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Research article

Using an integrated model of TPB and TAM to analyze the pandemic impacts on the intention to use bicycles in the post-COVID-19 period

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A R T I C L E   I N F O

Article history:
Received 1 June 2021
Received in revised form 25 February 2022
Accepted 26 May 2022
Available online 30 May 2022

Keywords:
Bicycle
Intention to use
Theory of planned behavior
Technology acceptance model
COVID-19

A B S T R A C T

Due to the rapid increase in bicycle usage during the pandemic, this study aims to ascertain the effects of COVID-19 and the role of psychosocial factors on the intention to cycle in the future. An integrated model of the theory of planned behavior (TPB) and technology acceptance model (TAM) was modified and utilized with a sample of 473 cyclists in Yogyakarta, Indonesia. The results confirm that the awareness change because of the advent of COVID-19, especially related to the environment, negative impacts of motorized vehicles (including road safety burden), and climate change issues, has the strongest power to influence bicycle use intention. The positive effect of COVID-19 also significantly influenced subjective norms and perceived behavioral control. Meanwhile, attitudes toward cycling and its perceived usefulness did not significantly contribute to bicycle use intention. Attitudes to use bicycles also could not mediate the relationship between COVID-19 and the intention to use bicycles. Based on the study findings, a set of policy initiatives was proposed, including cycling campaigns related to environmental issues, promoting bicycle use by public figures, providing a segregated bike lane, and introducing bicycle-specific programs, such as bicycle usage in cultural events.

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1. Introduction

The COVID-19 pandemic has had a tremendous effect on all aspects of human society [1] and has reshaped cities worldwide in many ways [2]. In addition, policies implemented due to the outbreak, such as remote work, school closure, partial or full-fledged lockdown, and social distancing protocols, have managed to affect urban mobility patterns. While empirical evidence shows a significant decline in the number of motorized vehicles on roads during the outbreak [3–7], an increasing number of people have turned to using active transport, such as cycling, to minimize the risk of infection [8–10]. The shift has significant advantages, such as improving air quality, alleviating traffic congestion, and enhancing urban liveability.

The dramatic drop in motorized mobility due to the COVID-19 pandemic caused the air quality in many cities across the globe to improve [11]. A study found that various pollutants, such as PM2.5, PM10, CO, and NO2, decreased during this period in 22 cities covering different regions of India [12]. Furthermore, the air quality index in north, east, south, west, and central India reduced by 44%, 29%, 22%, 32%, and 15%, respectively. A significant decrease in pollution has also happened in Southeast Asian countries [13], Western European countries [14], Northern South America [15], and China [16]. These significant reductions reported by many cities indicate that the green transportation sector can provide major air quality benefits. Therefore, future cleaner transport policies could bring air pollution close to the World Health Organization guidelines.

The number of cyclists across the globe increased during the restriction of human mobility. Jobe and Griffin conducted a survey of bike-share users in San Antonio, Texas, and their results showed that unemployed people have increased their bike usage by 43% during the pandemic [10]. Moreover, the respondents stated that they intend to increase the use of bikes after COVID-19 restrictions are lifted. Bicycles have also become an attractive transport mode for people in Thessaloniki, Greece. This mode is likely to become a preferable mobility option for people who are already registered users in a bike-sharing system and those who were previously commuting in private cars [9]. Some European cities used the situation during the pandemic as momentum to provide a dedicated infrastructure for bicycles, and this initiative successfully induced a rapid increase in cycling between 11% and 48% [17]. Studies also show an increase in bicycle use during the pandemic in developing countries, such as Indonesia [18] and Bangladesh [19].

The disruption created by COVID-19, however, has significantly introduced many benefits of bicycle use from various perspectives, including reductions in motorized vehicle use, benefits of a healthy and
environmentally friendly way to travel, and reductions in road fatalities. These benefits contribute to a city’s resilience and sustainability. For these reasons, exploring bicycle use intention after the pandemic ends has become a principal issue to achieve a sustainable urban transportation particularly in cities located in developing countries that are mainly dominated by motorized vehicles.

Previous studies related to bicycle use intention are plentiful; however, there is limited quantified evidence regarding bicycle use intention due to the COVID-19 pandemic. Particularly, to some extent, the perceived user cycling behavior and its various benefits should be measured to help adapt to the ongoing pandemic. Therefore, using a behavioral theory, this study mainly explores how the COVID-19 pandemic has impacted the intention of cycling in the future, which would change the lifestyle of urban mobility. This study also attempts to integrate and expand the theory of planned behavior (TPB) and technology acceptance model (TAM) in investigating the determinant factor influencing the intention of cycling. Addressing the objective of this study will serve as a reference in the promotion of bicycle use aimed at solving congestion in urban areas. In this paper, the labels “in the future,” “in the post–COVID-19,” and “after the pandemic ends” have a similar meaning and are used interchangeably.

The remainder of this paper is structured as follows: The literature review is presented in Section 2. The model and methods, including the research conceptual model, hypothesis, and analysis methods used in this study, are explained in Section 3. The materials are discussed in Section 4, which also presents the study area, questionnaire design, and data collection. The results from the survey and analysis are discussed in Section 5. Finally, the conclusions and suggestions for policy implications and future research based on the findings are presented in Section 6.

2. Literature review

The literature shows that studies on bicycle use intention incorporating the latent variable of psychological constructs have used a number of different behavioral frameworks, such as the hybrid choice model (HCM) [20], TPB [21], and TAM [22]. The HCM is a relatively new behavior framework that has been developed as an extension of discrete choice models by taking into account psychological factors as latent variables. Studies on cycling intention based on the HCM framework can be seen in Maldonado-Hinarejos et al. [23] and Sottie et al. [24]. The first study [23] examined the bicycle use intention in London by considering the impacts of cycling attitudes and perceptions on the cycling demand. They found that four latent variables constructed from 19 cycling attitudes and perception indicators have a significant role in the bicycle use process. The second study [24] explored the role of perception consisting of three latent variables of the benefits of cycling, bicycle infrastructures, and bike ability in terms of usefulness and safety in the propensity to commute by bicycle in Cagliari, Italy. They found that the benefits of cycling and the availability of bicycle infrastructure significantly affect the propensity to cycle.

Meanwhile, the TPB model is the most common method used in transport studies to examine the intention of travel mode choice. In this model, intentions are hypothesized to stem from three aspects: attitudes toward the behavior, subjective norms, and perceived behavioral control (PBC). For example, in a study on the cycle commuting intention in the Spanish city of Victoria-Gasteiz, the authors found that the intention to cycle was determined by a positive attitude and the presence of subjective norms [25]. In addition, another study investigating the behavioral intention in a bicycle tourism context with a sample of bicycle club members in China reveals that all TPB variables positively and significantly affected the behavioral intention of bicycle touring as a form of sustainable tourism activity [26].

However, because the TPB model only considers the effects of user-related or internal factors on the use intention, some studies on bicycle use intention then used the TAM. This model could capture external factors, such as the effect of bicycle facilities on the intention of bicycle use. This model has three primary factors influencing an individual’s intention: perceived ease of use, perceived usefulness, and attitudes. The adoption of the TAM in predicting public bicycle use was conducted by Hazen et al. [27]. They discovered that approximately 50.5% of 421 respondents intended to use bicycle-sharing programs in Beijing, China. In a research comparing users and non-users of bike sharing in Taiwan (i.e., YouBike), a random sample of people from five districts in Taiwan was used to ascertain the perceived ease of use, perceived usefulness, and attitudes toward a bike-sharing use intention [28]. The results indicated that only perceived usefulness and attitudes significantly and positively affected the intention to use YouBike for users and non-users.

The TPB and TAM are extended from the ideas of the theory of reasoned action (TRA) by Ajzen and Fishbein [21], making it possible for the two models to be integrated. Adding the TAM into the TPB model makes it capable of investigating internal and external factors affecting the intention of bicycle use. Many studies integrated the TPB and TAM in analyzing the determinant factors influencing travel behaviors. For example, a study proposed an integrated model of the TPB and TAM to investigate the intention to use shared parking in Taipei, Taiwan [29]. They found that TPB-related factors (attitudes, subjective norms, and PBC) and TAM-related factors (attitudes, perceived usefulness, and perceived ease of use) significantly influenced the intention of share parking use. Some studies also modified the integration of the TPB and TAM to create a more applicable model compared with previous models. For example, a study used the integrated model to investigate the effects of perceived green values, perceived green usefulness, perceived pleasure to use, PBC, and social norms on green loyalty to a public bike system in Taipei, Taiwan [30]. In this study, the author modified the attitudes toward protecting the natural environment as a mediator between the five influencing factors and the dependent variable of green loyalty.

This study also attempts to expand the integrated model of the TPB and TAM by taking into account the positive effect of COVID-19 related to the change in bicycle use and perception and the awareness of the environment, climate change issues, and motorized vehicle negative impacts. Previous studies show that the advent of COVID-19 has positively promoted an increase in environmental awareness. A study found that COVID-19 has changed people’s perception of environmental sustainability in Brazil and Portugal [31]. Residents in these countries perceived that the pandemic has increased their environmental awareness. Because of the pandemic, they are also encouraged to minimize water consumption and realized that water is a finite environmental resource and separate organic and recyclable waste. A study also found that the advent of COVID-19 prompted people in Iran to cycle, which not only increased their environmental awareness but also reduced their stress during the lockdown [32]. Nonetheless, the use of the HCM is hard to apply in this study for two reasons: The first reason is related to the relationship between the latent variable of the positive effect of COVID-19 and the latent variables of psychological constructs. The HCM can only examine the relationship between latent and observed variables or between latent variables and the utility function. The second reason is associated with the dependent variable, which is also in the form of a latent variable. In the HCM, the dependent variable has to be an observed variable, either a binary or categorical variable.

3. Model and methods

3.1. Research conceptual model and hypothesis

Fig. 1 provides a full overview of our conceptual model and hypotheses. The dependent variable is individuals’ intentions to use bicycles in the future. The positive effects of COVID-19 could influence attitudes,
subjective norms, PBC, and intention toward bicycle use. As shown in Fig. 1, this study proposes the following hypotheses:

- H1: Perceived ease of bicycle use has a positive effect on the perceived usefulness of bicycle use.
- H2: Perceived ease of bicycle use has a positive effect on attitudes to use a bicycle.
- H3: Perceived usefulness of bicycle use has a positive effect on the intention toward bicycle use.
- H4: Attitudes to use a bicycle have a positive effect on the intention toward bicycle use.
- H5: COVID-19 has a positive effect on attitudes to use a bicycle.
- H6: Subjective norm has a positive effect on the intention toward bicycle use.
- H7: PBC has a positive effect on the intention toward bicycle use.
- H8: COVID-19 has a positive effect on subjective norms.
- H9: COVID-19 has a positive effect on PBC.
- H10: COVID-19 has a positive effect on the intention toward bicycle use.
- H11: Perceived usefulness of bicycle use has a positive effect on attitudes to use a bicycle.

3.2. Research method

This study used confirmatory factor analysis (CFA) and structural equation modeling (SEM) to apply the integrated TPB and TAM. Because the model involved the latent variables, the CFA was first conducted to confirm the validity of the observed indicators (items) constructing the latent variable, as proposed by Anderson and Gerbing [33]. Items with standardized factor loadings (SFL) less than 0.4 must be excluded from the constructed latent variable [34]. After eliminating the items and constructing the latent variable, Cronbach’s alpha values were calculated to analyze the reliability of the model’s construct and confirm the acceptable internal consistency for each construct. Only latent variables with Cronbach’s alpha values over 0.7 can be included in the SEM model [35].

According to Hair et al. [34], the SEM is a multivariate method that is used to model a correlation between latent and observed variables and among latent variables. The SEM consists of two models: measurement model and structural model. The measurement model, as shown by the dotted lines in Fig. 1, is used to find the correlation between latent and observed variables. Meanwhile, the structural model, as shown by the straight lines in Fig. 1, is used to analyze the correlation among latent variables. In estimating the coefficients, this study applied the maximum likelihood, which is commonly used in studies related to the TPB [36–38]. SEM and CFA were employed using the IBM SPSS AMOS 26 [39].

Furthermore, there are several models’ fit criteria in the assessment of the SEM output [34]. The fit measures aim to indicate whether or not the proposed model fits the data well. This study used three models’ fit criteria consisting of (1) the ratio of the chi-square value to degrees of freedom, where values of 3 or less indicate a good fit; (2) the root-mean-square error of approximation (RMSEA), where values of 0.08 or less represent a reasonable model-data fit; and (3) the adjusted goodness of fit index (AGFI) and comparative fit index (CFI), where values equal to or higher than 0.9 show that the model has fit criteria.

4. Materials

4.1. Study area

Yogyakarta is emerging as one of Indonesia’s most densely populated cities, with 11,495 population per square kilometer. It has 373,589 inhabitants within the area of 32.50 km². It has a flat
topography and a climate that is moderately hot (27 °C average temperature). During the rainy season, the average rainfall unit reaches 300 mm [40]. Studying bicycles in Yogyakarta is relevant for several reasons: First, with a dense and medium city size and flat topography, as shown in Fig. 2, the city condition supports residents to use bicycles in their daily lives. Second, Yogyakarta historically had a good reputation as the “City of Bicycles.” For more than a decade, the local government together with bike communities would like to reclaim this title by introducing various massive cycling campaigns, such as “Sego Segawé” and Jogja Last Friday Ride (JLFR). “Sego Segawé” is the abbreviation of the Javanese language that means “bicycle to school and work.” This campaign aims to encourage workers and students to use a bicycle when going to school or office. Consequently, the local government has constructed bicycle facilities in some main streets, such as bike lanes, green boxes for waiting at signalized intersections, and bike parking facilities at bus shelters, central business district areas, and universities/offices. Meanwhile, JLFR is a movement where hundreds of cyclists cycle around the city on the last Friday night of every month. This activity is open to the public who would like to join the event with various kinds of bicycles. Lastly, in line with global trends, Yogyakarta has also experienced rapid rises in bicycle use rates because of the advent of COVID-19 [18].

4.2. Questionnaire design

As shown in Fig. 1, there are five latent variables for the TPB and TAM and one latent variable of the COVID-19 effect asked to respondents in order to test our proposed hypotheses. For the first latent variable, attitudes to use a bicycle were measured using the following sentence with four specific items: “I feel that using a bicycle during the pandemic is (1) fast (AT1), (2) healthy (AT2), (3) pleasant (AT3), and (4) convenient (AT4).” Subjective norms as the second latent variable were assessed with the following items: “During the pandemic, (1) most people who are important to me think that I should use a bicycle (SN1), (2) my colleagues support me to use a bicycle (SN2), and (3) public opinion affects my choice to use a bicycle (SN3).” Furthermore, perceived behavioral control for the third latent variable was measured using the following items: “During the pandemic, (1) using a bicycle is easy for me (PBC1) and (2) my freedom to use a bicycle is high (PBC2).” Looking into the latent variable of the TAM, perceived usefulness of bicycle use was measured using four items: (1) “Using bicycle would make me safer” (PU1), (2) “Using bicycle would make my time more efficient” (PU2), (3) “Using bicycle would cost me less” (PU3), and (4) “Overall, using a bicycle is useful” (PU4). Meanwhile, perceived ease of bicycle use was assessed with the following items according to the bicycle facilities in the study area: (1) “Bicycle lane makes it easier for me to use a bicycle” (PEU1), (2) “Green box for waiting at signalized intersections makes it easier for me to use a bicycle” (PEU2), (3) “Bicycle parking makes it easier for me to use a bicycle” (PEU3), and (4) “Current bicycle facilities support the bicycle and public transport intermodality” (PEU4).

Considering COVID-19 effects, this latent variable was measured by asking respondents to indicate how significant the impact of the COVID-19 pandemic was on their perception and travel behavior change, with the basic statement of “For me, COVID-19 has changed my (1) perception of bicycle use (C1), (2) travel behavior especially related to bicycle use (C2), (3) awareness of negative impacts caused by motorized vehicle use (C3), (4) awareness of environmental issues (C4), and (5) awareness of climate change issues (C5).” The response alternatives for the six influencing variables of bicycle use intention used a five-point Likert scale from 1 for “strongly disagree” to 5 for “strongly agree.” The use of a five-point Likert scale was also used in other studies applying the integrated model of TPB and TAM [30,43,44].

Finally, the respondents were asked about their intention toward bicycle use in the future. This question was assessed using the following question with four specific items: “After the pandemic ends, how interested are you to use a bicycle for (1) sport (IN1); (2) time-constrained activities, such as going to work, campus, or meeting (IN2); (3) time-unconstrained activities, such as leisure, social, and shopping activities (IN3); and (4) first- and last-mile mode, such as for a trip to a bus stop (IN4)?” This question was also answered using a five-point Likert scale, ranging from 1 for “strongly uninterested” to 5 for “strongly interested.”

4.3. Data collection

Due to the difficulty of conducting face-to-face interviews during the pandemic, a web-based questionnaire was distributed within 2 months, from December 2020 to February 2021, via various online forums, including WhatsApp, Facebook, Instagram, Twitter, and Line. We also asked our colleagues to help distribute the online questionnaire. This survey method (convenience and snowball sampling) is a popular approach on travel behavior studies during the COVID-19 pandemic [45–48]. Because this study aims to explore the intention of bicycle use in the post-COVID-19 period, the target audience is cyclists during the pandemic who are 18 years or older and have lived in Yogyakarta for at least 5 years.

To encourage as many people as possible to become participants, five vouchers of a million IDR were given to five lucky randomly selected participants. Several travel behavior studies using online surveys also used incentives to attract more participants [18,49,50]. However, to minimize the response bias resulting from the incentives, the participants were reminded that the incentives are not related to their answers (i.e., from “strongly disagree” to “strongly agree”). The participants were requested to answer the questions according to their perceptions without intervention by anything, including the incentives itself. The participants were also reminded that the survey was solely for research. These reminders were clearly stated in the survey background section. Meanwhile, to control a participant filling out a questionnaire several times for more opportunities to get incentives, the participant must mention their email address and phone number if they want to get the incentives.

Furthermore, three trap questions, as proposed by Liu and Wronski [51], and two interrelated questions were randomly placed in the questionnaire forms to check that the participants answered the online

Fig. 2. Geographical and topographic map of Yogyakarta.
Source: [41,42]
The questions consist of “pleasant and bad experiences” in the attitude question section and “easiness and difficulty” in the PBC question section. For example, once the respondents strongly agree that “using a bicycle is easy for me,” they have to answer “strongly disagree” or “disagree” for the item “cycling is difficult for me.” The participants with incorrect answers in the trap questions and those with inconsistent answers in the interrelated questions were eliminated from the study. Out of the 622 participants, the valid final sample consisted of 473 respondents.

5. Results and discussion

5.1. Survey results

From the 473 valid samples, 66% of the respondents were males. Thirty-five percent of the respondents were between 35 and 54 years of age, 58% were between 18 and 34 years old, and 7% were 55 years old or older. With regard to the respondents’ academic level, the respondents were relatively well educated, in which 57% has a bachelor’s degree and 22% has a graduate’s degree. Thirty-eight percent of the respondents were relatively well educated, in which 57% has a bachelor’s degree and 22% has a graduate’s degree. Eighty percent of the respondents indicated that their monthly income is less than 2 million IDR (approximately USD 138), 39% reported that their monthly income is within the range of 2–5 million IDR (or USD 138–345), and 23% reported that their monthly income is more than 5 million IDR. In terms of occupation, 21% of them are civil servants, 27% work in private companies, 12% are business people, 28% are university students, and 12% are unemployed and retired people.

Table 1 shows the mean and standard deviation of each item of the seven latent variables. There were some important trends in the response. The mean value of their intention to use a bicycle was high for sports activities (μAT1 = 4.37) and time-unconstrained activities, such as leisure, social, and shopping activities (μAT3 = 4.24). Except cycling is fast, most of the respondents stated that they agree and strongly agree that cycling is healthy (μAT4 = 4.66), pleasant (μAT5 = 4.52), and convenient (μAT6 = 4.43). On the contrary, they tended to disagree that subjective norms affect their choice to cycle, in which the mean value of SN1 (their important people), SN2 (their colleagues), and SN3 (public opinion) were 2.67, 2.53, and 2.71, respectively. Regarding COVID-19 effects, most of them agreed that COVID-19 had changed their awareness of environmental (μC1 = 4.04) and climate change issues (μC5 = 3.99), but they tended to state neutrally related to the COVID-19 effect on the change in bicycle use (μC1 = 3.06) and bicycle perception (μC2 = 3.06).

5.2. CFA results

Table 1 also shows the CFA results. It reveals that four items, consisting of two items of the COVID-19 effects (C1: COVID-19 has changed my perception of bicycle use and C2: COVID-19 has changed my travel behavior especially related to bicycle use), one item of the attitudes to use a bicycle (AT1: fast) and one item of the perceived usefulness of bicycle use (PU1: using bicycle would make me safer), must be excluded from our conceptual model because its SFL is less than the suggested minimum criterion of 0.4 [34]. Moreover, except for PBC, all Cronbach’s alpha values are higher than the minimum acceptable level of 0.7 [35].

5.3. SEM results

After eliminating four items, the fit measures for the SEM show that the proposed model meets the requirements of fit standards. The ratio of the chi-square value to degrees of freedom was 2.942, which was less than the cut-off value of 3; the RMSEA was 0.064 (less than the cut-off value of 0.08); and the AGFI and CFI were 0.904 and 0.9, respectively, which were higher than the minimum value of 0.9.

Fig. 3 and Table 2 display the path coefficients for each causal relationship. The R-square value for intention toward bicycle use was 0.875, implying that perceived usefulness, attitudes, subjective norms, PBC, and COVID-19 effects explained the variance of bicycle use intention by 87.5%. Supporting Hypotheses 1 and 2, the model results reveal that perceived ease of bicycle use positively and significantly influenced perceived usefulness (β = 0.149, p < 0.05) and attitudes toward bicycle use (β = 0.087, p < 0.10). Hence, the availability of bicycle facilities, such as bicycle lanes, green boxes for waiting at signalized intersections, bicycle parking, and bus and bicycle intermodality facilities, could increase the perceived usefulness of bicycle use and attitudes toward

![Fig. 3. Model results of the SEM path diagram.](image-url)
bicycle use. However, for Hypotheses 3 and 4, perceived usefulness and attitudes failed to significantly influence the intention toward bicycle use in the future. This finding implies that although people had positive attitudes and perceived usefulness because of the perceived ease of bicycle use, they still had no interest in bicycle use after the pandemic ends. This finding is inconsistent with those of previous studies out of the COVID-19 context showing that attitudes and perceived usefulness positively affect bicycle use intention in Gorgan, Iran [49], Taiwan [52], and Tianjin, China [53].

Furthermore, the estimates of the standardized coefficients show that the COVID-19 pandemic turns out not to be associated with attitudes toward bicycle use (Hypothesis 5), implying that the COVID-19 pandemic did not change attitudes toward bicycle use (i.e., bicycle is healthy, pleasant, and convenient). This finding was not in line with our hypothesis in which the pandemic has positive effects on the awareness on environmental and climate change issues and adverse effects of motorized vehicles and results in positive cycling attitudes. This finding is also inconsistent with that of a study in Germany showing that COVID-19 has an impact on attitude change toward cycling [54]. A couple of studies have also found this counterintuitive result, reporting that many people who shift from motorized transport to cycling during the pandemic might experience the health and well-being benefits of cycling [46,55]. Meanwhile, similar to Hypotheses 6 and 7, the model results also found that subjective norms (β = 0.103, p < 0.05) and PBC (β = 0.078, p < 0.01) were significantly and positively associated with the intention toward bicycle use after the pandemic ends. This result aligns with the finding found in the United Kingdom, where PBC plays a significant role toward switching to cycling [46].

Regarding the latent variable of the subjective norm, having support from people around and colleagues and the public opinion on bicycle use during the pandemic could increase the respondents’ intention to cycle. A study in New Zealand also shows that the perceived social pressure by peers has a significant influence on growing the frequency of cycling [56]. Finally, regarding the effect of the COVID-19 pandemic, except on attitudes toward bicycle use, all hypothesized relationships (Hypotheses 8, 9, and 10) were found to be significantly supported. The results show that the COVID-19 pandemic positively affected subjective norms (β = 0.140, p < 0.01), PBC (β = 0.141, p < 0.1), and the intention toward bicycle use in the future (β = 0.177, p < 0.05).

Considering the indirect and mediation effects, as shown in Fig. 3 and Table 3, the results show that the COVID-19 pandemic indirectly affected bicycle use intention through PBC (β = 0.122, p < 0.05) and subjective norms (β = 0.014, p < 0.05). In other words, regarding the effects of COVID-19 on the intention toward bicycle use, there is evidence of direct and indirect paths mediated by PBC and subjective norms. Interestingly, when comparing the factors influencing bicycle use intention, COVID-19 (β = 0.177) appeared to be the most influential factor, followed by subjective norms (β = 0.103) and PBC (β = 0.078). Therefore, the COVID-19 pandemic and subjective norms were strong enough to influence people’s intention to cycle in the future compared to their own desire to cycle. This result is corroborated with prior works that reported that the COVID-19 pandemic would very likely affect long-term travel behaviors, which resulted in being a catalyst of positive change toward more sustainable mobility, such as cycling and walking [4,6,45]. This phenomenon also explains why the attitudes toward bicycle use and perceived usefulness of bicycle use did not correlate with bicycle use intention after the pandemic ends. One of the other interesting findings was also related to the influencing factors of attitudes toward bicycle use. Moreover, perceived ease of use and perceived usefulness significantly influenced attitudes, but attitudes were found to not be associated with bicycle use intention. This finding implies that although the existing bicycle facilities affect bicycle users’ perceived ease of use and usefulness of cycling, they only affect cyclists’ attitudes toward bicycle use but have not been able to affect their intention to use a bicycle after the pandemic ends. This finding differs from the study’s hypotheses and is inconsistent with those of previous studies showing that bicycle infrastructure facilities could significantly support bicycle use in an urban area [23,24,57,58].

### 6. Conclusions and policy implications

This study contributes to cumulating knowledge on the effects of COVID-19 on the intention of bicycle use in the future. This study proposes 11 hypotheses, with the constructs of the integrated model of TPB and TAM, to investigate the factors influencing the use of bicycles after the pandemic ends. After the completion of data analysis, this study found that eight paths among the original hypotheses were empirically and statistically significant. As a result, for theory, this study has made three main contributions: First, out of the study’s hypotheses, only the latent variables of the TPB (i.e., subjective norms and PBC) and not the latent variables of the TAM significantly impacted the intention to use bicycles. Second, this study found that the advent of COVID-19 has increased the awareness of the environment, climate change issues, and motorized vehicle negative effects, which include road crashes, injuries, and fatalities. Third, this study also found that the positive impacts of COVID-19 became the most determinant factor influencing bicycle use intention in the post-COVID-19 period.

For practice, the findings of this study could be a basis to propose policies aiming to increase bicycle demand after the pandemic. Considering this study’s findings concerning the positive effects of COVID-19, first, the government should take this pandemic as a momentum to revive the bicycle demand in Yogyakarta. It is because the study found a significant and positive relationship between COVID-19 effects and cycling intention, as hypothesized. Second, the findings reveal that (1) COVID-19 has successfully changed the awareness of environmental issues, climate change, and negative impacts caused by motorized vehicle use, and (2) the positive effects of COVID-19 became the most influential factor of bicycle use intention among the two TPB variables. Hence, cycling promotion policies, emphasizing that cycling is environmentally friendly, could be proposed by the government to maintain people’s concern about the environment and climate change issues that arise during the pandemic. This initiative could result in the increase of bicycle use intention in the post-COVID-19 period.
Furthermore, the findings reveal that subjective norms have a positive correlation to bicycle use intention in the post-COVID-19. Thus, effective marketing strategies to improve cycling social status could be implemented by the government to attract more bicycle riders in the future. Policies, such as creating cultural events and advertisements on bicycle use by public figures or the city mayor, should be implemented by the government. The government could also promote a bike-to-work policy and establish regulations related to transit-bicycle intermodal, such as bicycles allowed entry into transit. This is, because the findings for the loading factor value show that cycling to work and cycling to transit stops become the two highest standard loadings for the latent variable of bicycle use intention. Lastly, it also needs to consider the unexpected findings where attitudes toward bicycle use and perceived usefulness did not correlate to bicycle use intention, although current bicycle facilities’ perceived ease of use positively affected cycling attitudes and perceived usefulness. Due to this finding, the government needs to revitalize existing painted bike lanes into segregated bike lanes. Providing segregated bike lanes could increase the significance of perceived ease of use on attitudes and perceived usefulness and result in significant effects on attitudes and perceived usefulness on the intention to use bicycles. A lesson can also be drawn from the provision of pop-up bike lanes in European cities implemented during the pandemic, which has led to a substantial increase in bicycle use [17].

With respect to limitations, the sample size of this study is relatively small. Another limitation is related to the online-based data collection, which can lead to population representation bias. These shortcomings need to be addressed in the next research agenda. Future studies should also develop an expanded TPB and TAM integrated model to examine bicycle use intention in conjunction with other variables, such as perceived risk when riding a bicycle, because our research model revealed that attitudes and perceived usefulness did not correlate with bicycle use intention. A study found that high perceptions of perceived risk decrease the switching intention to use public bicycles in Beijing, China [59]. Making the COVID-19 variable as a mediating factor in the relationship among perceived usefulness, attitudes, subjective norms, PBC, and bicycle use intention could also be addressed in future research to compare some of the ambiguous findings from this study.

Declaration of competing interests
None.

Acknowledgments
This study was funded by the Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Indonesia.

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