serious-to-after the most serious period, indicating the importance of mobility trips for religious activities in developing countries. This finding is justifiable as the youth in Pakistan believe their nationality and religion are the most important parts of their identity (Najam and Bari, 2017). The post-pandemic world will be likely to suffer from a reduction in public transport usage, which needs to be tackled by disseminating information regarding public transport usage benefits. Transportation agencies need to look upon the substantial increase in car trips, which will cause congestion and air pollution in the long run (Vickerman, 2021). Pandemic-based restriction policies should consider the religious trips, as it has not been substantially reduced during the most serious period of COVID-19, and recovering faster unlikely to other trips by purposes. As mobility behavior is sensitive to the COVID-19 severity, transport policies incorporating the variations in individuals’ mobility behavior will help develop pandemic resilient plans for future health threats.

The developed random parameter bivariate ordered probit models paved the way to understand the individuals’ mobility behavior in COVID-19 severity through the lens of personal and perceived characteristics. Findings suggest that the individuals’ mobility behavior varies according to the trip mode and trip purpose in a pandemic change from before-to-serious and serious-to-after most serious period. Individuals’ mobility had been reduced when COVID-19 severity changed from the before-to-serious period and recovered again in the change of serious-to-after the most serious period. In general, people with higher ages were more likely to reduce their all trips in COVID-19 severity change of the before-to-serious period, and fast recovering their trips in COVID-19 severity change of serious-to-after most serious period. Gender has also played an important role as males were more likely to reduce their total trips than females but less likely to reduce their purchasing necessities and hospital trips in a COVID-19 severity change form before-to-serious. It implies that males were more exposed to this COVID-19 threat at hospitals and commercial areas selling necessary items, as males continued to have such trips when COVID-19 severity changed from before-to-serious. The significant relationship of individual characteristics with trip generation in COVID-19 severity change suggests incorporating individuals’ characteristics while designing resilient pandemic policies, locked-down decisions, and traffic management in pandemics. For example, males of higher ages are less likely to reduce their trips during the most serious periods and should be provided with the education to take preventive measures to protect themselves when exposed to public places. Resilient pandemic policies may include funding to support the public transportation suffering from the sudden reduction in passengers as well as total revenue during and after the most serious period of COVID-19 spread. Likewise, transport policy for an efficient and accessible on-line logistic system can reduce the trips to buy necessities in the pandemic period in developing countries (Abdullah et al., 2021). Regional variation, including income, public transportation capacity, and availability of alternatives to work, should be considered for lockdown decisions. Because of the lockdown, areas with a large population of daily wage workers might be highly affected by poverty. Pinchoff et al. (2021) found that the males living in slums are more likely to travel by public transportation without considering the high risk of COVID-19 due to the increase in economic insecurity in Kenya. Therefore, policy initiatives to ensure the COVID-19 mitigation measures on public transportation are important in the pandemic period. In line with various traffic management programs, public shared bicycle programs for the short distance commute would be helpful for the lower-income people as an alternate to the public transportation during locked down. Further, the new concept of responsible transport needs sufficient attention in transport policies for developing countries as it encompasses individuals’ health and well-being, as indicated in a recent study (Budd and Ison, 2020).

The structural equation modeling approach’s findings verified that a positive relation of attitude with the individuals’ willingness to use public/shared transportation in post-pandemic still exists. However, perceived COVID-19 threats significantly resisting the individuals’ willingness to use public/shared transportation. Thus, transportation agencies and shared automobile companies should disseminate information through the campaign to reduce the perceived COVID-19 threats. Also, strictly following the policies of wearing a mask and taking a temperature before boarding on public/shared transport will be a new normal till the vaccine has not been injected into all the citizens. This will also help enhance the safety perceptions and reduce the threats of being affected by COVID-19. The majority of Pakistanis students are aware of COVID-19 spread and severity (Hussain et al., 2021), but the general population feels anxiety and fear due to COVID-19 spread, as mentioned in a recent study (Nadeem and Khaliq, 2021). Besides enforcing preventive measures to COVID-19 spread, the post-pandemic world needs educational interventions and awareness campaigns to encourage the public to use public/shared transportation.

Despite providing useful findings by shedding light on the COVID-19 impacts on individuals’ mobility in Pakistan, this study has some limitations. First, the unavailability of nationwide self-reported or travel survey data in Pakistan led us to rely on the

Table 9
Bootstrapping validity test.

| Paths          | Original Mean | Mean.Boot | Std.error | 95% confidence intervals |
|---------------|---------------|-----------|-----------|--------------------------|
| COVID– > INT  | -0.09         | -0.10     | 0.03      | (-0.15, -0.04)           |
| SN – > INT    | 0.07          | 0.07      | 0.04      | (-0.02, 0.16)            |
| ATT– > INT    | 0.71          | 0.70      | 0.04      | (0.62, 0.79)             |

COVID– Perceived COVID-19 threats; SN= Subjective norms; ATT = Attitudes; INT= Willingness to use public/shared transportation.
questionnaire survey-based data we collected. Questionnaire survey-based collected data has its own limitations as it is based on self-reported answers to the questions (Jones et al., 2013; Preston, 2009). Second, a large proportion of the survey respondents were students. Despite forming a large portion of the population who travel daily, a more generalized and large population sample in future research will help obtain the results that can be generalized to a broader context. The study incorporated limited variables to predict willingness to use public/shared transport in the post-pandemic period considering its scope, which can be extended in future studies by adding convenience, safety, anxiety to a pandemic, perceived behavioral controls. Future studies are also recommended to consider the differences among various countries regarding COVID-19 impacts on individual mobility.

5. Conclusions

The COVID-19 pandemic has changed the travel habits and behaviors of the worlds’ population. The present research has explored peoples' mobility behavior, including trips by modes (public transport, shared transport, paratransit transport, car, two-wheelers, and walking) and trips by purpose (commute/education trips, leisure trips, buy necessities/hospital trips, and religious trips) in before outbreak, most serious period, and after the most serious period of COVID-19 pandemic. Further, it also provides information about the Perceived COVID-19 threats on individuals’ willingness to use public transportation in the post-pandemic world.

Focusing on the overall mobility trends, the study’s findings provide important insights for transportation planners and policymakers to better prepare for traffic management plans in the future that are resilient to a pandemic spread. This study confirms that the individuals’ mobility behavior is sensitive to the COVID-19 severity in developing countries, especially in Pakistan. Thus, transportation organizations need to collect and incorporate the individuals’ mobility data for transportation system resiliency planning to prevent future health threats. Sufficient efforts will be required to bring public attention to public transportation usage in the post-pandemic era. Individuals’ characteristics (age, gender, education, living area, and monthly income) and perceived details (safety perceptions, COVID-19 threat perceptions, and travel restrictions) play an important role concerning the behavioral change in COVID-19 severity periods. Thus, such information should be considered for inclusive transportation planning and policy preparation. Regardless of developed and developing countries, COVID-19 has disruptively affected the whole world. However, the pandemic effects in developing countries, especially in Pakistan, may have long-lasting impacts considering the limited resources and facilities. Thus, more research is required, especially in developing countries’ contexts, to understand and minimize the COVID-19 impacts on mobility as well as finding more avenues to promote safer modes of transportation in the post-pandemic era, in the perspective of public health.

CRediT authorship contribution statement

Jaeyoung Lee: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – review & editing. Farrukh Baig: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft. Amjad Pervez: Data curation, Data collection, Investigation, Writing – review & editing.

Appendix

![Figure (A-1). Likert distributions of Perceived COVID-19 threats.](image-url)
Fig. ure (A-2). Likert distributions of latent constructs of theory of reasoned action.

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