Publications

11-3-2021

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Kasim, K., Winter, S. R., Liu, D., Keebler, J., & Spence, T. (2021). Passengers' Perceptions on the Use of Biometrics at Airports: A Statistical Model of the Extended Theory of Planned Behavior. *Technology in Society*, 67(). <https://doi.org/10.1016/j.techsoc.2021.101806>

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Passengers' perceptions on the use of biometrics at airports: A statistical model of the extended theory of planned behavior

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ARTICLE INFO

Keywords:

Biometric technology
Privacy concerns
Passengers' behavioral intentions
Theory of planned behavior
Technology acceptance
Structural equation modeling

ABSTRACT

This study reviewed the factors which influence passengers' behavioral intentions on using biometrics at airports. The theory of planned behavior (TPB) served as the theoretical foundation and included perceived usefulness and perceived ease of use. The study also examined the effect of passengers' privacy concerns on their behavioral intentions and assessed the moderating influence of privacy on the influencing factors. Following a quantitative method, 689 participants responded to an online survey while data analysis was conducted using structural equation modeling (SEM). Attitudes and subjective norms were found to significantly influence passengers' behavioral intentions to use biometrics. However, perceived behavioral control (PBC), as well as perceived usefulness and perceived ease of use did not have a significant effect on intentions. Four of the six hypotheses involving privacy concerns were supported. Of the five hypotheses proposed to assess the moderating role of privacy, three were supported. However, since the effect sizes were small, the final model did not include the moderation effects. The final model was found to account for 80.2% of the variance in intentions and 35.2% of the variance in privacy concerns. The findings provide useful theoretical contributions and practical applications to support the adoption of biometric systems at airports, while recommendations for further study are presented.

1. Introduction

Biometrics use within the airport environment has been well-demonstrated in areas such as access control, passenger check-in and boarding, and at customs and immigration checkpoints. The basic principle of biometrics derives from using human behavioral or physiological characteristics for identification or verification [1,2]. Human characteristics that are used for recognition include faces, fingerprints, voices, signatures, and irises. Other less common methods that are also in use are palm print, hand geometry, vein pattern, retina, and gait recognition. Considering the amount of air transport passengers worldwide is forecast to increase from 4.1 billion in 2017 to approximately 8.2 billion a year by 2037 [3,4], biometrics appears to be a fast and effective means for the identification and verification of passengers at airports. Biometric systems for verification are usually more sensitive and accurate than systems for identification. Verification is also considered to be a one-to-one process, while identification is a one-to-many process [2,5]. For airport processes, the biometric systems are likely to involve both identification and verification as passengers'

identities will need to be validated based on a presented biometric characteristic before the specific transaction could be concluded.

The literature on passengers' use of biometrics at airports has focused on passengers' concerns about their privacy, personal security and on the overall passenger experience. From the studies reviewed, privacy appears to be a major concern for passengers' regarding the use of biometrics. However, findings show that passengers were willing to trade some rights to their privacy and support the use of biometrics when biometrics use results in noticeable improvements in the airport travel experiences enjoyed by passengers [6–8]. Furthermore, the study by Moradoff [9] noted that although privacy issues with biometrics could result in implications for individual human rights, the use of a Privacy Impact Assessment (PIA) from the start could help reduce the impact of intrusions to an individual's privacy. Subsequently, studies that evaluated PIAs [10–12] have found them effective in managing privacy risks. Regarding concerns about their security, studies suggest that passengers have found the use of biometrics acceptable where it was required to fulfil conditions necessary to enhance their personal security [13–15].

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While the previous studies have acknowledged the role of biometric technologies in the completion of the required airport processes, there is limited research on how passengers perceive the technology and their intentions to utilize the technology in situations where it is optional to use. Thus, the purpose of this study was to investigate the influencing factors of passengers' intentions to use biometric technologies at airports. The study utilized factors of the theory of planned behavior (TPB) along with perceived usefulness and perceived ease of use to examine passengers' intentions. The research also explored the moderating role of privacy on passengers' intentions and included a perceived threat from COVID-19 scale as a control variable to account for the coronavirus pandemic (COVID-19).

This study is considered significant because the use of biometric technology allows the efficient use of airport personnel and resources to create a conducive flying experience for passengers. Although a previous study by Morosan [16] examined passengers' intentions to use biometric e-gates, the current study included passengers' perspectives on the entire airport process from check-in to boarding the aircraft. Furthermore, utilizing privacy concerns as a moderating variable in this study provided one of the first known assessments of the impact of passengers' privacy concerns on the relationships between the independent variables and the dependent variable.

2. Theoretical framework and research hypotheses

2.1. TPB and application to prior studies

The theory of planned behavior (TPB) guided the research as the theoretical framework. Per [17,18], the TPB advances the notion that an individual's intention to perform a particular behavior depends on three factors, attitude, subjective norms, and perceived behavioral control (PBC). Attitude measures the assessment of an individual's disposition towards a specific behavior, subjective norms consider the social factors that may influence the performance of the behavior while PBC is concerned with the person's expectation regarding the level of difficulty to perform the behavior [18]. The TPB model also shows that PBC has a direct effect on behavior and an indirect effect through intentions.

There has been previous research using the TPB to predict users' intentions in the use of technology and in travel-related studies. While some studies affirmed the influence of the three TPB factors on behavioral intention, other studies found support for the influence of attitudes and subjective norms on intentions, and no influence of PBC on intentions.

For example, Hsiao and Yang [19] in their study of travelers' intentions to use High Speed Rail (HSR) in Taiwan found that attitudes, subjective norms and PBC all had significant impacts on behavioral intentions. The study by Jing, Huang, Ran, Zhan, and Shi [20] which examined the factors that influenced travelers' use of autonomous vehicles (AVs) and shared autonomous vehicles (SAVs) also found that attitudes, subjective norms and PBC were significant predictors of behavioral intention. Similarly, Borhan, Ibrahim, Miskeen, Rahmat, and Alhodairi [21] in their study of the intentions of car drivers to use LCCs intercity travel in Libya found that attitudes, subjective norms, and PBC all had significant effects on intentions.

Conversely, the study by Al-Ziadat [22] which examined the revisit intentions of tourists to Jordan found that attitudes and subjective norms positively influenced tourists' revisit intentions, but PBC did not significantly influence intentions. Buaphiban and Truong [23] evaluated passengers' buying intentions towards low-cost carriers (LCCs) tickets in Thailand and found that attitudes and subjective norms had positive impacts on buying intentions while PBC did not influence buying intentions. Similarly, Pan and Truong [24] used the TPB to examine the factors that influence passengers' intentions to use LCCs in China. Although their study found that there were other significant factors, among the TPB factors attitudes and subjective norms significantly influenced passengers' intentions to use LCCs, while PBC was not

considered an important factor.

The review of the literature suggests that the TPB could be applied to this study since the focus is on understanding passengers' behavioral intentions. The TPB is also appropriate to this study as the aim of the study is to obtain participants' perceptions on biometric technology. The use of the TPB helps to gather attitudes from users that could help biometric system providers with updates and changes as the technology continues to evolve. Furthermore, this study also includes additional variables to the TPB model following the suggestion that using additional variables improves the predictive power of a TPB model and helps address unexplained variances in the TPB [25]. Ajzen [18] also noted that the TPB could be used with additional predictors once the predictors can adequately account for the most significant variances.

Existing research on passengers' use of biometrics at airports appear to be focused on the level of passengers' overall acceptance with the use of biometrics. Notably, the Consumer Technology Association (CTA) reported that 62% of U.S. adults with some prior uses of biometrics agreed that the use of biometrics at airports or national borders would be a good idea [26]. Similarly, a survey by the information technology company, UNISYS found that 81% of U.S. air travelers supported the use of biometrics in enhancing their security and convenience at airports [27]. Although the studies highlight the importance and usefulness of biometrics, there is a significant lack of empirical research to investigate passengers' behavioral intentions to utilize biometrics at airports. The use of additional variables with the TPB as employed in this study provided reliable research regarding the additional possible influencing factors of passengers' intentions and any influence or interaction resulting from concerns over privacy.

2.2. Overview of biometrics

The term biometrics is derived from two Greek words, *bio*, meaning life, and *metron*, meaning measure [28,29]. Biometrics can thus be described as the use of physiological or behavioral characteristics of humans to establish or verify identities [30,31].

While the use of biometrics features of humans is not entirely new, biometrics processes today are mostly automated and performed by computers. However, history shows that humans have in the past directly assessed personal characteristics unique to individuals. For example, fingerprints were reported to have been used for business transactions in ancient Babylon, while Chinese merchants in the 14th century identified children by stamping inks on their palms and feet [28,30]. Fingerprints have also been used over the last one hundred years to identify individuals as part of forensic investigations. The field of biometrics has continued to evolve such that biometric features such as face, iris and voice are now routinely used in various applications worldwide [32].

A typical biometric process normally consists of three steps: enrollment, template creation, and matching [1,9]. Enrollment is the initial acquisition of an individual's biometric sample while the creation of a template entails the storing of certain features of the sample as a small file. Finally, template matching is the comparison of a biometric template with many other templates for identification or verification [31]. The use of biometric technologies by individuals can be categorized as employee, citizen, or consumer-facing. This study of passengers' use of biometrics at airports considers the specific role of passengers in a consumer-facing setting.

2.3. Biometric technology at airports

The use of biometric technologies at airports has increased significantly since the U.S. Department of Homeland Security (DHS) selected facial recognition technology as the specific biometric method for passenger identification and verification during entry and exit procedures into the U.S. Data from the U.S. DHS showed that as of August 2019, 22 airports in the U.S had deployed the Customs and Border Protection

(CBP) Traveler Verification Service (TVS) to manage immigration exits and in some cases entry [33]. The use of biometrics in this case is mandated by government and is thus considered as a citizen-facing scenario. Apart from the government-enforced uses of biometrics, which are primarily to enhance security, airports and airlines have also started using biometric technology to optimize the passenger handling process. For example, the report by Gohringer [34] noted that the use of biometric technology at airports allowed seamless passenger travel and provided access to statistical data about passenger movements. He further suggested that a passenger could be assigned a unique biometric identifier to cover all activities at the airport. A similar report by Farrell [6] suggested that the integration of airline and airport biometric technologies with government watch-lists would allow passengers enjoy the full benefits provided by using biometrics.

While privacy and security are important, passengers appear to welcome the use of biometrics at airports with one survey showing that more than 90% of passengers would use biometrics where it was available [35]. Finally, the study by Morosan [8] considered passengers' views on the disclosure of biometric information to electronic gates (e-gates) and found that privacy concerns had only a moderate impact on passengers' willingness to disclose information. He also suggested that future studies of passengers' behaviors could include other behavioral variables. The current study included perceived ease of use, perceived usefulness, and privacy concerns as additional variables that could influence passengers' intentions.

2.4. Privacy concerns with the use of biometrics

The concept of 'privacy concerns' is related to an individual's belief that a system contains the necessary organizational or technical structures to prevent a breach of privacy [36]. Although it was earlier noted that passengers' compare their privacy concerns with the use of biometrics against the benefits, it is also possible that passengers' intentions and actions may change depending on the type of biometric technology involved. Attitudes may also change as the technology evolves. Nanavati et al. [31] noted that passengers' concerns about their privacy with the use of biometrics could either be related to a person's beliefs (personal privacy), or to the exchange of a person's information (information privacy). The context of this current study considers information privacy as it is thought that this will be more critical to individuals in the deployment of biometric technologies [31]. This notion was also supported by the study of Neo, Rasiah, Tong, and Teo [37]; which found that passengers were concerned about information privacy as it relates to the mandatory provision of biometric data.

2.5. Research model and justification of hypotheses

The current study seeks to determine how the TPB factors and the extra constructs of perceived usefulness and perceived ease of use influence passengers' intentions to use biometrics at airports. Perceived ease of use and perceived usefulness are two key variables from the technology acceptance model (TAM) of Davis [38] that deal with user acceptance of technology. While not a direct focus of this study, the two variables from TAM were included based on studies that suggested the factors could influence passengers' intentions to use technology [39–41]. Further justification for the use of the additional variables in this study considers the following: first, Bradley [42] stated that perceived ease of use will influence attitudes towards use, which in turn leads to intention to use, and finally, actual use. Secondly, an earlier study by Davis, Bagozzi, and Warshaw [43] had noted that perceived usefulness should be included in research into technology as it could be more significant than perceived ease of use.

This research also seeks to evaluate the influence of participants' privacy concerns on behavioral intentions and to determine any moderating role of privacy on intentions. Finally, a perceived threat of COVID-19 scale was included in the model as a control variable to

quantify any influence the pandemic may have on the findings. The definitions of the constructs used are presented in Table 1 while the theoretical research model and hypotheses are shown in Fig. 1. The following presents the hypotheses for the study.

The link between attitudes and behavior appears to be well established from the available literature. In one of their earlier works, Fishbein and Ajzen [44] had suggested that a person's attitude could be used to predict the behavior. Subsequent studies have also shown that different behaviors could be explained by analyzing the underlying attitudes displayed by individuals [45–48]. Additionally, several studies have examined the moderating impact of privacy on consumer attitudes and intentions in various fields such as e-commerce, mobile banking, and the use of technology [49–52]. Thus, we hypothesize:

H1. Attitudes positively influence passengers' intentions to use biometric technologies at airports.

H1-1: The level of privacy concerns will moderate the positive relationship between passengers' attitudes and intentions to use biometric technologies at airports.

As noted earlier, several studies found subjective norms to positively influence intentions in the areas of technology and travel [19–24]. Subjective norms have also been found to be relevant to intentions with the use of biometrics [53,54]. However, it appears there is a lack of empirical studies on the moderating effect of privacy on the subjective norms-intentions relationship. Thus, the following hypotheses were proposed:

H2. Subjective norms positively influence passengers' intentions to

Table 1
Definitions and sources of study constructs.

Construct	Number of Items	Definitions	Sources
Attitudes	4	"A passenger's positive or negative feelings about using biometrics"	Chen, Fan, & Farn (2007); Taylor & Todd (1995)
Subjective Norms	3	"A passenger's perception that most people important to the passenger think that the passenger should or should not use biometrics"	Chen, Fan, & Farn (2007); Reza Jalilvand & Samiei [99]; Taylor & Todd (1995)
Perceived Behavioral	3	"A passenger's perception of the control regarding the decision to use biometrics"	Taylor & Todd (1995)
Control Perceived Ease of Use	4	"The degree to which a passenger believes that using biometrics would be free of effort"	Lu, Chou, & Ling Lu, Chou, & Ling [39]; Wang, Wang, Lin, & Tang (2003)
Perceived Usefulness	3	"The degree to which a passenger believes that using biometrics would be advantageous for them"	Lu, Chou, & Ling [39]; Wang, Wang, Lin, & Tang (2003)
Privacy concerns	3	"A passenger's perception of the collection, use, and management of the passenger's personal information while using biometrics"	Albashrawi & Motiwalla [61]; Hong & Thong [58]
Coronavirus (COVID-19)	3	"A passenger's perception of the threat of the impact of the coronavirus crisis on the use of biometrics"	Conway, Woodard, & Zubrod [119]
Intention to Use	3	"A passenger's intentions to use biometrics"	Al Ziadat [22]; Lu, Chou, & Ling [39]; Wang, Wang, Lin, & Tang (2003)

Note: Definitions from Ref. [120].

Fig. 1. Research model and hypotheses.

use biometric technologies at airports.

H2-1: The level of privacy concerns will moderate the positive relationship between subjective norms and intentions to use biometric technologies at airports.

The concept of PBC is focused on an individual's perceived ability to perform a behavior and considers circumstances when there is a lack of full volitional control over the specific behavior [55]. Per the TPB, the influence of PBC on behavior could either be direct, or indirect (through

intentions). While there is some research on the effect of PBC on passengers' intentions in general [23,24], there is a need to study the effect of PBC on passengers' intentions to use biometrics. The need is further reinforced by the apparent lack of direct studies of the moderating effect of privacy concerns on the PBC-intentions relationship. Thus, we propose:

H3. Perceived behavioral control positively influences passengers' intentions to use biometric technologies at airports.

H3-1: The level of privacy concerns will moderate the positive relationship between perceived behavioral control and intentions to use biometric technologies at airports.

Perceived ease of use is concerned with the degree of effort required to use a system as perceived by a user of that system [38]. Although perceived ease of use is usually thought of in terms of the use of an information technology system, it has been utilized as a variable to study consumers' intentions in the travel industry [39–41,56]. The study by Tan, Qin, Kim, & Hsu [57] also found some effects of privacy concerns on the perceived ease of use-intentions relationship. Therefore, we propose:

H4. Perceived ease of use positively influences passengers' intentions to use biometric technologies at airports.

H4-1: The level of privacy concerns will moderate the positive relationship between perceived ease of use and intentions to use biometric technologies at airports.

Davis [38] described perceived usefulness as the extent to which an individual believes that a particular system would improve the performance of a task. Since both perceived usefulness and perceived ease of use are crucial elements in the TAM, they are normally considered together when conducting research into the use of technology. The review as seen from the previous hypotheses also shows that the two variables are related with behavioral intention to use. As with perceived ease of use, Tan et al. [57] also found privacy concerns to moderate the effect of perceived usefulness on intentions. Therefore, we propose:

H5. Perceived usefulness positively influences passengers' intentions to use biometric technologies at airports.

H5-1: The level of privacy concerns will moderate the positive relationship between perceived usefulness and intentions to use biometric technologies at airports.

Information privacy is concerned with the control of the interaction between an individual's personal information and the dissemination of the information to other persons or systems [58]. Since biometrics deals with human's personal characteristics, the concept of information privacy is crucial with the use of biometrics systems. Several findings that explored privacy concerns related to the use of biometric systems reported that higher privacy concerns resulted in a reduced level of behavioral intentions [53,59,60]. Thus, we propose:

H6. Privacy concerns negatively influence passengers' intentions to use biometric technologies at airports.

There have been several studies that examined the relationship between individuals' attitudes and their reported concerns of privacy towards the use of biometrics [59,61–63]. While there were some differences with the magnitude and direction of the relationship across the studies, overall, the results indicated that individuals expressed concerns about their privacy. Thus, H_7 was proposed:

H7. Attitudes negatively influence passengers' privacy concerns toward biometric technologies at airports.

Perceived ease of use and perceived usefulness can be considered as part of the factors involved in the evaluation of the usability of a biometric system. While there is some evidence that privacy concerns have some effects on the perceived ease of use and perceived usefulness of biometric systems [36,64,65], it appears that users normally evaluate their privacy concerns about a system within a context of the expected benefits from the system [6–8,66]. Thus, two relationships were proposed:

H8. Perceived ease of use negatively influences passengers' privacy concerns with the use of biometric technologies at airports.

H9. Perceived usefulness negatively influences passengers' privacy concerns with the use of biometric technologies at airports.

The study by Xu, Dinev, Smith, and Hart [67] found an indirect effect of social norms (as a factor of subjective norms) on individuals' privacy concerns. Specifically with biometric systems, other studies also considered the relationship between subjective norms and users' privacy concerns with biometrics [68,69]. Thus, H_{10} was proposed:

H10. Subjective norms are related to privacy concerns with the use of biometric technologies at airports.

While the effect of PBC on intentions appears to have been well studied in the literature, this study sought to investigate the direct influence of PBC on individual's privacy concerns. The review of the available literature suggested the existence of a relationship particularly as it relates to a patient's privacy concerns over their information [70,71]. Therefore, the hypothesis was proposed:

H11. Perceived behavioral control is related to privacy concerns with the use of biometric technologies at airports.

2.6. Control variable

As this study progressed, COVID-19 had been officially declared a pandemic affecting all regions in the world. While the pandemic can be considered a one-off event, it was important to include COVID-19 as a control variable to determine the extent to which passengers' behavioral intentions were influenced by the pandemic. Per the suggestion by Becker [72] and Judge and Bono [73]; this variable was treated as one of the exogenous variables.

3. Methodology

3.1. Pilot study and initial assessment of measurement instrument

Two pilot studies were conducted in this research. The first showed some reliability and validity; thus, the instrument was amended, following which a second was conducted to check the changes made to the instrument. Both pilot studies utilized a sample of at least 100 participants from Amazon ® Mechanical Turk ® (MTurk), however only the results from the second pilot study will be reported in this section.

There were 102 responses received from which there were 98 useable responses (55 males and 43 females) with an average age of 39.29 ($SD = 11.44$) years. Three cases missing one value each and one case missing two values had the values replaced using known value replacement as suggested by Hair, Black, Babin, and Anderson [74]. The CFA model was constructed and analyzed using IBM ® SPSS ® AMOS 24 with the following results for model fit: (CMIN/df = 1.721; CFI = 0.942; GFI = 0.768; AGFI = 0.693; NFI = 0.874; RMSEA = 0.086). While the values appeared to indicate an unsatisfactory model fit, an examination of the modification indices (MI) showed that there was no meaningful MI value that could make a change to the model fit. Several fit indices are also known to be affected by sample size (i.e., GFI, AGFI, NFI, and RMSEA) [75–77]. Therefore, considering the small sample size of the pilot study ($n = 98$), it was decided to proceed.

The factor loadings for all question items were greater than 0.5 while construct reliability and Cronbach's Alpha (α) for all constructs were greater than 0.7. In addition, the maximum shared variance (MSV) values for all constructs were lower than the corresponding average variance extracted (AVE) values, while the square roots of the AVEs are all greater than the inter-construct correlations. The instrument was therefore used for the main study since it demonstrated acceptable reliability and construct validity (as assessed using convergent validity and discriminant validity). Participants from both pilot studies were excluded from the main study.

3.2. Main Study

3.2.1. Sampling frame and sample size

The sample was a convenient sample from MTurk while the minimum sample size required was determined using the online sample size calculator by Soper [78] as based on the method by Westland [79] for determining sample size. The following parameters were set in this study: effect size (f^2) to 0.2, significance level (α) to 0.05, and the statistical power level ($1-\beta$) to 0.8. With 13 latent variables and 26 observed variables, the minimum sample size was calculated at 511 persons.

3.2.2. Initial data screening

There were 757 responses received from participants via the MTurk platform. Initial data screening removed eight cases that were missing answers to two or more Likert scale questions. Further data screening resulted in the removal of 60 cases with similar answers across all the Likert scale questions which suggested unengaged respondents. The remaining 689 cases were considered useable for the main data analysis. Missing values were found across different variables and determined to be random, thus the values were replaced with known valid values. Data was assessed as normal as seen from the values of skewness (range -0.134 to -1.215) and kurtosis (range -0.979 to $+1.992$). This is in line with the recommendations of Singh and Sharma [80]; normality is acceptable with absolute values of skewness and kurtosis within the range of $+2$ and -2 , and Byrne [81] kurtosis values below 7 are indicative of data normality.

3.2.3. Participants

Participants for the study were selected from MTurk. The MTurk platform provides researchers with access to participants that consent to completing online tasks for a small reward. Several studies have confirmed that participants recruited via MTurk are closely representative of the U.S. population and that the data from participants is especially useful and can be considered as valid as normal laboratory data [82–85].

The 689 participants that completed the study (402 males, 284 females, three did not respond) reported an average age of 38.17 ($SD = 12.24$) years. Average annual income was \$60,998 ($SD = \$42,247$, $MDN = \$50,000$). Table 2 summarizes the demographics.

This study utilized U.S. Census data to evaluate the representativeness of participants. While there were some slight differences in age, education and income, the sample was found to be representative of the U.S. population.

3.2.4. Research instrument and survey procedure

The research instrument was an electronic questionnaire developed using Google Forms®. Participants accessed the questionnaire via a URL link on the MTurk website. Upon accessing the survey, participants were required to complete the consent form and respond to two screening questions to ensure that only residents of the U.S. 18 years or older responded to the survey. Next, participants were provided with instructions and information about biometric systems to help with the completion of the questionnaire. The following scenario was then presented to the participants: “You have arrived at your local airport for a scheduled flight between two major cities. Upon approaching the check-in area, you are advised that there is an option to complete your entire check-in, baggage drop and aircraft boarding using only facial recognition as the means of identification and verification for the flight.” The questions were based on the constructs as shown in Table 1, and used five-point, Likert scale with anchors from “strongly disagree” (-2) to “strongly agree” ($+2$). The item questions along with the mean and standard deviation are presented in Table 3. Participants were then asked an additional question on COVID-19 and their perception of intentions to use biometrics. They were also provided with the opportunity to include any additional comments before answering demographic questions. Finally, participants entered a code that was used to receive their compensation

Table 2

Summary of demographic characteristics of participants.

Characteristics	Subgroup Categories	Frequency (N = 689)	Percentage**
Age	≤29 years	183	26.6%
	30–39 years	262	38.0%
	40–49 years	119	17.3%
	50–59 years	68	9.9%
	≥60 years	57	8.3%
Gender	Male	402	58.3%
	Female	284	41.2%
	No response	3*	0.4%
Highest Level of Education	High school certificate	161	23.4%
	Bachelor's Degree	363	52.7%
	Master's Degree	143	20.8%
	Doctorate Degree	20	2.9%
	No response	2*	0.3%
Ethnicity	American Indian or Alaska Native	2	0.3%
	Asian or Asian American	58	8.4%
	Black or African American	49	7.1%
	Hispanic or Latino	30	4.4%
	Mixed Race	19	2.8%
	Native Hawaiian or other Pacific Islander	1	0.1%
	White or Caucasian	529	76.8%
	No response	1*	0.1%
Annual Total Income (USD)	≤9999	26	3.8%
	10,000–19,999	49	7.1%
	20,000–34,999	111	16.1%
	35,000–49,999	113	16.4%
	50,001–74,999	187	27.1%
	≥75,000	177	25.7%
	No response	26*	3.8%
Previous use of facial recognition technology at airport	No	550	79.8%
	Yes, once only	67	9.7%
	Yes, more than once	70	10.2%
	No response	2*	0.3%
Any effect of COVID-19 crisis on perception of intention to use biometrics at airports?	Yes	131	19.0%
	No	558	81.0%

Note: *Number of respondents who did not respond to question; ** Values may not add up to 100% due to rounding.

and exited the survey.

3.2.5. Research design, analytical methods, and ethical considerations

The research utilized a correlational design while the data analysis and evaluation were conducted using IBM® SPSS Statistics Version 24® and IBM® SPSS AMOS Graphics 24®. Data analysis was conducted in three steps: descriptive statistics, confirmatory factor analysis (CFA), and structural equation modeling (SEM). In addition to participants' informed consent obtained at the start of the study, respondents were assured of anonymity and confidentiality. The researchers followed all guidelines and received approval from the university's Institutional Review Board (IRB) before data collection.

4. Results

4.1. Measurement model

The measurement model was evaluated using confirmatory factor analysis (CFA). As earlier noted from the kurtosis values, the data met the assumption of normality, so no data transformation was required. An

Table 3
Summary of item questions with mean and standard deviation.

Construct	Item Questions	Mean (N = 689)	Average Mean for Construct	SD	Average SD for Construct
AT	AT1: "Using biometrics at airports is a good idea"	.56	.47	1.197	
	AT2: "Using biometrics at airports is a wise idea"	.48		1.197	
	AT3: "I like the idea of using biometrics at airports"	.47		1.271	
	AT4: "Using biometrics at airports would be pleasant"	.36		1.153	1.205
SN	SN1: "People who influence my behavior would think that I should use biometrics at airports"	.16		1.055	
	SN2: "People who are important to me would think that I should use biometrics at airports"	.11		1.088	
	SN3: "People whose opinions I value would prefer me to use biometrics at airports"	.11	.13	1.070	1.071
PB	PB1: "I would be able to use biometrics at airports"	1.04		.890	
	*PB2: "The choice to use biometrics at airports is entirely up to me"	.43		1.239	
	PB3: "I have the resources and the knowledge and the ability to make use of biometrics at airports"	.93	.80	.896	1.009
PE	PE1: "My interaction with biometrics at airports is clear and understandable"	.80		.989	
	PE2: "Learning to use biometrics at airports is easy for me"	.97		.877	
	PE3: "It would be easy for me to become skillful at using biometrics at airports"	.99		.902	
	PE4: "I would find biometrics at airports easy to use"		.93	.876	.911
PU	PU1: "Using biometric systems would enable me conduct airport identification and verification processes quickly"	1.07		.883	
	PU2: "Using biometric systems would make it easier for me to conduct airport identification	.97		.920	

Table 3 (continued)

Construct	Item Questions	Mean (N = 689)	Average Mean for Construct	SD	Average SD for Construct
CV	and verification processes"				
	PU3: "I would find biometric systems useful in conducting airport identification and verification processes"	.88	.97	.978	.927
	CV1: "Thinking about the coronavirus (COVID-19) makes me feel threatened"	.35		1.232	
	CV2: "I am afraid of the coronavirus (COVID-19)"	.44		1.242	
PR	CV3: "I am stressed around other people because I worry I will catch the coronavirus (COVID-19)"	.35	.38	1.277	1.250
	PR1: "I am concerned that when I give personal information to biometric systems for some reason, the owner of the system would use the information for other reasons"	.65		1.252	
	PR2: "I am concerned that my information could be breached when using biometric systems"	.66		1.253	
	PR3: "I am concerned that my information could be shared or sold when using biometric systems"	.65	.66	1.264	1.256
IN	IN1: "Assuming that I have access to biometrics systems at airports, I intend to use them"	.27		1.172	
	IN2: "I intend to increase my use of biometrics at airports in the future"	.15		1.160	
	IN3: "Even if there are other options available, I intend to use biometrics at airports"	.08	.16	1.172	1.168

Notes: * Item reworded from first pilot study. Statements from Kasim [120].
AT = Attitudes; SN = Subjective Norms; PB = Perceived Behavioral Control; PE = Perceived Ease of Use.
PU = Perceived Usefulness; CV = Coronavirus (COVID-19); PR = Privacy Concerns; IN = Intention to Use.

assessment for possible outliers using Mahalanobis distance (D^2) values did not reveal any values that were distinct from the other values, there were eight cases that were considered as outliers due to their D^2 values being above 100. However, since deleting one outlier at a time and conducting the CFA process each time did not result in any significant change to the model, it was decided to retain the possible outliers in the model.

Next, an evaluation of model fit revealed a satisfactory fit as evidenced by the values shown in Table 4 (results before PB2 removed). The subsequent assessment of reliability and validity of the model showed that the PB2 item at 0.394 was the only factor loading less than the reference value of 0.5. Similarly, Cronbach's Alpha (α) for the PBC construct was 0.650 while the AVE was 0.471, both figures lower than the reference values of 0.7 and 0.5, respectively. To assess the discriminant validity, the MSV value for the PBC construct was the only one seen to be higher than the associated AVE value among all the constructs, while the square root of the AVEs were greater than the inter-construct correlations for all constructs except for the PBC construct.

From the first pilot study, the PB2 item had been reworded from "Using biometrics at airports is entirely within my control" to "The choice to use biometrics at airports is entirely up to me." The rewording of the item had resulted in satisfactory reliability and validity, however, the unacceptable reliability and construct validity of the CFA model again appeared to be related to the PB2 item. While Hair et al. [74] noted there should be at least three items per factor, they also advised that the literature should be consulted and that an item could be deleted in cases of low factor loading or if there are issues with model integrity, model fit, or construct validity.

Several researchers have noted that two items could be sufficient for a CFA model [86–88]. Furthermore, the significant between-construct error covariances between items AT4.

("Using biometrics at airports would be pleasant") and PB2 ("The choice to use biometrics at airports is entirely up to me") could suggest a degree of overlap and redundancy between the items [74,81]. It was therefore decided to delete the PB2 item from the model and reevaluate the model fit.

From Table 4, it is seen (from the values after PB2 removed) that all the fit indices showed improvement in the model with the PB2 item removed. Additionally, two predictive fit indices, the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) also show that the model with the PB2 item removed is a better fitting model since the values were lower. Since a satisfactory model fit had been obtained, the next step was to check the reliability and validity of the model.

The results as shown in Table 5 provide evidence that all factor loadings were above the reference value of 0.5, α for all constructs was above 0.7, AVE values above 0.5, and all AVE values less than the corresponding MSV values, indicating acceptable reliability and construct validity. Table 6 also shows that the square roots of the AVEs are all greater than the inter-construct correlations, further supporting the discriminant validity of the model. The model with the PB2 item removed was therefore utilized for the structural model assessment.

4.2. Structural model

4.2.1. Model evaluation

The structural model (or SEM model) was evaluated using the same method used to assess the CFA model. First, the assessment for normality

Table 4
Fit Indices for CFA Model – Before and After PB2 item removed.

Model Fit Indices/ Criteria	Standard Values	Results (Before PB2 removed)	Results (After PB2 removed)	Acceptable (Yes/No)
CFI	≥ 0.95	0.974	0.977	Yes
GFI	≥ 0.90	0.928	0.934	Yes
AGFI	≥ 0.90	0.906	0.913	Yes
NFI	≥ 0.90	0.958	0.962	Yes
RMSEA	≤ 0.05	0.047	0.046	Yes
Normed Chi-Square (CMIN/df)	$1 < \chi^2/df < 3$	2.504	2.425	Yes
AIC		838.652	754.891	
BIC		1201.472	1108.640	

for the structural model showed that the data met the assumption of normality while there were no outliers that could be considered for deletion. This was followed by the evaluation of model fit which resulted in the following values for the fit indices: (CMIN/df = 2.425; CFI = 0.977; GFI = 0.934; AGFI = 0.913; NFI = 0.962; RMSEA = 0.046). The values are similar to the values from the CFA model (after PB2 item removed) as seen in Table 4, thus there was no need to re-specify the model.

4.2.2. Hypotheses testing

The testing of the hypotheses for the SEM model involved the analysis of the relationships from the IBM® SPSS® AMOS output. While the Critical Ratio (*t*-value) and the *p*-value were used to assess the statistical significance of a relationship, the unstandardized regression weights signified the changes in the predicted variables for a one-unit change in the predictor. The hypotheses testing in this study was conducted taking two separate SEM models into consideration – one without moderation effects, and the second with moderation effects. Since the results from the two SEM models were similar, only the results from the SEM model with moderation effects were presented in this section. The SEM model with interaction effects and unstandardized path coefficients displayed is shown in Fig. 2.

The results for all the hypotheses including the *t*-values, *p*-values, and the standardized estimates are shown in Table 7. From the results, six hypotheses ($H_1, H_2, H_6, H_7, H_8, H_{11}$) were supported, while five hypotheses ($H_3, H_4, H_5, H_9, H_{10}$) were not.

4.2.3. Moderations (interaction effects)

To assess the moderation effects, five new variables were created using the products of the exogenous variables (AT, SN, PB, PE, PU) and the moderating variable (PR). Following the suggestion of Williams, Vandenberg, and Edwards [89]; the significance of the product of the variables was used to provide the statistical test of the interactions. As seen from the results in Table 7, three of the five hypotheses for the moderations were supported ($H_{1-1}, H_{2-1}, H_{5-1}$) while two hypotheses (H_{3-1}, H_{4-1}) were not supported.

4.2.4. Control variable

Becker [72] suggested that to determine the effect of the control variable, the model should be evaluated with and without the control variable. Therefore, the COVID-19 variable (CV) was removed from the model and the hypotheses testing conducted. The results without the CV variable showed a good model fit (CMIN/df = 2.761; CFI = 0.976; GFI = 0.934; AGFI = 0.911; NFI = 0.964; RMSEA = 0.051) and were similar to the results obtained with the CV variable (as seen in Table 4). In addition, there was no change in the relationships since all the hypotheses were in the same direction. The results therefore suggest that there was minimal influence from perceived threat from COVID-19 on the model.

4.2.5. Final SEM model

The SEM model with interactions did not have a satisfactory model fit (CMIN/df = 39.399; AGFI = 0.320; RMSEA = 0.236). In addition, the effect sizes of the interactions were small and added unnecessary complexity to the model. It was therefore determined that the model without interactions was the most parsimonious model and was adopted as the final model for the study. The model fit results (CMIN/df = 2761; CFI = 0.976; GFI = 0.934; AGFI = 0.911; NFI = 0.964; RMSEA = 0.051), showed that all the model fit indices were satisfactory while the RMSEA was slightly above the reference value.

Thus, the final SEM model as shown in Fig. 2 does not include the interactions or the control variable. The model explained 80.2% of the variance in intentions and 35.2% of the variance in privacy concerns.

5. Discussion

The summary of demographic characteristics as presented in Table 2

Table 5
Reliability Analysis and Validity for CFA Model (After PB2 item removed).

Construct	Item Question	Factor Loadings ($\geq .5$)	CR ($\geq .7$)	Cronbach's Alpha ($\geq .7$)	AVE ($\geq .5$)	MSV ($< \text{AVE}$)
Attitudes	AT1	.937	.940	.937	.796	.780
	AT2	.921				
	AT3	.922				
	AT4	.780				
Subjective Norms	SN1	.886	.930	.930	.816	.526
	SN2	.931				
	SN3	.893				
Perceived Behavioral Control	PB1	.817	.772	.771	.629	.601
	PB3	.769				
Perceived Ease of Use	PE1	.762	.896	.893	.683	.601
	PE2	.843				
	PE3	.864				
	PE4	.833				
Perceived Usefulness	PU1	.851	.880	.877	.709	.552
	PU2	.851				
	PU3	.824				
Coronavirus (COVID-19)	CV1	.895	.911	.911	.774	.055
	CV2	.905				
	CV3	.838				
Privacy	PR1	.917	.940	.940	.840	.317
	PR2	.909				
	PR3	.923				
Intention to Use	IN1	.928	.941	.941	.843	.780
	IN2	.907				
	IN3	.919				

Table 6
Discriminant Validity for CFA Model (After PB2 item removed).

	CV	AT	SN	PB	PE	PU	PR	IN
CV	0.880*							
AT	0.151	0.892*						
SN	0.235	0.725	0.904*					
PB	0.012	0.459	0.352	0.793*				
PE	0.016	0.494	0.367	0.775	0.826*			
PU	0.120	0.743	0.531	0.606	0.637	0.842*		
PR	0.051	-0.552	-0.379	-0.169	-0.268	-0.330	0.916*	
IN	0.182	0.883	0.710	0.396	0.442	0.658	-0.563	0.918*

Note. * Indicates Square root of AVEs.

Fig. 2. Final SEM model (supported hypotheses in Blue Font). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

shows that respondents are younger, have more advanced educational qualifications, and reported incomes lower than the national U.S. population, using data from Refs. [90,91]. The ethnic distribution of respondents fairly resembles the U.S. population. These findings are

similar with results that have utilized samples from MTurk [92–96].

Hypothesis 1 found that passengers' attitudes positively influenced intentions to use biometrics. The outcome is in line with the relationship postulated by the TPB and is supported by studies that confirmed a positive relationship between attitudes and intentions [97–99]. Other studies also confirmed that consumers displayed positive attitudes towards biometrics [14,54,62]. It is possible that the positive views of respondents were influenced by the anticipated benefits from the use of biometrics. Some of the benefits identified by respondents include faster boarding times, increased security, and the improved convenience in concluding airport processes.

Hypothesis 2 was supported indicating that respondents felt that the opinions of the most important people to them were relevant in their decision to use biometrics. The relationship is consistent with the TPB and is in accordance with studies that confirmed a positive relationship between subjective norms and intentions to perform a behavior [53,54]. Since people are normally willing to share positive travel experiences, it is possible that the thoughts of sharing the experience of the use of biometrics with people close to them influenced the responses.

Hypothesis 3 was not supported indicating that respondents did not consider PBC to be a factor with the intentions to use biometrics. It also implies that the perception of the control of respondents over the decision to use biometrics does not influence the decision. While the finding in this study is contrary to the relationship of the TPB, other studies have

Table 7
Hypotheses testing SEM model with moderation effects.

Hypotheses	Standardized Estimates	t-value	p-value	Result
H ₁ : Attitudes are positively related to intentions	.666	18.512	***	Supported
H ₂ : Subjective norms are positively related to intentions	.114	5.052	***	Supported
H ₃ : Perceived behavioral control is positively related to intentions	-.017	-.578	.563	Not Supported
H ₄ : Perceived ease of use is positively related to intentions	.028	.897	.370	Not Supported
H ₅ : Perceived usefulness is positively related to intentions	.044	1.402	.161	Not Supported
H ₆ : Privacy concerns are negatively related to intentions	-.149	-8.109	***	Supported
H ₇ : Attitudes are negatively related to privacy concerns	-.853	-13.972	***	Supported
H ₈ : Perceived ease of use is negatively related to privacy concerns	-.307	-5.089	***	Supported
H ₉ : Perceived usefulness is negatively related to privacy concerns	.282	4.798	***	*Not Supported
H ₁₀ : Subjective norms are related to privacy concerns	.067	1.427	.153	Not Supported
H ₁₁ : Perceived behavioral control is related to privacy concerns	.283	4.720	***	Supported
Moderations				
H ₁₋₁ : The level of privacy concerns will moderate the positive relationship between attitudes and intentions	.172	5.310	***	Supported
H ₂₋₁ : The level of privacy concerns will moderate the positive relationship between subjective norms and intentions	-.044	-2.125	.034**	Supported
H ₃₋₁ : The level of privacy concerns will moderate the positive relationship between perceived behavioral control and intentions	-.036	-1.284	.199	Not Supported
H ₄₋₁ : The level of privacy concerns will moderate the positive relationship between perceived ease of use and intentions	.010	.348	.728	Not Supported
H ₅₋₁ : The level of privacy concerns will moderate the positive relationship between perceived usefulness and intentions	-.085	-2.718	.007**	Supported
Control Variable				
Effect of COVID-19 on passengers' behavioral intentions while controlling for the other variables	.050	3.402	***	Supported
Effect of COVID on passengers' privacy concerns while controlling for the other variables	.109	3.537	***	Supported

Note. *** $p < .001$. ** $p < .05$. *Hypothesis in reverse direction.

also found that PBC did not significantly predict intentions [24, 100–102].

This finding could be explained from the nature of the scenario for this study which involved a voluntary decision to use biometrics. It is possible that respondents viewed this decision as demonstration of complete control and therefore did not think perceived control was important. Since the hypothesis was not supported, it is probable that the theoretical model for the study could have suggested either a negative relationship, or an indirect relationship through one of the other factors.

Hypothesis 4 and Hypothesis 5 were not supported indicating that respondents felt perceived ease of use and perceived usefulness were not influencing factors in their intentions to use biometrics. Although the result may be considered surprising since the TAM [38] postulates that both variables influence behavioral intention and use of technology, other studies have also found that the effects of either one or both variables on intentions were not significant. For example, Hussein [103]; Mohammed [104]; Mohd Suki and Mohd Suki [105] found perceived ease of use was not a significant determinant of intentions, while Kasi-lingam [106]; Teo and Milutinovic [107]; Wang, Lew, Lau, and Leow [108]; and Wong [109] found perceived usefulness to have a limited effect on intentions.

The findings in this study could have been influenced by the specific type of biometric technology that was adopted. It is possible that a different type of biometric technology, for example fingerprint or iris scan could have resulted in a different outcome. Additionally, a different sample could also show a different result. As majority of respondents (79.8%) had not used biometric technology at airports, their perceptions of ease of use or usefulness may have been influenced by uses of other biometrics devices (such as smartphones and watches), and therefore do not think that the two factors will be important with their decision to use biometrics in this scenario. Respondents could have also felt that factors such as trust or emotions may be more important than perceived ease of use and perceived usefulness in the decision to use biometrics.

Hypothesis 6 was supported implying that as privacy concerns increase, there is a reduced tendency to use biometrics. As noted earlier in this study, other studies have also confirmed this relationship [53,59, 60]. The concerns about privacy in this study are likely related to concerns about the handling and use of passengers' data.

Hypothesis 7 was supported indicating that passengers' attitudes had a negative influence on their privacy concerns with biometrics. While some studies found a significant negative relationship between attitudes and perceptions of privacy [59,110], other studies have found either a positive relationship or a non-significant negative relationship [7,14, 63]. The finding in this study implies that a passenger with more positive attitudes towards biometrics would likely have lower concerns about privacy with the use of biometrics. As with hypothesis 6, it appears that most concerns are related to the use of data collected from the biometric system.

Hypothesis 8 was supported indicating that an increased perception of ease of use will result in decreased privacy concerns towards biometric systems. While this relationship appears not have been widely assessed, Oh et al. [64] considered perceived ease of use as a component of usability and noted that the usability of a system was accompanied by reduced privacy concerns.

Hypothesis 9 proposed a negative relationship between perceived usefulness and passengers' privacy concerns with the use of biometric technologies. The hypothesis was not supported, a result that could be considered surprising since Hypothesis 8 with perceived ease of use was supported. However, it was noted that the result was not in the hypothesized direction thus suggesting that the relationship could be positive rather than the negative one proposed from the theoretical model of this study. One possible explanation in this study is that

respondents could be biased in their responses especially considering the result of the other hypothesis with perceived usefulness. It is also possible that a different sample may have had a different outcome.

Hypothesis 10 was not supported suggesting that passengers did not consider that the opinions of the people most important to them were relevant as it pertains to their privacy concerns with the use of biometrics. Although the literature on this relationship appears to be limited, it is possible that participants from a highly individualistic country such as the U. S. would not necessarily consider the opinions of others before deciding on the use of biometrics. It may be appropriate to review the theoretical model and reevaluate the hypothesis when the results are compared with previous studies on this topic [67–69].

Hypothesis 11 was supported indicating that there was a positive relationship between PBC and privacy concerns. This result does not appear to be consistent with some past studies that reported reduced privacy concerns with increased perceived control of personal information [111,112]. However, it is possible that the respondents in this study may not have associated the context of PBC as it was applied to this study. Nevertheless, the result provides a reason to consider a directional hypothesis for the relationship.

From the results of the interaction effects, three of the five interactions were statistically significant. However, as earlier noted, the effect sizes were small and provided limited value to the model. Specifically, the review of the finding on the moderating influence of privacy concerns on the attitudes-intentions relationship appeared to support the ‘privacy paradox’ in that passenger concerns about privacy were considered secondary to the perceived benefits from the use of biometrics [66,113].

5.1. Theoretical contributions

The approach adopted in this study to extend the TPB with two factors of the TAM (perceived usefulness and perceived ease of use) and study passengers’ behavioral intentions could be considered a significant theoretical contribution. Although the analysis of the results reveals that passengers’ intentions were more influenced by the TPB factors than the TAM factors, it is instructive to note that PBC did not predict intentions in this study. The study of the moderating effects of privacy on passengers’ behavioral intentions also provided a notable contribution. While privacy concerns were found to negatively influence passengers’ intentions, the moderations (interaction effects) were removed from the final model as their inclusion did not result in any significant improvement to the model. Finally, the investigation of the effect of COVID-19 (control variable) provided valuable information that helped exclude COVID-19 as an explanation for the findings. In addition, there was no significant difference between the models with and without the control variable. These findings in respect of privacy concerns and the effect of COVID-19 are significant contributions to the literature.

5.2. Practical applications

There are some practical suggestions that could be useful to stakeholders involved with the applications of biometric systems. Since attitudes were found to be a strong predictor of passengers’ intentions, airport owners and operators, airlines, and biometric systems providers need to ensure that the design and use of biometric systems provides passengers with positive feelings and enjoyable experiences with biometrics. The positive feelings are crucial to intentions and will ultimately influence the continued deployment and use of biometric systems. Furthermore, the research results confirm the need for biometric system operators to focus on providing customer-centric systems with the most current technologies.

The implication of the finding regarding subjective norms and intentions is that passengers are likely to take the opinions of the people most important to them into consideration as regards the decision to choose to use or not use biometrics. Therefore, consideration could be

given to the inclusion of customer experience survey or feedback forms following biometric use, with the opportunity to share the experience with friends and family. It is important that the actual feedback system should be designed to be friendly and easy to use since that process itself will be a part of the passenger experience. A shared positive experience is likely to provide a common platform for discussions among friends and family and could result in eagerness or anticipation of further use of biometrics.

There were also significant relationships involving privacy concerns which suggests that privacy is important and should be addressed with the implementation of biometric systems. Practically, the use of biometric systems implies that some personal information will be provided by users. It is therefore imperative that passengers should be assured that their personal data would be secure and not be made available to third parties. It is also important that privacy agreements stating the conditions of the data provision and use of data are provided to passengers, and that passengers who do not wish to use the system are able to decline at any time. The results highlight that the owners and operators of biometric systems should provide those assurances and necessary information to a user prior to the start of any transaction using biometrics. The use of a PIA, as noted earlier should help to mitigate some of the potential risks to privacy. Furthermore, awareness sessions and product support materials to improve the general knowledge on biometrics could be included as part of the introduction of a biometric system.

The results suggest that any effects of COVID-19 could be discarded as alternative explanations for the conclusions in this study. Although the pandemic has a major impact on the world economy, it appears that COVID-19 was not directly associated with passengers’ behavioral intentions or with their privacy concerns. However, it is noted that a joint report by the group representing the world’s major airports, Airport Council International (ACI), and IATA, the airline’s association suggested that airports should pursue an increased use of biometrics to help reduce passengers’ physical interactions [114]. This may seem to be a practical consequence from the pandemic.

5.3. Limitations

There are some limitations that are applicable to this study. First, the use of a convenience sample from MTurk implies that the results may not be generalizable except to persons completing online human intelligence tasks. While this is a limitation, other studies have suggested that participants from MTurk are broadly representative of the U.S. population [82,115,116].

Secondly, the cross-sectional nature of the study meant that respondents views were dependent on the conditions at the time. Although the study included a control variable to account for the perception of the threat of COVID-19 which was occurring during the study, it is not known how participants would respond at a different time. Additionally, as a survey, there is a limitation of respondents being restricted to specific categories. This was mitigated by giving respondents the option to include any additional comments with their responses.

Thirdly, the scope of the study was limited to the examination of passengers’ intentions to use biometrics at airports within the context of a domestic flight. The current study is limited to that scenario, but it is acknowledged that results could be different for another scenario or for international flights. It is assumed that a passenger’s intention to use would be followed by actual use of biometrics. This assumption follows from the review of the TPB which suggests that actual behaviors could be predicted from intentions [17,117,118]. Similarly, although 79.8% of respondents did not have any prior use of biometrics at airports, this statistic highlights the purpose of the current study to examine participants’ intentions with biometrics. Further research should be conducted to check on these findings as a future study as the use of biometric technology becomes more widespread.

Finally, the study was also limited to the effects of the factors of the

TPB and the additional factors of perceived usefulness and perceived ease of use on passengers' behavioral intentions. The study did not consider any effects of perceived usefulness and perceived ease of use on attitudes. While the inclusion of privacy concerns and the assessment of the moderating effects may have helped broaden the scope, it is probable that there are other factors that could affect passengers' intentions.

6. Conclusions and recommendations for further study

The current study investigated factors that could influence passengers' behavioral intentions to use biometric technologies at airports. Additionally, the study explored the moderating effects of passengers' privacy concerns on the influencing factors and included COVID-19 as a control variable to account for the pandemic that occurred during the study. Attitudes and subjective norms were found to positively influence passengers' intentions while privacy concerns negatively influenced intentions. The results also showed that there were significant relationships between privacy concerns and three other factors, attitudes, perceived behavioral control and perceived ease of use. Although privacy concerns were found to moderate the relationships between passengers' intentions and three factors, attitudes, subjective norms, and perceived usefulness, the effects were small and therefore were not included in the final model. The final model accounted for 80.2% of the variance in intentions and 35.2% of the variance in privacy concerns.

Future studies should be extended to separate sampling frames within and outside the U.S. to expand the generalizability of the findings from this study. Additionally, the study could also be repeated at different times using a similar methodology to determine if the results from this study can be replicated. Finally, since this research was conducted with focus on facial recognition as the specific type of biometric technology, future study could examine intentions to use biometrics with focus on other types of biometrics. Some of these include fingerprints, voice, iris scans, and palm scans, while other forms of biometric technologies such as behavioral biometrics and passive biometrics would also benefit from further research.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Credit statement

Kabir O. Kasim: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Project administration. Scott R. Winter: Conceptualization, Methodology, Writing – review & editing, Supervision. Dahai Liu: Writing – review & editing, Formal analysis. Joseph R. Keebler: Writing – review & editing, Formal analysis. Tyler B. Spence: Writing – review & editing.

Declaration of competing interest

None.

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