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Can continued anti-epidemic measures help post-COVID-19 public transport recovery? Evidence from Taiwan

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ABSTRACT

Introduction and objective: COVID-19 has transformed economic activities and travel behavior, especially for public transport use. When a pandemic ebbs, clarifying travel behavior changes and whether to continue public transport anti-epidemic measures is essential for a post-COVID-19 public transport renaissance. Therefore, this study investigated citizens’ metro use behavior across the pre- to in-COVID-19 phases and post-COVID-19 mode choice in transit service and anti-epidemic policies.

Methods: Through face-to-face interviews, 235 citizens were systematically sampled in proportion to district populations in Kaohsiung, Taiwan, as respondents to conduct analysis of variance for metro use changes and mixed logit modeling for mode choice.

Results: Analysis of variance indicated an overall decrease in metro use from the pre- to in-COVID-19 phase and, for loyal-metro-user citizens, a recovery after entering the post-COVID-19 phase. Moreover, a mixed logit model illustrated that post-COVID-19 metro use was facilitated by mandatory mask wearing in the metro system, rather than transit service levels, and affected by age, number of household children, and pre-COVID-19 travel habits.

Conclusions: Continuing mandatory mask wearing within public transport in an early post-pandemic time and fostering transit use habits in non-pandemic times can help recover post-COVID-19 transit ridership. Moreover, a transit use promotion scheme may not need to target loyal users with original use before and no complete suspension after COVID-19.

1. Introduction

1.1. Background

Urban mobility demand has changed during the Coronavirus disease 2019 (COVID-19) pandemic since early 2020 worldwide. In Taiwan, located in East Asia, profound changes in travel patterns occurred in the first half of 2020. According to the cellular data obtained from Taiwanese residents, from middle January (when the Taiwanese government announced the COVID-19 alert) to middle August in 2020, trips with purposes for shopping necessities and open spaces increased respectively by 9% and 24%; however, those for public transit stations and workplaces decreased respectively by 7% and 12% (Google, 2020). Regarding travel mode use changes, during this period, private car trips increased by 15%, walking trips increased by 8%, and however public transit trips decreased by...
These changes have suggested that trips are more likely to be made for necessary life needs and low infection risk places but not for crowded places, such as entertainment and commercial venues, which are the major venues visited by confirmed COVID-19 cases (Kan et al., 2021).

Moreover, citizens’ judgment on high-risk places or occasions is also affected by anti-epidemic policy measures. For example, public transport has been listed in the venues of high infection and transmission risks by the Central Epidemic Command Center of Taiwan (CECC, 2020), mandating passenger mask wearing and temperature screening.

The implementation of epidemic prevention measures may transfer public transit demand to private transport, leading to the public transit operation and development crisis in the COVID-19 era.

Even if the pandemic turns to ebb in the future, travelers probably may not fully recover the level of public transit use before the COVID-19 outbreak, and the increasing tendency of private transport may threaten environmental sustainability. For this reason, Shaheen and Wong (2020) proposed short-term (within 1 year), medium-term (1 to 3 years), and long-term (4 to 6 years) strategies for sustainable transport recovery from COVID-19 impact, respectively, through restructuring funding and partnership based on prioritizing frequent public transport users, shaping active travel environment, and integrating electric vehicles into shared mobility for

| Date       | Feb 15 | March 15 | April 15 | May 15 | June 15 | July 15 | Aug 15 |
|------------|--------|----------|----------|--------|---------|---------|--------|
| The global | 50,580 | 153,517  | 1,914,885| 4,338,658| 7,823,289| 13,150,643| 21,026,755|
| Growth from the previous month (%) | —  | 304% | 1247% | 227% | 180% | 168% | 160% |
| Percent of world population (%) | <0.00% | <0.00% | 0.02% | 0.06% | 0.10% | 0.17% | 0.27% |
| Taiwan    | 18     | 59       | 395      | 440    | 445     | 451     | 482    |
| Growth from the previous month (%) | —  | 328% | 669% | 111% | 101% | 101% | 107% |
| Percent of Taiwanese population (%) | <0.00% | <0.00% | 0.002% | 0.002% | 0.002% | 0.002% | 0.002% |

Note: Organized from WHO (2020).

| Mode          | Type (Area served) | Main trip purposes                        | Phase Source from which data calculated |
|---------------|--------------------|-------------------------------------------|----------------------------------------|
| Taiwan High Speed Railway | Inter-city (Taiwan’s western corridor) | Working, business, and tourism | Pre-COVID-19 (A) × 100% |
|               |                    |                                           | Pre-COVID-19/Pre-COVID-19(A/A) × 100% |
|               |                    |                                           | [same monthly period (D)] × 100%       |
| Kaohsiung City Bus | Intra-city (Kaohsiung City, Taiwan) | Working, school, and shopping | Pre-COVID-19/Pre-COVID-19(B/A) × 100% |
|               |                    |                                           | Pre-COVID-19/Pre-COVID-19(C/A) × 100% |
|               |                    |                                           | [same monthly period (E)] × 100%       |
|               |                    |                                           | [same monthly period (F)] × 100%       |
| Kaohsiung Metro | Intra-city (Kaohsiung urban area, Taiwan) | Working, school, shopping, and tourism | Pre-COVID-19/Pre-COVID-19(B/A) × 100% |
| Taipei Metro  | Intra-city (Taipei urban area, Taiwan) | Working, school, shopping, and tourism | Pre-COVID-19/Pre-COVID-19(C/A) × 100% |

Note: Unit: person-trips. Pre-COVID-19: Before January 15, 2020 (Volume data count from January 1, 2020). In-COVID-19: From January 15, 2020 to June 7, 2020. Post-COVID-19: After June 8, 2020 (Volume data count to the end of June).

11% (Apple, 2020). These changes have suggested that trips are more likely to be made for necessary life needs and low infection risk places but not for crowded places, such as entertainment and commercial venues, which are the major venues visited by confirmed COVID-19 cases (Kan et al., 2021).

Moreover, citizens’ judgment on high-risk places or occasions is also affected by anti-epidemic policy measures. For example, public transport has been listed in the venues of high infection and transmission risks by the Central Epidemic Command Center of Taiwan (CECC, 2020), mandating passenger mask wearing and temperature screening. The implementation of epidemic prevention measures may transfer public transit demand to private transport, leading to the public transit operation and development crisis in the COVID-19 era.

Even if the pandemic turns to ebb in the future, travelers probably may not fully recover the level of public transit use before the COVID-19 outbreak, and the increasing tendency of private transport may threaten environmental sustainability. For this reason, Shaheen and Wong (2020) proposed short-term (within 1 year), medium-term (1 to 3 years), and long-term (4 to 6 years) strategies for sustainable transport recovery from COVID-19 impact, respectively, through restructuring funding and partnership based on prioritizing frequent public transport users, shaping active travel environment, and integrating electric vehicles into shared mobility for

1 Travelers with forehead temperature ≥ 37.5 °C or ear temperature ≥ 38.0 °C were banned from taking public transport.
travelers captive to private modes. Nevertheless, the short-term goal cannot be achieved without considering emerging demand with COVID-19. For example, the Taiwanese government had eliminated the first wave of COVID-19 community transmission since middle May 2020 and avoided a domestic pandemic through early border control and stringent quarantine procedures (See Table 1); however, public transit demand has not fully recovered despite, for the case of Kaohsiung, the largest city in southern Taiwan, adopting the same headway and enhanced transfer availability compared to the pre-COVID-19 phase (see Table 2). This situation implies that COVID-19 has impacted intra-city public transport for work, school, shopping, and tourism, served by Kaohsiung City Bus for the whole city and Kaohsiung Metro for the urban area. Furthermore, understanding the unprecedented travel demand is needed to improve transport equity since epidemic impacts on access to healthcare and avoidance of high infection risk are uneven across sociodemographic groups (Hsieh et al., 2021; Hua et al., 2021; Liu et al., 2021; Palm et al., 2021).

This study defined three phases by important anti-epidemic events to observe the impact of COVID-19 on public transport passenger volume in Taiwan. (1) Pre-COVID-19: The time before the government officially issued the national alert for COVID-19 on January 15, 2020. (2) In-COVID-19: The period from January 15, 2020 to June 7, 2020, during which the government gradually established standard operating procedures for epidemic prevention, such as mandatory public transport mask wearing and temperature screening. (3) Post-COVID-19: The time after 8 June, 2020, on which the government, considering that community transmission had been limited, declared the “Epidemic New Life Movement” to relax multifarious life bans, including mandatory public transport mask wearing, but appealed to community works and living habits to prevent the epidemic (see Fig. 1). Based on the definition, Table 2 shows that the impact of COVID-19 on public transport, excluding the cause of seasonal influence by displaying year-over-year volume, has markedly emerged both in inter- and intra-city travel. As the primary inter-city mode of transport for work, business, and tourism, Taiwan High Speed Railway lost over half of average daily passengers from the pre-COVID-19 to in-COVID-19 phase and only partially recovered in the post-COVID-19 phase (MOTC, 2020). Travel within urban areas has also changed even despite having eliminated community transmission. For example, similar demand shrinking and insufficient post-COVID-19 demand recovery occurred in bus and metro systems, especially for the latter, in Kaohsiung (DBAS, 2020; KRTC, 2020).

1.2. Research questions

Marked as the transition from the in- to post-COVID-19 phase, lifting mandatory mask wearing in public transport symbolized a reduction in the epidemic alert level in Taiwan. The purpose of the lifting was to mitigate public transit inconvenience for passengers. As a result, however, public transit ridership recovery was insufficient. The result was probably because the lifting of an epidemic prevention policy may increase citizens’ perceived infection risk in contact with non-mask-wearing passengers, even though diminishing the perceived epidemic alert level. Hence, for the government’s public transit promotion during a low-risk period, such as the defined post-COVID-19 phase without community transmission, an urgent research question is: (1) Do lifting mandatory anti-epidemic measures in public transport benefit or harm post-COVID-19 ridership recovery?

Moreover, public transport operators have resumed or enhanced service levels adopted in the pre-COVID-19 phase, but ridership has not recovered. Therefore, to evaluate public transport system operation after controlling a pandemic, a crucial question is: (2) Do public transport service levels affect post-COVID-19 mode choice?

Furthermore, as shown by the statistics, changes in public transport ridership across the three COVID-19 phases (pre-, in-, and post-COVID-19) were first decreasing and then only partially recovering. Therefore, to efficiently recover ridership levels, clarifying what type of passengers, instead of all passengers, should be targeted for the promotion of public transit use is necessary. For example, an efficient promotion policy must consider the possibility that the public transport demand of loyal users may spontaneously return to the pre-COVID-19 level and thereby reduce the financial burden. Thus, it helps subsidy mechanism design to examine the question: (3) Do loyal public transport users change use intensity across COVID-19 phases?

Clarifying the above three questions could facilitate mode split forecasts, transport and anti-epidemic policy evaluation, and public transport promotion in the COVID-19 era when the epidemic level continuously changes.

2. Literature review

This section reviews transport research on COVID-19-related policies and behavioral responses, including anti-epidemic measure adoption and travel behavior changes, by COVID-19 phases. These worldwide studies regarded launching a large-scale lockdown or

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2 The Central Epidemic Command Center of Taiwan resumed mandatory mask wearing in public transport since August 5, 2020.
national epidemic policy as a demarcation between the pre- and in-COVID-19 phase and its cessation as one between the in- and post-COVID-19 phase. Therefore, the literature review was organized to present overall responses to the epidemic and travel behavior changes across different epidemic phases.

2.1. Overall responses to COVID-19

To provide a relatively comprehensive and seamless conceptual framework to address current and potential COVID-19 impacts, J. Zhang (2020) advanced the PASS (P: Prepare–Protect–Provide; A: Avoid–Adjust; S: Shift–Share; S: Substitute–Stop) policymaking instructions for COVID-19 health threat mitigation. The applications of these instructions may rely on the accumulation of empirical studies on travel behavior under COVID-19. Buehler and Pucher (2021) examined cycling frequency across Europe, the Americas, and Australia from January 2019 to 2020 by location, trip purpose, and cycling facility type for an overall impact on and countermeasures of cycling. Based on finding the increased cycling trends and the demand for shifts from public transport, they recommended that governments expand cycling infrastructure and policy programs, such as protected on-road bike lanes, car-free zones, and shared streets, to support travel demand under COVID-19. This result implied that cycling could be a sustainable alternative to public transport during an in-COVID-19 phase, and cycling and public transport could provide mutual aid in a post-COVID-19 phase.

Organizing empirical evidence, Gkiotsalitis and Cats (2020) recommended that the models capable of aiding public transport service planning were urgently necessary given that the models considering contagious respiratory diseases were absent in the pre-COVID-19 time. In their review, although mask use and temperature checks for public transport were suggested to hinder the virus from spreading in the post-shutdown phase, the association of these intervention measures with travel behavior was not explored. In contrast to most research on the short-term impact of COVID-19 on travel behavior, Delbosc and Mccarthy (2021) studied the long-term COVID-19 impact on Australian young adults’ life plans and future mobility. Interviews disclosed that daily travel was profoundly affected by the pandemic, but long-term mobility decisions (e.g., residential and job locations, working from home, and car ownership) were additionally mediated by life milestones (e.g., education completion, career choice, and childbirth). The study also found that COVID-19 has accelerated car dependence owing to changed life plans and that the long-term impact on mobility was indirect and unevenly spread. Therefore, though private transport promotion and investment seem a solution to epidemic risk, the solution has aggravated social inequality and environmental problems. Public transport still needs a boost after an epidemic peak.

2.2. Travel behavior from pre- to in-COVID-19 phase

For travel behavior change caused by the first COVID-19 lockdown in early April 2020 following a nationwide contact ban in Germany, anti-COVID-19 measures focusing on restricting social contacts have been conducted to lower the speed of virus spread. For the Germany case, Kolarova et al. (2021) reported increased car use and decreased public transport use, less frequent substantial shopping replaced by online shopping, and relative activeness of young adults going out for leisure or errands. However, habitual bicycle users remained at the same rate (9%) across the pandemic outbreak. Compared to the decreasing ridership and negative perception of public transport, active travel as individual and green mobility such as walking and cycling has become increasingly crucial and potential for enhancing its current policies during the pandemic, including pop-up (corona/emergency) bike lanes, especially praised in Berlin. Unfortunately, in this case, individual socio-economic and travel characteristics were not used to realize mode choice mechanisms, and the influence of epidemic countermeasures in public transport was not explored.

During Australia’s COVID-19 lockdown in March and April 2020, working from home (WFH) has become regular. In addition, by promptly recognizing COVID-19 and bringing in regulations and associated mandatory restrictions, and the compliance of the public with the recommended and regulated guidelines, Australia has done relatively well in controlling the virus spread (Beck and Hensher, 2020). For this case, Hensher et al. (2021) found decreases in total trips, including private and public transport, and in commuting and non-commuting purpose trips; afterward, they advanced a model identifying WFH and its impacts on commuting car and public transport trips, enabling forecasting the number of weekly commuting trips by private and public modes. The WFH strategy as an effective response to the pandemic may entail that the strategy could facilitate both organizations’ improvements in productivity and employees’ benefits. Thus, the success in introducing WFH into Australia may result from a high percentage of citizens (70%) believing their productivity under WFH to be the same or higher than at the office. This belief is because the spent time for original long commuting could be spent with family and on leisure. Finally, in addition to focusing on WFH, the study recommended that travel patterns without epidemic prevention restrictions should be further modeled.

For an example of developing countries, Abdullah et al. (2021) explored Pakistan’s travel pattern changes before and during the pandemic. Pakistan conducted a nationwide lockdown in April 2020 for around a month and continuously extended it in some areas in megacities with severe clusters, called smart lockdown. The extension is partly because public transport in developing countries often carries millions of people beyond design capacity. The overcapacity in public transport has caused hygiene and social distancing maintenance problems. Therefore, the study on the case also considered travelers’ perceived health safety in public transport. The results revealed a significant mode shift from public transport to private cars for long distances (over 5 km). The study also elicited epidemic prevention factors of public transport that were considered by travelers during COVID-19 but did not examine their effects on mode choice.

2.3. Travel behavior in post-COVID-19 phase

Aiming at post-pandemic travel decision mechanisms, Luan et al. (2021) explored the impact of COVID-19 on travel mode choice...
and car purchase intention by using data collected in June 2020 after the epidemic’s highest timepoint in China, which could be treated as a post-COVID-19 phase. They concluded that public transport was the primary choice for long trips, that ride-hailing service use sharply declined, and that carless people intended to buy electric scooters more than automobiles. That is, even though the pandemic ebbed, people tended to travel alone for short daily trips. Thus, the study provided sufficient information on citizens’ travel mode preferences in the low infection-risk time but, unfortunately, did not clarify the influence of anti-epidemic measures in public transport on the preferences.

COVID-19 and coercive countermeasures have also affected travelers’ psychology affecting travel decision mechanisms. To present strategies for safe travel in post-COVID-19 times, Aaditya and Rahul (2021) explored the impact of the novel psychological constructs regarding COVID-19 on mode choice given the assumed post-pandemic scenario in India. The study clarified that disease awareness and perceived lockdown strictness primarily affected mode choice. Moreover, perceived safety in public transport (characterized by social distancing and sanitization measures) influenced the willingness to use public transport. The result implied that lifting anti-epidemic control in public transport may disadvantage ridership recovery after a lockdown. Therefore, further research needs to clarify the influence of epidemic prevention measures in public transport based on a factual post-pandemic situation. If anti-epidemic measures do affect travel behavior, the prediction or desirable outcome of post-pandemic travel demand should consider the measures.

2.4. Summary of literature review

The efforts to mitigate COVID-19 impact have provided insights into policymaking instructions, the capture of travel behavior changes before and during the pandemic, and the simulated profiles of post-pandemic travel behavior. However, less research has explored the association of post-COVID-19 public transport ridership recovery, compared to in- and pre-COVID-19 phases, with anti-epidemic measures in public transport. Hence, to bridge the research gap, the present study took Taiwan as the empirical example, which accommodated a temporary two-month post-COVID-19 period without domestic disease cases, lockdown, and mandatory mask use (including that in public transport), to explore public transport use behavior across COVID-19 phases and post-COVID-19 mode choice with public transport anti-epidemic policies.

3. Methods

This study took Kaohsiung Metro (in Kaohsiung City, Taiwan), which was extensively impacted by COVID-19 (see Table 2), as the empirical case of public transport. Citizens in the Kaohsiung urban area, being the primary service area of the metro system, were treated as the population. For the three research questions of this study regarding travel behavior changes and mode choice in the COVID-19 era, two surveys and corresponding analyses were conducted: (1) metro use behavior across the three COVID-19 phases, examined by the analysis of variance (ANOVA) of metro use frequency changes; (2) stated preference (SP) for mode choice in the scenarios composed of service and anti-epidemic policies of public transport, illustrated by an error-component mixed logit model considering SP’s repeated observations within respondents. This section describes the adoption of variables, experimental design for SP acquisition, modeling methodology considering SP responses, data collection, and respondent characteristics.

3.1. Variables and experimental design

Initially, to investigate metro use behavior changes by ANOVA, this study took weekly metro use frequency as the dependent variable, the COVID-19 phase containing three periods as the factor, and the binary loyal metro use as the segmentation variable used to examine the difference in COVID-19 impact. The group of loyal metro users was defined as the respondents with any metro use (≧1 trip) in all three COVID-19 phases, the non-loyal-metro-user group: The citizens with no metro use (0 trip) in all three COVID-19 phases.

| Variable | Definition | COVID-19-related travel behavior change reference for variable adoption |
|----------|------------|-------------------------------------------------------------------------|
| Dependent variable | Metro use frequency | The average number of trips by metro per week | — |
| Explanatory variable | COVID-19 phase | Three categories were distinguished: | Aaditya and Rahul (2021); Abdullah et al. (2021); Beck and Hensher (2020); Delbosc and Mccarthy (2021); Hensher et al. (2021); Kolarova et al. (2021); Luan et al. (2021) |
| | In-COVID-19: Before January 15, 2020 (COVID-19 alert announcement) | Allen et al. (2019); Gao et al. (2019) |
| | Post-COVID-19: Since June 8, 2020 (lifting mandatory mask wearing in public transport) until late July 2020 (the end of the present study’s survey) | — |
| Segmentation variable | Loyal metro user | Two categories were distinguished: | — |
| | Loyal-metro-user group: The citizens with any metro use (≧1 trip) in all three COVID-19 phases | — |
| | Non-loyal-metro-user group: The citizens who were not loyal metro users | — |
Table 4
Variables in modeling mode choice (metro or not) in post-COVID-19 phase

| Variable | Definition | Mode choice reference for variable adoption |
|----------|------------|---------------------------------------------|
| Dependent variable | Metro use | Stated preference for metro use given a scenario composed of public transport and epidemic prevention policy attributes in a certain level = 1; stated preference for other mode use given the scenario = 0 |
| Explanatory variable (public transport service policy; SP attributes) | Waiting time | Average metro waiting time was specified as four levels: • 2.5 min (off-peak average waiting time of a commuting line [Wenhu Line] of Taipei [the capital of Taiwan] Metro) • 3 min • 3.5 min (average waiting time of Kaohsiung Metro before April 2020) • 4 min (average waiting time of Kaohsiung Metro adapted to the epidemic from April 2020 to middle July 2020) |
| | Transfer availability | Available sets of transfer modes from metro stations were specified as three levels: • Bus (as reference) • Bus and shared bicycles = 1; otherwise = 0 • Bus, shared bicycles, and shared electric scooters = 1; otherwise = 0 |
| Explanatory variable (epidemic prevention policy; SP attributes) | Temperature screening | Temperature screening in the metro system was specified as two levels: • Not implemented (as reference) • Temperature screening required for entering metro ticket gates = 1; otherwise = 0 |
| | Mandatory mask wearing | Mandatory mask wearing in the metro system was specified as three levels: • Not implemented (as reference) • Mandatory mask wearing required for entering metro cars = 1; otherwise = 0 • Mandatory mask wearing required for entering metro ticket gates = 1; otherwise = 0 |
| Explanatory variable (household socio-economic characteristic) | Number of household cars | Number of cars owned by the household to which an individual belonged |
| | Number of household scooters | Number of scooters owned by the household to which an individual belonged |
| | Number of household members aged below 5 | Number of members aged below 5 in the household to which an individual belonged |
| | Number of household members aged 6-17 | Number of members aged 6-17 in the household to which an individual belonged |
| | Number of household members aged 18-64 | Number of members aged 18-64 in the household to which an individual belonged |
| | Number of household members aged above 65 | Number of members aged above 65 in the household to which an individual belonged |
| Explanatory variable (individual socio-economic characteristic) | Gender | Male = 1; female = 0 |
| | Age | Individual age was separated into five categories: • Below 17 years (as reference) • 18 to 34 years = 1; otherwise = 0 • 35 to 49 years = 1; otherwise = 0 • 50 to 64 years = 1; otherwise = 0 • Above 65 years = 1; otherwise = 0 |
| | Income | Individual monthly income was separated into six categories: • Below NT$10,000 (as reference) • NT$10,001 to $25,000 = 1; otherwise = 0 |

(continued on next page)
### Table 4 (continued)

| Variable | Definition | Mode choice reference for variable adoption |
|----------|------------|---------------------------------------------|
| Occupation | Individual occupation state was separated into three categories: | Aaditya and Rahul (2021); Golshani et al. (2018); Shabanpour et al. (2017) |
| • NT$25,001 to $40,000 = 1; otherwise = 0 | • The non-student unemployed (as reference) |
| • NT$40,001 to $55,000 = 1; otherwise = 0 | • Student = 1; otherwise = 0 |
| • NT$55,001 to $70,000 = 1; otherwise = 0 | • Employment = 1; otherwise = 0 |
| • Above NT$70,001 = 1; otherwise = 0 (NT $1 = US$0.036) | |
| Car driving license possession | Holding car driving license = 1; otherwise = 0 | Kamargianni et al. (2014); Van et al. (2014) |
| Scooter driving license possession | Holding scooter driving license = 1; otherwise = 0 | Included for scooter as a prevailing mode in Taiwan |
| Explanatory variable (pre-COVID-19 travel habit) | Pre-COVID-19 main travel mode (past habitual travel mode) | Bamberg (2013) |
| Pre-COVID-19 weekly metro use frequency (past habitual travel level) | The main travel mode before the COVID-19 announcement (January 15, 2020) | Bamberg et al. (2007); Gardner and Abraham (2008) |
| • Metro (as reference) | • Car = 1; otherwise = 0 |
| • Scooter = 1; otherwise = 0 | • Walk = 1; otherwise = 0 |
| • Bicycle = 1; otherwise = 0 | • Bus = 1; otherwise = 0 |

### Table 5

Scenarios of orthogonal experimental design for stated preference choices.

| Scenario | SP attributes: public transport service policy | SP attributes: epidemic prevention policy |
|----------|-----------------------------------------------|-----------------------------------------|
|          | Waiting time (4 levels) | Transfer availability (3 levels) | Temperature screening (2 levels) | Mandatory mask wearing (3 levels) |
| 1        | 3 min | Bus | Not implemented | Mandatory mask wearing required for entering metro cars |
| 2        | 4 min | Bus | Temperature screening required for entering metro ticket gates | Not implemented |
| 3        | 3.5 min | Bus | Temperature screening required for entering metro ticket gates | Not implemented |
| 4        | 2.5 min | Bus, shared bicycles, and shared electric scooters | Not implemented | Mandatory mask wearing required for entering metro ticket gates |
| 5        | 4 min | Bus and shared bicycles | Not implemented | Mandatory mask wearing required for entering metro cars |
| 6        | 3 min | Bus | Temperature screening required for entering metro ticket gates | Not implemented |
| 7        | 3.5 min | Bus | Not implemented | Not implemented |
| 8        | 3.5 min | Bus and shared bicycles | Not implemented | Not implemented |
| 9        | 3 min | Bus, shared bicycles, and shared electric scooters | Not implemented | Mandatory mask wearing required for entering metro ticket gates |
| 10       | 4 min | Bus | Not implemented | Mandatory mask wearing required for entering metro ticket gates |
| 11       | 4 min | Bus, shared bicycles, and shared electric scooters | Temperature screening required for entering metro ticket gates | Not implemented |
| 12       | 2.5 min | Bus | Not implemented | Not implemented |
| 13       | 3.5 min | Bus, shared bicycles, and shared electric scooters | Temperature screening required for entering metro ticket gates | Mandatory mask wearing required for entering metro cars |
| 14       | 2.5 min | Bus | Temperature screening required for entering metro ticket gates | Mandatory mask wearing required for entering metro cars |
| 15       | 3 min | Bus and shared bicycles | Temperature screening required for entering metro ticket gates | Not implemented |
| 16       | 2.5 min | Bus and shared bicycles | Temperature screening required for entering metro ticket gates | Mandatory mask wearing required for entering metro ticket gates |
trip) in all three COVID-19 phases. The purpose of this definition was to feature original metro use before COVID-19 and no complete suspension of the use after COVID-19. The detailed definitions and adoption references of the variables are shown in Table 3.

Then, to model mode choice for metro use in the post-COVID-19 phase, binary choice of whether to choose metro as the dependent variable was treated as explained by metro service and anti-epidemic policies, household and individual socio-economic characteristics, and past travel habit (travel mode and level) in pre-COVID-19 times. Policy variables were specified as SP attributes to produce variances in policy levels for policy evaluation since those levels did not appear in the current circumstance except the current levels. The detailed definitions and adoption references of the variables are exhibited in Table 4.

In the SP scenarios of mode choice, the service level of Kaohsiung Metro was characterized by waiting time and transfer availability. The average headway in the survey period during the post-COVID-19 phase followed the in-COVID-19 level, such that the current average waiting time (4 min) was longer than before responding to COVID-19 (3.5 min). Thus, the pre-COVID-19 level of 3.5 min and the other two possible levels of 3 and 2.5 min as the improvement scenarios were specified to design SP scenarios. Moreover, the current transferring public and shared modes of the metro contained bus service and a recently developed shared bicycle system built with each metro station. Therefore, the level without the shared bicycle system was incorporated to examine the effect of developing active transport to respond to COVID-19 on metro use. In addition, the level with shared electric scooters as an available type of transferring mode surrounding metro stations was added to the transfer availability levels to evaluate the effect of shared electric scooters on metro use facilitation.

Moreover, in the post-COVID-19 phase, the Taiwanese government lifted the policy of mandatory mask wearing for entering metro ticket gates. Therefore, no mandatory requirement, the in-COVID-19 mask-wearing policy, and a possible intermediate level of other possible levels of temperature screening was included in SP scenarios. Considering the multiple levels of the above four policy attributes (waiting time, transfer availability, temperature screening, and mandatory mask wearing), this study applied the orthogonal experimental design method to balance experimental cost and response validity by avoiding the collinear attribute combinations (Borille and Correia, 2013; Chi and Bloebaum, 1996). Thus, a full-factorial experiment with the original 72 scenarios was reduced to the one with 16 scenarios composed of policy attribute levels (see Table 5). Each respondent was asked to choose whether to use metro in two randomly selected scenarios.

### 3.2. Model

For mode choice, a binary logit model for whether to use a mode of interest is applicable. However, in an efficient stated preference survey, respondents are often asked to choose alternatives in multiple scenarios to obtain more variances in policy attributes and reduce survey costs. This operation produces what has been called a pseudo panel (i.e., a type of panel data with repeated observations) (Yáñez et al., 2011), where the observations from each respondent may be interdependent. For the possibility of such interdependence, this study applied a mixed logit model with an error component to accommodate the unobserved individual heterogeneity among the choices in the pseudo panel to replace a general logit model (Ortúzar and Willumsen, 2011).

Regarding econometric specification in this study, the individual $i$’s utility $h_i$, contained in a logit model and representing observed heterogeneity across individuals, was assumed through linear specification as follows:

$$h_i = b + c'X_i + d'Y$$  \hspace{1cm} (1)

where $X_i$ is a column vector of individual-specific variables (including individuals’ household characteristics), $Y$ is a column vector of policy variables (public transport service and anti-epidemic policies as SP attributes), $b$ is an unknown constant, and $c'$ and $d'$ are column vectors of unknown parameters.

In addition, unobserved individual heterogeneity ($\mu_i$), as discussed above, needs to be incorporated. Therefore, Eq. (1) was rewritten as follows:

$$h_i = b + \mu_i + c'X_i + d'Y, \mu_i \sim N(0, \sigma_\mu)$$  \hspace{1cm} (2)

With denoting individual $i$’s binary choice as $w_i$ based on $\sigma_{(w_i)}^2 = 1$ by normalization and the parameter $\rho = \sigma_\epsilon^2 / (\sigma_{(w_i)}^2 + \sigma_\epsilon^2)$, representing the autocorrelation between pseudo-panel waves in errors, the scale parameter of the error component ($\sigma_\epsilon$) was formulated as follows:

$$\sigma_\epsilon = \sqrt{\rho/(1-\rho)}$$  \hspace{1cm} (3)

Thus, in the case of binary choice, the probability of choosing an alternative for individual $i$ was constructed as follows:

$$P(w_i) = \frac{\exp[w_i(h + \mu_i + c'X_i + d'Y)]}{\sum_{i\epsilon\{1,0\}} \exp[w_i(h + \mu_i + c'X_i + d'Y)]}$$  \hspace{1cm} (4)

where $b + \mu_i$ accounted for each individual $i$’s specific constant term that, however, was unvaried in the individual’s multiple SP choice scenarios. Maximum likelihood estimation was used to derive the unknown parameters in Eq. (4), the scale parameter of the error component ($\sigma_\epsilon$), and the autocorrelation between pseudo-panel waves ($\rho$).
3.3. Data collection

This study treated the citizens of the Kaohsiung urban area, the largest city in southern Taiwan, as the population and the metro system of Kaohsiung Mass Rapid Transit as the public transport case (see Fig. 2). This urban area features a population density of 9,829 inhabitants per km$^2$ in 11 administrative districts covering an area of 153.59 km$^2$ and two cross-shaped metro lines distributed across the city. The study area encompasses the Kaohsiung urban area and the metro system of Kaohsiung Mass Rapid Transit (MRT) (see Fig. 2).

Table 6
Comparison in respondent characteristics between present study and census.

| Characteristic                  | The present survey (N = 235) | Census       |
|--------------------------------|------------------------------|--------------|
| Gender                         | Male 45%                     | 48.5%        |
|                                | Female 55%                   | 51.5%        |
| Age                            | Below 17 20%                 | 12% (Below 15)|
|                                | 18–34 40%                    | 71% (16–64)  |
|                                | 35–49 22%                    |              |
|                                | 50–64 13%                    |              |
|                                | Above 65 5%                  | 17%          |
| Monthly income (NT$ = US$0.036)| Below 10,000 45%             | Median: 23,392$^5$|
|                                | 10,001–25,000 16%            |              |
|                                | 25,001–40,000 21%            |              |
|                                | 40,001–55,000 8%             |              |
|                                | 55,001–70,000 6%             |              |
|                                | Above 70,001 4%              |              |
| Car license ownership          | Yes 51%                      | 55%          |
|                                | No 49%                       | 45%          |
| Scooter license ownership      | Yes 70%                      | 62%          |
|                                | No 30%                       | 38%          |

Note: $^6$ The census differs in the age layer division from the present survey. Hence, this table can only exhibit the census percentages aged below 15 and 16–64 versus the respondents below 17 and 18–64. $^5$ Since the census statistics do not provide a layered income distribution in the Kaohsiung urban area (the study area), this table presents the income median in the whole Kaohsiung City, showing that the income median among the respondents lay in the layer that comprised the income median among the population.

3.3. Data collection

This study treated the citizens of the Kaohsiung urban area, the largest city in southern Taiwan, as the population and the metro system of Kaohsiung Mass Rapid Transit as the public transport case (see Fig. 2). This urban area features a population density of 9,829 inhabitants per km$^2$ in 11 administrative districts covering an area of 153.59 km$^2$ and two cross-shaped metro lines distributed across the city.
There are three cities with a metro system in Taiwan. Taipei has the longest history of public transport system development than others. Taipei Metro has operated since 1996. Nowadays, Taipei is a well-transit-developed city with complete bus and mass rapid transit networks. By contrast, the development of mass rapid transit in Kaohsiung is later than in Taipei. The operation of Kaohsiung Metro began in 2008. To date, however, there are only two lines in the Kaohsiung Metro network, and the construction work of additional lines is still developing to extend the service coverage. In 2020, the public transport market share based on the main mode in Taiwan was 16.0%, whereas that in Kaohsiung as a transit-developing city was merely 6.3% (MOTC, 2021). It needs to be noted that the COVID-19 impact on metro systems may differ between cities with different transit development stages. Table 2 shows that the COVID-19 impact on the metro in the transit-developing city, Kaohsiung, was larger than that on the metro in the transit-developed city, Taipei. The Kaohsiung Metro ridership declined more steeply between the pre- and in-COVID-19 phase. The investigation into the Kaohsiung case could probably provide insights for other transit-developing cities that desire to improve transit systems but face the epidemic challenge in the near future.

Given the investigation into three-phase travel behavior, the questionnaire survey was conducted through face-to-face interviews with explaining the phase periods to respondents for data quality. The data collection procedure was established to increase the sample representativeness as follows. (1) Set the sampling rate above 1.5‰ after removing invalid samples as the objective. (2) Decide the expected number of respondents in each district in proportion to the district population. (3) Randomly sample 32 streets as the interview locations, whose respective number in a district was proportional to the expected number of respondents in the district. (4)
Systematically invite each fifth person passing the interviewer. Finally, 235 valid respondents were interviewed, and the SP mode choices of 470 choosers taken by these respondents (each of whom was provided with two choice scenarios) were collected. To understand the sample representativeness, Table 6 compares the distributions of respondent characteristics with those in the census. Gender and vehicle license ownership reflected the closeness between the sample and the population, while the comparison in age implied a limitation upon the inference from the sample of seniors.

4. Results

4.1. Metro use changes across COVID-19 phases

This study employed ANOVA with repeated measures to examine weekly metro use frequency changes across the three COVID-19 phases. Initially, based on one-way (phase) ANOVA results, as shown in Table 7 and Fig. 3, total respondents (representing ordinary citizens in the Kaohsiung urban area) had a significant decrease in weekly metro use frequency from the pre- (1.66 times/week) to in-COVID-19 phase (1.38) ($p < 0.01$) and a significant recovery from the in- to post-COVID-19 phase (1.57) ($p < 0.01$). Although the post-COVID-19 metro use level was lower than the pre-COVID-19 one, the difference between both phases was not statistically significant ($p > 0.1$).

Then, to clarify the impact of COVID-19 on loyal metro-user citizens and its difference from those who used other modes entirely without using metro during any phase, two groups were separated to conduct one-way ANOVA. One group was named the “loyal-metro-user group,” comprising the respondents who used metro at least once in all three phases. The other group was named the “non-loyal-metro-user group,” comprising the respondents who did not use metro during any phase. Table 7 and Fig. 4 report the results. The loyal-metro-user group significantly decreased weekly metro use frequency from the pre- (2.11 times/week) to in-COVID-19 phase (1.79) ($p < 0.01$) but significantly increased it after entering the post-COVID-19 phase (1.98) ($p < 0.05$), which recovered to the pre-COVID-19 level ($p > 0.1$). However, although the non-loyal-metro-user group also significantly decreased weekly metro use frequency from the pre- (1.15) to in-COVID-19 phase (0.92) ($p < 0.01$), a significant recovery did not emerge in the post-COVID-19 phase (1.08) ($p > 0.1$).

Furthermore, to confirm the interaction effect of the phase of COVID-19 and the loyalty to metro on metro use frequency, three (pre-, in-, and post-COVID-19 phases) by two (loyal- and non-loyal-metro-user groups) ANOVA was executed. Table 7 shows that both the phase and group factors significantly affected metro use frequency, but their interaction effect on metro use frequency did not arise. Namely, as exhibited in Fig. 4, both groups had a similar trend of changes in metro use frequency across the COVID-19 phases.

4.2. Mode choice in post-COVID-19 phase

Although the modeling approaches and the determinants of mode choice have been familiarized in transport planning, COVID-19 may restructure the need hierarchy in transit (Allen et al., 2019) because the prior studies (Aaditya and Rahul, 2021; Luan et al., 2021) implied that COVID-19 had increased physiological safety needs even after a pandemic (namely, in a post-COVID-19 phase defined in the present study). Hence, the present model clarified the determinants of mode choice of whether to use metro in post-COVID-19 times and evaluated the influence of lifting mandatory mask wearing in public transport on post-COVID-19 metro use. Furthermore, the model modification applied the suggestion from Ortúzar and Willumsen (2011) that nonsignificant policy variables with a sign corresponding to a priori notions be included (probably turning to be significant if based on a large sample size), but other-type variables be rejected if not significant at the 80% confidence level.

The final estimation is reported in Table 8. The model had an acceptable fit with a rho-squared value of 0.324. Moreover, it was worth noting that the incorporated error component had a significant effect on mode choice ($p < 0.01$) with a high autocorrelation (0.828) within respondents between SP choices in different policy scenarios. The presence of the autocorrelation implied that a general

![Fig. 4. Weekly metro use frequency and comparison between COVID-19 phases and groups (*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.](image-url)
those aged below 17 significantly influence the metro choice probability. However, the mask-wearing requirement for entering metro cars was not significant. Mask wearing for entering ticket gates increased the metro choice probability significantly. Concerning the variables of anti-epidemic policies that might decrease riding convenience and comfort, first, the rule of mandatory public transport use did not significantly influence the metro choice probability in the post-COVID-19 phase. The estimation results of the error-component mixed logit model. Discrete choice model without an error component might lead to biased coefficients in this empirical case. Therefore, this study adopted the estimation results of the error-component mixed logit model.

According to the estimation results, waiting time and transfer availability as conventionally key transport policy predictors of public transport use did not significantly influence the metro choice probability in the post-COVID-19 phase ($p > 0.1$). However, concerning the variables of anti-epidemic policies that might decrease riding convenience and comfort, first, the rule of mandatory mask wearing for entering ticket gates increased the metro choice probability significantly ($p < 0.05$); in contrast, the effect of the mask-wearing requirement for entering metro cars was not significant ($p > 0.1$). Then, the temperature screening rule did not significantly influence the metro choice probability ($p > 0.1$), implying that respondents may perceive mutual mask protection as a more effective epidemic prevention measure than preventing people with fever from riding metro.

Regarding socio-economic characteristics, respondents aged above 18 had a significantly lower probability of choosing metro than those aged below 17 ($p < 0.1$). This propensity appeared more undeniable for seniors aged above 65 ($p < 0.05$). This result may result

| Explanatory variable of metro choice probability | Coefficient | Standard error | Significance |
|-----------------------------------------------|-------------|---------------|-------------|
| Constant                                      | 10.689**    | 5.362         | 0.046       |

Public transport service policy
- Waiting time (minute): $-0.413$, $p > 0.1$
- Transfer availability (bus & shared bicycle): $0.795$, $p < 0.05$
- Transfer availability (bus, shared bicycle, & shared e-scooter): $0.748$, $p < 0.05$

Epidemic prevention policy
- Temperature screening: $1.006$, $p < 0.05$
- Mask-wearing requirement (for entering car): $1.001$, $p < 0.05$
- Mask-wearing requirement (for entering gate): $1.890**$, $p < 0.01$

Individual socio-economic characteristic
- Gender (male): $-5.454**$, $p < 0.01$
- Age (18–34): $-5.492**$, $p < 0.01$
- Age (35–49): $-4.967*$, $p < 0.1$
- Age (above 65): $-7.527**$, $p < 0.01$

Monthly income
- (NT$10,001–$25,000): $-0.413$, $p > 0.1$

Monthly income (NT$25,001–$40,000): $-0.413$, $p > 0.1$

Monthly income (NT$40,001–$55,000): $-0.413$, $p > 0.1$

Monthly income (NT$55,001–$70,000): $-0.413$, $p > 0.1$

Monthly income (above NT$70,001): $-0.413$, $p > 0.1$

Occupation
- (student): $-0.470$, $p > 0.1$
- (non-student unemployed): $-0.470$, $p > 0.1$

Number of household members aged above 18
- $0.766$, $p < 0.05$ (dummy relative to metro)
- $0.766$, $p < 0.05$ (dummy relative to bus alone)
- $0.766$, $p < 0.05$ (dummy relative to the non-student unemployed)
- $0.766$, $p < 0.05$ (dummy relative to female)
- $0.766$, $p < 0.05$ (dummy relative to below NT$10,000)

Number of household members aged 18
- $0.766$, $p < 0.05$ (dummy relative to below 17)
- $0.766$, $p < 0.05$ (dummy relative to no mask-wearing requirement)
- $0.766$, $p < 0.05$ (dummy relative to below NT$10,000)

Number of household members aged 6
- $0.766$, $p < 0.05$ (dummy relative to below 17)
- $0.766$, $p < 0.05$ (dummy relative to no mask-wearing requirement)
- $0.766$, $p < 0.05$ (dummy relative to below NT$10,000)

Number of household members aged below 5
- $0.766$, $p < 0.05$ (dummy relative to below 17)
- $0.766$, $p < 0.05$ (dummy relative to no mask-wearing requirement)
- $0.766$, $p < 0.05$ (dummy relative to below NT$10,000)

Number of household scooters
- $0.766$, $p < 0.05$ (dummy relative to metro)
- $0.766$, $p < 0.05$ (dummy relative to bus alone)
- $0.766$, $p < 0.05$ (dummy relative to the non-student unemployed)
- $0.766$, $p < 0.05$ (dummy relative to female)
- $0.766$, $p < 0.05$ (dummy relative to below NT$10,000)

Number of household cars
- $0.766$, $p < 0.05$ (dummy relative to metro)
- $0.766$, $p < 0.05$ (dummy relative to bus alone)
- $0.766$, $p < 0.05$ (dummy relative to the non-student unemployed)
- $0.766$, $p < 0.05$ (dummy relative to female)
- $0.766$, $p < 0.05$ (dummy relative to below NT$10,000)

Scooter driving license possession
- $3.474$, $p < 0.01$

Car driving license possession
- $3.474$, $p < 0.01$

Household socio-economic characteristic

Pre-COVID-19 travel habit
- Pre-COVID-19 main travel mode (car): $-9.122**$, $p < 0.01$
- Pre-COVID-19 main travel mode (scooter): $-7.454**$, $p < 0.01$
- Pre-COVID-19 main travel mode (walk): $-3.869$, $p < 0.01$
- Pre-COVID-19 main travel mode (bicycle): $-4.056$, $p < 0.01$
- Pre-COVID-19 main travel mode (bus): $-4.062$, $p < 0.01$

Pre-COVID-19 weekly metro use frequency
- $0.889**$, $p < 0.01$

Error component
- Scale parameter of error component: $3.988***$, $p < 0.01$

Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

In the SP scenarios, waiting time was specified at four levels: 2.5, 3, 3.5, and 4 min.

- Dummy relative to bus alone.
- Dummy relative to no mask-wearing requirement.
- Dummy relative to female.
- Dummy relative to below 17.
- Dummy relative to below NT$10,000.
- Dummy relative to the non-student unemployed.
- Dummy relative to without driving license.
- Dummy relative to without scooter driving license.

Pre-COVID-19 travel habit
- Pre-COVID-19 main travel mode (scooter): $-7.435**$, $p < 0.01$
- Pre-COVID-19 main travel mode (walk): $-3.869$, $p < 0.01$
- Pre-COVID-19 main travel mode (bicycle): $-4.056$, $p < 0.01$
- Pre-COVID-19 main travel mode (bus): $-4.062$, $p < 0.01$

Pre-COVID-19 weekly metro use frequency
- $0.889**$, $p < 0.01$

Error component
- Scale parameter of error component: $3.988***$, $p < 0.01$

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- Dummy relative to below 17.
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- Dummy relative to the non-student unemployed.
- Dummy relative to without driving license.
- Dummy relative to without scooter driving license.

Pre-COVID-19 main travel mode (scooter): $-7.435**$, $p < 0.01$
- Pre-COVID-19 main travel mode (walk): $-3.869$, $p < 0.01$
- Pre-COVID-19 main travel mode (bicycle): $-4.056$, $p < 0.01$
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Pre-COVID-19 weekly metro use frequency
- $0.889**$, $p < 0.01$

Error component
- Scale parameter of error component: $3.988***$, $p < 0.01$
from the government’s suggestions on not going out for unnecessary activities and to crowded places, especially for seniors vulnerable to the epidemic. Also, the number of household members aged 6–17 was significantly negatively associated with the metro choice probability ($p < 0.1$), probably because of the household demand for joint trip generation (Kobayashi et al., 1996). Moreover, pre-COVID-19 travel patterns were also influential in post-COVID-19 metro use. That is, the respondents whose pre-COVID-19 main travel mode was car ($p < 0.05$) or scooter ($p < 0.1$) had a lower tendency to choose metro than those whose pre-COVID-19 main travel mode was metro. In contrast, there was no significant difference in the metro choice probability between the respondents whose pre-COVID-19 main travel mode was walking, cycling, bus ($p > 0.1$), and metro (as the reference category). In addition, pre-COVID-19 weekly metro use frequency was significantly positively associated with the post-COVID-19 metro choice probability ($p < 0.1$), despite metro use frequency reductions from the pre- to in-COVID-19 phase (see Table 7).

5. Conclusion and discussion

This study investigated citizens’ metro use behavior across the pre-, in-, and post-COVID-19 phases and the post-COVID-19 stated preference mode choice in the scenarios constituted by public transport service and anti-epidemic policies. Therefore, this study clarified COVID-19 impact on metro use frequency changes across the three phases, the predictors of post-COVID-19 metro use choice, and most importantly, the controversial question of whether the government should continue mandatory anti-epidemic measures in public transport for ridership recovery when a higher level of epidemic alert is reduced or removed. Consequently, the analysis results showed a significant decrease in metro use from the pre- to in-COVID-19 phase and, for loyal metro-user citizens, a significant recovery from the in- to post-COVID-19 phase. Notably, the results also suggested that a continued mandatory mask-wearing policy facilitated and pre-COVID-19 travel habits affected post-COVID-19 metro use. These findings could provide answers to the three proposed research questions, as discussed below.

(1) Do loyal public transport users change use intensity across COVID-19 phases?

The statistically significant differences in metro use frequency emerged between the pre- and in-COVID-19 phase (showing a decrease) and between the in- and post-COVID-19 phase (showing an increase). However, given group distinction, the post-COVID-19 metro use frequency recovery from the in-COVID-19 phase was found only from loyal metro users who did not wholly escape from metro use in each phase. Hence, although loyal users significantly decreased metro use frequency after the COVID-19 outbreak, they significantly recovered it to the pre-COVID-19 level when perceiving a reduction in epidemic alert. In addition to the revealed influence of pre-epidemic travel patterns on post-COVID-19 metro use, these results implied that fostering public transport use habits in a low infection-risk period could help ridership recovery from a colossal epidemic impact.

(2) Do lifting mandatory anti-epidemic measures in public transport benefit or harm post-COVID-19 ridership recovery?

The Taiwanese government lifted the policy of mandatory wear-masking requirement in public transport on June 8, 2020 after controlling the first wave of COVID-19 community transmission with gradually built standard operation procedures for epidemic prevention. However, the government, still taking control of the epidemic during the not implemented mask-wearing period, decided to resume the mask-wearing policy on August 5, 2020. Is lifting or resuming the mask-wearing policy better for public transport renaissance in a post-COVID-19 phase? Although lifting the mask-wearing policy may lower riding inconvenience and discomfort, the perceived transmission risk may increase, and thus, the willingness to take metro may decline. Physiological safety needs may arise as crucial focuses even in post-COVID-19 times with the disease’s vast and long-term health threat. Hence, a continued and more stringent mandatory mask-wearing rule for entering ticket gates, rather than the one for entering metro cars, may benefit ridership recovery from a pandemic.

This finding regarding mandatory mask-wearing benefits corresponds to Nguyen and Pojani (2021), indicating that mandates worked better than awareness-raising campaigns and that mask use and, differently from our finding, hand sanitizer use were sufficient to keep the minor threats of COVID-19 while still maintaining regular bus operations most of the time. Similarly, Dzisi and Dei (2020) presented the necessity of mandatory mask use within public transport. In that case, the use of fines and policing to enforce the mask use policy might be better ways for public transport travelers to adhere to the policy. However, it is noteworthy that although the validity of wearing masks to prevent the epidemic from spreading has been confirmed in many studies (Eikenberry et al., 2020; Mitze et al., 2020), the attitudes toward mask-wearing policy are still considerably different among countries worldwide (Gkiotsalitis and Cats, 2020). In conclusion, wearing masks could protect oneself from viral infection and protect others from getting infected. Therefore, the mandatory mask-wearing policy seems essential because it offers a double barrier against COVID-19 transmission.

In contrast, lifting temperature screening in public transport could be considered to increase riding convenience under low infection risk because this measure may be irrelevant to citizens’ perceived infection risk in public transport during post-COVID-19 times.

(3) Do public transport service levels affect post-COVID-19 mode choice?

Changes in waiting time and transfer availability were found not to affect post-COVID-19 metro use. The two factors belong to the components of reliability, treated as the most basic/functional attribute (needing to be first satisfied) in the hierarchy of transit needs than safety, customer services, and comfort (more hedonic in this order) based on Maslow’s hierarchy of needs (Allen et al., 2019).
However, this hierarchy may probably fit merely in normal times. With the potential threat from COVID-19, the need for safety appears dominant in travel decisions, and other needs may shift into relative irrelevance to transit users. For the present case, mask-wearing protection for physiological safety may respond to the focal need, whereas transit system changes in waiting time and transfer availability regarding reliability did not influence mode choice in the post-COVID-19 phase.

In addition, the policies of temperature screening and mask wearing in public transport might bring the adverse effects of lowering perceived customer services and comfort but did not undermine post-COVID-19 metro use. Thus, it could be speculated that COVID-19 has restructured the hierarchy of transit needs such that safety may shift into the most basic need, as illustrated in Fig. 5. In this structure, citizens may not first pursue satisfaction with other attributes before satisfying safety needs. The confirmation of this structure should entail future research integrating epidemic safety into the physiological safety of public transit needs, including criminal security, road safety, and noise and pollution exposure safety identified before COVID-19 (Allen et al., 2019). Despite demanding further investigations, this finding may imply that citizens in a well-controlled region would not be soon relieved to use public transport under global pandemics, but "continued" anti-epidemic measures help public transit renaissance as a region escapes from a pandemic.

CRediT author statement

Hsu-Sheng Hsieh: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition, Hao-Ching Hsia: Methodology, Investigation, Writing - Review & Editing.

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