

The Effect of Robo-taxi User Experience on User Acceptance: Field Test Data Analysis

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Abstract

With the advancement of self-driving technology, the commercialization of Robo-taxi services is just a matter of time. However, there is some skepticism regarding whether such taxi services will be successfully accepted by real customers due to perceived safety-related concerns; therefore, studies focused on user experience have become more crucial. Although many studies statistically analyze user experience data obtained by surveying individuals' perceptions of Robo-taxi or indirectly through simulators, there is a lack of research that statistically analyzes data obtained directly from actual Robo-taxi service experiences. Accordingly, based on the user experience data obtained by implementing a Robo-taxi service in the downtown of Seoul and Daejeon in South Korea, this study quantitatively analyzes the effect of user experience on user acceptance through structural equation modeling and path analysis. We also obtained balanced and highly valid insights by reanalyzing meaningful causal relationships obtained through statistical models based on in-depth interview results. Results revealed that the experience of the traveling stage had the greatest effect on user acceptance, and the cutting edge of the service and apprehension of technology were emotions that had a great effect on user acceptance. Based on these findings, we suggest guidelines for the design and marketing of future Robo-taxi services.

Keywords: User Experience, User Acceptance, Robo-taxi, Structural Equation Modeling

1. Introduction

With the advent of the sharing economy and Robo-taxi (or self-driving taxi), the automotive industry is facing new changes in terms of technological, social, and regulatory trends. Robo-taxi is expected to alleviate traffic congestion and reduce the need for parking through an active car sharing service, as well as lower carbon emissions through the optimized operation by sharing connected road information (Kang et al., 2017). Furthermore, it will be a low-cost, affordable, and easily accessible option for people in the outskirts of cities or rural areas where advanced public transportation is not available (Rapid News Network, 2019). In this changing environment, multiple automakers, IT firms, and shared service companies are moving quickly to seize the initiative in the Robo-taxi market through the establishment of various partnerships (Venturebeat, 2019; The Verge, 2019; Korea Times, 2019; Aviation24.be, 2019; Carscoops, 2019; Market Realist, 2019).

However, high-quality technology does not necessarily mean that it is always accepted by consumers. Since self-driving is a technology directly related to safety, relieving the user's anxiety is a significant hurdle. As a result, various user-centered studies related to Robo-taxi have been conducted. Many studies use the survey approach to analyze the relationship between the user and self-driving vehicles or Robo-taxi (Hohenberger et al., 2017; Hulse et al., 2018; Tussyadiah et al., 2017). Others have conducted experiments on the interaction between the taxi and the user in an indirect way using simulation and VR (Jamson et al., 2013; Koo et al., 2015, 2016; Griesche et al., 2016; Cho et al., 2017). Recently, studies that test the interaction between the user and Robo-taxi based on actual field tests have also been conducted to overcome the limitations of virtual experiments conducted through surveys and simulators (Rothenbacher et al., 2016; Kim et al., 2017; Banks et al., 2018; Kim et al., 2020; Yoo et al., 2020). The user response can be analyzed using quantitative statistical methods as well as qualitative interviews. For example, some studies analyze factors affecting the acceptance of self-driving technology through structural equation modeling (SEM) or path analysis based on customer surveys (Osswald et al., 2012; Payre et al., 2014; Rödel et al., 2014; Choi and Ji, 2015; Ro and Ha, 2019).

This study performs SEM and path analysis based on actual user experience data for the Robo-taxi service to analyze factors affecting user acceptance. The differences between previous studies and this study are as follows. First, previous studies on SEM used survey data for people who had no experience with the Robo-taxi service. However, responses based on imagination about new technologies and services that they have never experienced before would differ greatly from reality. Specifically, regarding services directly related to safety, there are significant differences in user response before and after the experience (Yoo et al., 2020). This study differs in that it collected survey data after having people experience an unmanned taxi service. Second, we compared in-depth interview results and simultaneously analyzed video to interpret the meaning of statistical model analysis results. By performing quantitative and qualitative analysis in a balanced manner, we obtained more explainable and valid insights.

We constructed and analyzed three models using the user experience data on Robo-taxi obtained from previous studies (Kim et al., 2020; Yoo et al., 2020) performed by the authors. We analyzed the first model with SEM to identify how Robo-taxi service experience and demographic affect user acceptance. We analyzed the second model with SEM to identify how the positive and negative emotions of Robo-taxi service experience affect user acceptance. We analyzed the third model using path analysis to identify how main evaluation factors for the quality of the Robo-taxi service by stage (i.e., call, pick-up, traveling, drop-off) affect Robo-taxi service satisfaction.

The rest of this paper is organized as follows. Section 2 reviews the related previous works. Section 3 introduces the hypotheses and theoretical background of this study. Section 4 presents the field test process of obtaining the user experience data. Section 5 introduces three models for hypothesis testing and describes analysis results. Section 6 analyzes model results in detail and derives implications. Section 7 summarizes this study and describes its limitations.

2. Related Works

In this section, we introduce user-centered self-driving technology studies based on the survey, simulation, and field test. We also introduce studies on SEM for self-driving experience and technology acceptance models for

user experience.

2.1. Survey-based user research

Hohenberger et al. (2017) surveyed 1,603 people and found that people with high self-enhancement had low anxiety about self-driving vehicles. Hulse et al. (2018) surveyed 1,000 people in the UK on road safety and user acceptance. They argued that self-driving vehicles would be more attractive to males and young participants. Tussyadiah et al. (2017) surveyed 325 people on the influence of attitude and trust in technology on the intention to use self-driving taxis. They argued that consumers should trust that Robo-taxi would work as designed, and that expectations of reliability, functionality, and usefulness contribute to their intention to use.

2.2. Simulation-based user research

Studies have used simulation and VR to investigate the relationship between Robo-taxi and the user. Koo et al. (2015) conducted experiments with 64 participants using a driving simulator equipped with automatic braking, and presented an interaction model for the user to communicate with self-driving vehicles. The driving performance felt by drivers was improved when providing “reason” information as to why the vehicle behaved as it did rather than when providing the vehicle's “behavior” information. Koo et al. (2016) conducted simulation experiments with 40 participants, and showed that appropriate voice alerts alleviated drivers' anxiety. Cho et al. (2017) tested 68 participants using a driving simulator with different automation level, and showed that the anxiety was highest for automation level 3 and dropped slightly for automation level 4. Jamson et al. (2013) conducted experiments on 49 participants using a driverless car simulator and showed that drivers were willing to give up supervisory responsibilities. Griesche et al. (2016) examined the relationship of preference between the driver's own driving method and that of self-driving vehicles. The results revealed that most liked a similar driving style to their own, and all participants did not like small safety margins and high acceleration driving style.

2.3 Field-test based user research

Recently, user studies through field tests have been mainly conducted to overcome the limitations of surveys and simulators. Rothenbacher et al. (2016) modified the driver's seat of a vehicle in such a way that pedestrians could not see the driver, thus it was recognized as a fully autonomous vehicle. They investigated pedestrians' response and experience on self-driving vehicles within a university campus. Kim et al. (2017) implemented a taxi service within a university campus using a real self-driving vehicle, and tested passengers' response and the validity of self-driving driving technology. Banks et al. (2018) collected video data on user behavior through the field test of a partially automated self-driving vehicle, and analyzed the relationship between self-driving function and user behavior. Kim et al. (2020) tested user experience in Daejeon in Korea by implementing the Robo-taxi service. They suggested a solution that could compensate for the shortcomings of self-driving technology by introducing the concept of a virtual stop. Yoo et al. (2020) analyzed the anxiety factors of Robo-taxi based on the field test. They designed and implemented a Robo-taxi human-machine interaction (HMI) that could relieve anxiety and tested the service in the downtown area of Seoul, Korea.

2.4. SEM-based user research

SEM studies related to vehicle products and services have been actively underway. Various studies have been conducted on the adoption of eco-friendly vehicles such as electric vehicles (Will and Schuller, 2016, Zhang et al., 2018), and Shaaban and Kim (2016) conducted an SEM study on satisfaction with general taxi services. Regarding studies on self-driving vehicles and Robo-taxi, Payre et al. (2014) analyzed technology acceptability, attitudes, personality characteristics, and the intention to use self-driving vehicles with SEM. They surveyed 153 male drivers and observed a strong positive correlation between attitudes and the intention to use self-driving vehicles. Osswald et al. (2012) proposed a theoretical car technology acceptance model (CTAM) through an experiment with 21 participants using a simulator. Rödel et al. (2014) surveyed 336 people and investigated the factors of user acceptance and user experience such as the ease of use for self-driving vehicles, attitudes toward

system use, cognitive behavior control, and behavioral intention. Choi and Ji (2015) surveyed 552 drivers, and based on the technology acceptance model (TAM) and trust theory, analyzed whether the drivers adopted self-driving vehicles and what factors made them trust self-driving vehicles using SEM. Ro and Ha (2019) surveyed 1,506 participants and showed that convenience, safety, ethics, licenses, and cost had a direct effect on the acceptance attitude to self-driving vehicles, while convenience, safety, and financial cost had a direct effect on the intention to use self-driving vehicles. However, to the best of our knowledge, there has been no SEM research conducted based on actual user experience data obtained through the Robo-taxi field test.

2.5. Technology acceptance model and user experience research

TAM is a model in which the adoption and use of IT technology is determined by perceived usefulness and ease of use. Since our study identifies the relationship between user experience and user acceptance and satisfaction regarding new technology, it is also related to TAM studies (e.g., Davis, 1989; Venkatesh and Davis, 2000; Venkatesh et al., 2003; Yousafzai et al., 2007a, 2007b; Williams et al., 2015). However, relatively few studies cover both the TAM and the user experience (UX) model. This is because the TAM focuses on predicting the adoption of technology, whereas the UX model focuses on describing the emotions (i.e., perceived enjoyment, beauty, trust, satisfaction, anxiety) users feel when they encounter the product and service. It is important to investigate the user's emotions, aesthetic characteristics and experience together because user experience interacts with the practical aspect of the use of technology and UX (Hornbæk and Hertzum, 2017). There are studies support the fact that UX about the emotions that the user feels is important to user acceptance (Thüring and Mahlke, 2007; Hartmann et al., 2008; Van Schaik and Ling, 2008; Karapanos et al., 2009; O'Brien, 2010).

3. Hypothesis

3.1. The effect of user experience on user acceptance

As described in section 2.5, user perception of new technology has an effect on user acceptance (Bergmann and McGregor, 2011). Users who did not have direct experience in a given area perceived new technology by judging it on an abstract basis, but could judge based on more specific criteria after direct experience (Mervis and Rosch, 1981). Because users judge based on what they have experienced, user experience has been heavily covered in multiple studies on user acceptance (Chau, 1996; Jackson et al., 1997; Dishaw and Strong, 1999; Schaar and Ziefle, 2011).

We define the observed variables of user experience as the service quality of the Robo-taxi service by stage. We use the service quality evaluation values for a total of 4 stages: call, pick-up, traveling, and drop-off. The detailed evaluation method is described in section 4.3. We also selected overall satisfaction, intention to use, and willingness to pay (WTP) as the observed variables of user acceptance.

First, overall satisfaction refers to overall satisfaction after experiencing the Robo-taxi service. Satisfaction has been used as an important predictor variable of user behavioral intention (Ryu et al., 2012), and studies related to public transportation services have mainly analyzed factors affecting satisfaction to increase user acceptance (e.g., taxi service (Shaaban and Kim, 2016), subway service (Stuart et al., 2000), railway service (Eboli and Mazzulla, 2012)).

Second, intention to use evaluates whether there is a plan to use Robo-taxi in the future and represents the meaning of user acceptance. Choi and Ji (2015) argued that usefulness and trust were crucial factors for the intention to use self-driving vehicles, explaining the user's adoption factors of self-driving vehicles. In addition, many studies have analyzed the way to increase the intention to use self-driving vehicles (Hohenberger et al., 2017; Kaur and Rampersad, 2018; Ro and Ha, 2019).

Lastly, WTP is a variable for the reasonable price of the Robo-taxi service. Price perception and price acceptance play a vital role in affecting the user's consumption and post-consumption process (Han and Ryu, 2009; Matzler et al., 2006; Kang et al., 2017). Price is also a determinant of value perception (Varki and Colgate, 2001).

Based on these, we establish the following hypothesis:

H1a: The user experience of the Robo-taxi service will have an effect on user acceptance.

3.2. The effect of demographic on user experience and user acceptance

Hohenberger et al. (2016) demonstrated that there was a difference between gender and age regarding the willingness to use self-driving vehicles. Women felt more anxious when they used self-driving vehicles, whereas men felt less anxious. The difference in anxiety between genders decreased with age. Rödel et al. (2014) revealed a gender difference in terms of advanced driver-assistance systems (ADAS) technology, and women preferred vehicles equipped with many ADAS while men preferred non-autonomous or fully autonomous vehicles.

Other studies reveal the difference between men and women with respect to user experience with new technology. Women with a low-level of technology experience were more skeptical of smart technology than people with a high-level of technology experience, and both gender and experience were found to be decisive factors in the acceptance of smart devices (Schaar and Ziefle, 2011). Multiple studies revealed that the individual difference was a critical factor in describing both user acceptance and behavioral experience (Arning and Ziefle, 2009; Chua et al., 1999; Gefen and Straub, 1997).

We define the age, gender, and frequency of using taxis as the observed variables of demographic, and establish the following hypotheses:

H1b: Demographic has an effect on the user experience of the Robo-taxi service.

H1c: Demographic has an effect on the user acceptance of the Robo-taxi service

3.3. The effect of user emotion on user acceptance

Studies on the acceptance of self-driving vehicles and user emotion have mainly covered specific emotions related to safety such as anxiety and trust. Hohenberger et al. (2017) showed that anxiety had a negative effect on the willingness to use self-driving vehicles. Choi and Ji (2015) demonstrated that trust was a decisive factor in the intention to use self-driving vehicles. Similarly, Kaur and Rampersad (2018) found that trust and performance expectation were decisive factors in adopting self-driving vehicles. Stanton and Young (2000) considered the psychological variables related to driving automation such as feedback, locus of control, mental workload, driver stress, situational awareness, and mental representation.

Extensive research on the relationship between user emotion and user acceptance has been conducted in other service industries (Ladhari, 2009). According to Ali et al. (2016), customer satisfaction and price acceptance was affected when users felt lots of positive emotions through service experience. Lee et al. (2009) investigated the effect of the customer's positive and negative emotions on satisfaction and brand loyalty. Grace and O'Casey (2004) revealed that service experience, emotion, satisfaction, and brand attitude were related.

Most studies find positive emotions such as trust built up user acceptance whereas negative emotions such as anxiety and stress negatively affect user acceptance. We investigate which emotions greatly affect user acceptance among the detailed positive and negative emotions that the user feels through the experience of the Robo-taxi service. The 24 detailed emotions used as the observed variables are presented in section 4.3, and based on these, we establish the following hypotheses.

H2a: Positive emotions regarding Robo-taxi technology will have a positive effect on user acceptance.

H2b: Negative emotions regarding Robo-taxi technology will have a negative effect on user acceptance.

4. Data

This section presents the vehicle and service configuration used in the experiment (section 4.1), the experimental path (section 4.2), the survey design (section 4.3), and the participants (section 4.4). We used data obtained from the Robo-taxi field test studies (Kim et al., 2020; Yoo et al., 2020).

4.1. Robo-taxi vehicle and service configuration

It is difficult to provide the Robo-taxi service in a complex city center environment with current self-driving technology, and in addition, there are no laws and regulations in Korea for self-driving vehicles to drive on general roads. Therefore, we implemented the Robo-taxi service using the Wizard of OZ method, which is a way of getting participants to believe that they are using real services, but in reality, experimenters manually play the role of the automation system (Dahlbäck et al., 1993; Malsby et al., 1993). The driver's seat of the vehicle was completely cut off by a partition to block the subject's view, and they were told that safety personnel was also present but received control only in an emergency situation. In reality, vehicles were configured for safety personnel to drive with minimal movement and all driving and in-vehicle operation must follow instructions from the remote control tower. The survey confirmed that all subjects believed that it was fully autonomous driving after experiencing the service. Figure 1 shows the Robo-taxi service implementation and test scenes. The details of the experiment are described in Yoo et al (2020).

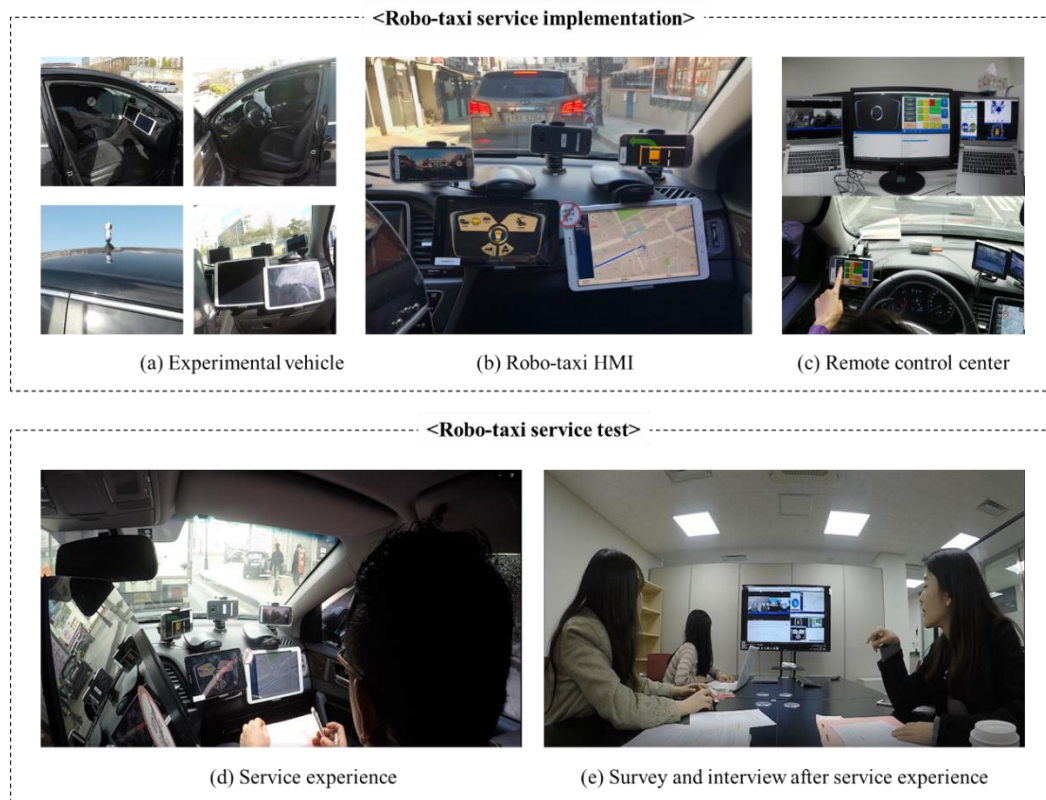


Figure 1. (a) From the upper left, front passenger seat, driver's seat, and the 360-degree camera attached in front of the passenger seat, the view seen when sitting in the passenger seat. (b) View from the passenger seat. There are three mobile phones used for 360-degree camera images, for recording the subject's images, and for directions. Of the two tablets, the left one is an app for communication with and the operation of the Robo-taxi, and the right one is for navigation. (c) (top) Robo-taxi control center environment, (bottom). Photo of controlling voice guidance through the app from the driver's seat. (d) The subject experiencing Robo-taxi in the field. (e) Interview with the subject while watching an experiment video after the Robo-taxi service (Yoo et al., 2020).

4.2. Robo-taxi service path

The experiments were conducted in the downtown area of Daejeon and Seoul in Korea. Figure 2 shows the path for the field test in each city.

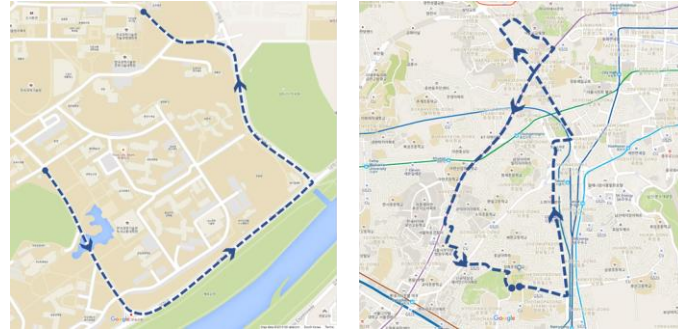


Figure 2. Experimental path in Daejeon (left) and Seoul (right)

The travel distance was approximately 4 km and the travel time was approximately 10 minutes for the experiment conducted in Daejeon (Kim et al., 2020). The Daejeon path was on a road in Yuseong-gu, and it was a quiet and wide road with relatively a small number of vehicles compared to Seoul. The travel distance was approximately 10 km and the travel time was approximately 50 minutes for the experiment conducted in Seoul (Yoo et al., 2020). The experimental path in Seoul was on a road near Seoul Station where there were many vehicles and floating populations, and narrow alleys and steep hills for vehicles to pass.

4.3 Survey and interview by service stage

The participants received the pre-guidance on the experiment, and the pre-survey and interview was also conducted. The participants returned to the laboratory for the post-survey and interview after experiencing the 4 stages of the Robo-taxi service (i.e., call, pick-up, traveling, drop-off).

First, the participants performed a quantitative test on a 7-point Likert scale with the evaluation factors shown in Table 1 for each service stage. We selected appropriate evaluation factors for the Robo-taxi service by referring to those used in evaluating transportation systems in previous studies (Eboli and Mazzulla, 2011, 2012; Redman et al., 2013; Shaaban and Kim, 2016; Stuart et al., 2000). The 1st level is to evaluate the service quality for each stage, and the evaluation factors corresponding to the 2nd level are detailed evaluation items that are likely to have an effect on the service quality. Table 2 presents the definitions of the evaluation factors.

In addition, the overall satisfaction and intention to use the service were surveyed on a 7-point Likert scale. For the WTP question, there are seven options regarding how much participants were willing to pay relative to a manned taxi: less than 50%, 50-74%, 75-99%, 100%, 101-124%, 125-149%, and 150% or more.

Table 1. Quantitative evaluation factors by stage

Stage	Evaluation factor	
	1 st level	2 nd level
Call	Service quality	Reliability, Predictability, Information, Kindness, Convenience, Promptness
Pick-up	Service quality	Reliability, Predictability, Information, Kindness, Safety, Communication, Accessibility, Punctuality, Confirmation
Traveling	Service quality	Reliability, Predictability, Information, Kindness, Safety, Communication, Convenience, Speed, Ride comfort, Pleasantness, Comfort
Drop-off	Service quality	Reliability, Predictability, Information, Kindness, Safety, Communication, Accessibility, Punctuality

Table 2. Definition of quantitative evaluation factors (Kim et al., 2020)

Evaluation factor	Description
Service quality	Felt satisfaction at each stage.
Reliability	Felt that the service was reliable.
Predictability	It was possible to predict what had to be done.
Information	Necessary information was received properly.
Kindness	Felt kindness in the service.
Safety	Felt it was safe.
Communication	Communication with the taxi was satisfactory.
Accessibility	The taxi came to the desired place.
Punctuality	The taxi arrived at the predicted time.
Convenience	It was convenient and easy to use.
Promptness	The service was carried out promptly.
Confirmation	It was easy to identify my taxi.
Speed	The speed was appropriate.
Ride comfort	The ride was smooth and comfortable.
Pleasantness	Felt pleasant in the taxi.
Comfort	Felt comfortable psychologically.

In addition to the evaluation by service stage, after experiencing the entire service, we conducted a quantitative survey that used a 7-point Likert scale for detailed emotions felt by the participants throughout the Robo-taxi service. Emotions, which were derived through brainstorming and a semantic differential method, were divided into positive and negative emotions. Table 3 shows 12 positive emotions and 12 negative emotions used in the evaluation.

Table 3. Emotion evaluation index (Kim et al., 2020).

Type	Emotions
Positive	Convenient, comfortable, familiar, safe, reliable, excellent, simple, sophisticated, ingenious, trendy, efficient, new
Negative	Nervous, uncomfortable, afraid, unpleasant, annoying, disappointing, stuffy, tiresome, complicated, dull, strange, frustrating

4.4 Participants

We recruited a total of 71 participants for the field test; 43 and 28 people participated in the experiment in Daejeon and Seoul, respectively. By gender, 45% were male and 55% were female. By age, 8% were in their teens, 65% in their twenties, 14% in their thirties, 7% in their forties, and 6% in their fifties. When we examined the frequency of using taxis for the participants, 42% used taxis less than once a week, 28% once a week, 24% 2-3 times a week, 4% 4-6 times a week, and 2% every day. The participants were paid 20,000 Korean won per hour for participation in the experiment. The entire experiment and interview took approximately three hours for each participant. We checked the reliability of the responses by asking what percentage of the Robo-taxi driving was completed during driving without the intervention of safety personnel. As a result, 74% responded that Robo-taxi seemed to have been running fully autonomously without the intervention of safety personnel, and the rest replied that it seemed to have been running partially autonomously with some intervention of safety personnel.

5. Models and Results

We performed SEM and path analysis using SPSS Amos 23 (IBM, 2020) based on experience data from 71 users collected through the field test. We analyzed the significance of the hypotheses defined in section 3. Each sub-section describes each of the three models.

5. 1. Model A: SEM for user experience and user acceptance

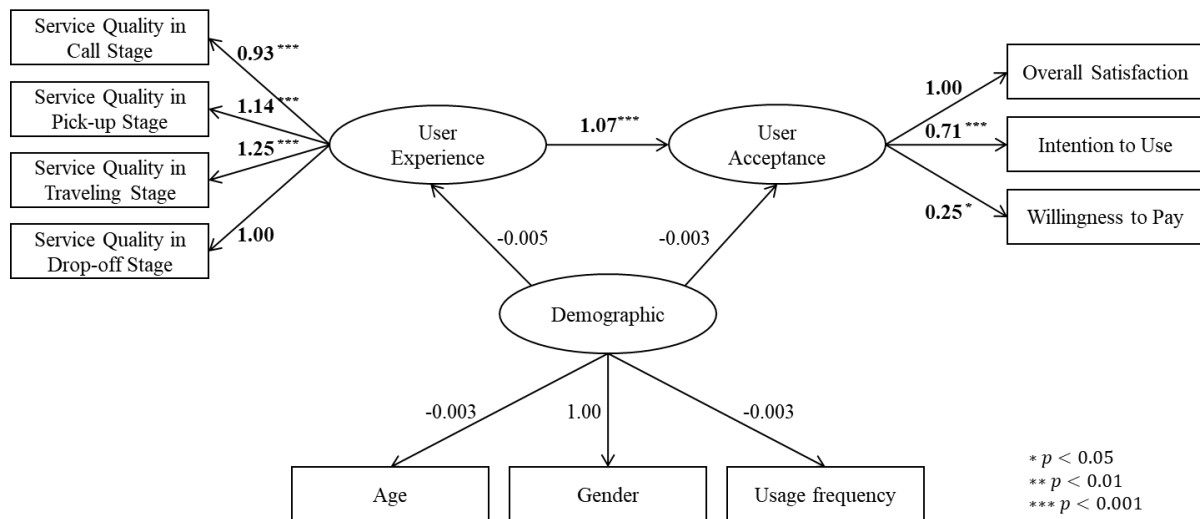


Figure 3. Relationship between user experience, user acceptance, and demographic as a Structural Equation Model (Model A)

Model A in Figure 3 assumes that user experience is related to user acceptance, and that demographic will have an effect on service experience and user acceptance. The service quality of each stage of the Robo-taxi service explained user experience. The data collected through the quantitative survey conducted after the experiment, that is, overall satisfaction regarding the service, intention to use Robo-taxi, and WTP, explained the potential variable, user acceptance. Age, gender, and taxi usage frequency explained demographic.

The results of goodness of fit test of the model showed that CFI = 0.84, GFI = 0.85, RMR = 0.09, RMSEA = 0.13. RMSEA slightly deviated from the threshold criterion yet showed acceptable fit. CFI is judged to be appropriate at 0.8-0.9 or higher (Bentler, 1990) and GFI is judged to be appropriate at 0.8-0.9 (Jöreskog and Sörbom, 1989). RMR is judged to be appropriate at 0.08 or lower (Hair et al., 1998), and RMSEA judged to be appropriate at lower than 0.08 (Browne and Cudeck, 1989). In Figure 3, the numbers above the arrows indicate the estimate of each relationship.

User experience was significant with $p < 0.001$ for user acceptance and has a positive correlation with a magnitude of 1.07. Demographic did not have a significant effect on user experience and user acceptance. Service quality in call, pick-up, traveling, and drop-off stages were all $p < 0.001$, which significantly explained the potential variable, user experience. Similarly, intention to use was $p < 0.001$ and WTP was $p < 0.05$, which significantly explained the potential variable. Of the observed variables of user experience, service quality in the traveling stage was highest with 1.25 when examining the estimate in standardized regression weights. For the rest, the regression coefficient was high in order of service quality in pick-up stage with 1.14, in drop-off stage with 1.00, and in call stage with 0.93. This indicates that the most important factor in user experience is service quality in the traveling stage. Of the observed variables of user acceptance, intention to use was 0.71 and WTP was 0.25 based on overall satisfaction of 1.00. The observed variables of demographic were all insignificant.

In conclusion, in the case of hypothesis H1a, user experience was positively correlated with user acceptance, thus the hypothesis was accepted. For hypotheses H1b and H1c, demographic had no effect on both user experience and user acceptance, thus the hypotheses were rejected.

5.2. Model B: SEM for positive and negative emotions and user acceptance

We evaluated a total of 24 emotions and used exploratory factor analysis (EFA) to select typical emotions. Using SPSS Statistics 23 (IBM, 2020), we fixed components to 2 and performed factor analysis using the Varimax factor rotation. The results are shown in Table 3.

Table 3. The results of factor analysis of 24 emotional factors

Factor	Component	
	1	2
Trendy	0.885	
Ingenious	0.834	
Sophisticated	0.825	
New	0.792	
Simple	0.768	
Excellent	0.745	
Convenient	0.742	
Efficient	0.711	
Disappointing	-0.668	
Frustrating	-0.637	
Annoying,	-0.576	
Strange	-0.560	
Complicated	-0.549	
Unpleasant	-0.527	
Tiresome	-0.510	
Stuffy	-0.451	
Familiar	0.434	
Dull	-0.307	
Uncomfortable		0.885
Afraid		0.862
Nervous		0.884
Safe		-0.755
Reliable		-0.579
Comfortable		-0.575

The total cumulative explanatory amount of the factor analysis was 55.285%. The result of the main component analysis revealed that component 1 was 0.874 and component 2 was also 0.874, indicating that the explanatory power was sufficient for the factors divided into two components. We selected factors with a factor component of 0.8 or high in the results of factor analysis. Trendy, ingenious, and sophisticated were selected as the final factors for positive emotions while uncomfortable, afraid, and nervous were selected for negative emotions. Positive emotions were represented as a potential variable called “cutting-edge.” Negative emotions were represented as a potential variable called “apprehensive.”

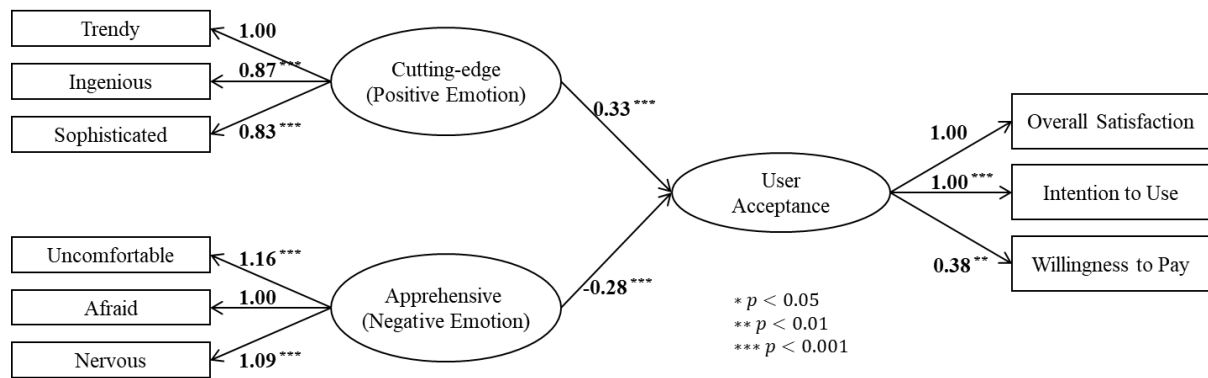


Figure 4. Model showing the relationship between positive and negative emotions and user acceptance (Model 2)

The model in Figure 4 is based on the assumption that the emotional factors representing cutting-edge and apprehensive are related to user acceptance. The results of goodness of fit test showed that GFI = 0.95, AGFI = 0.91, NFI = 0.95 and RMR = 0.10, thus showing acceptable fitness. RMR deviated slightly from the threshold criterion yet showed acceptable fit. GFI is judged to be appropriate at 0.8-0.9 or higher (Jöreskog and Sörbom, 1989), and AGFI is judged to be appropriate at 0.8-0.9 or higher (Hair et al., 1998). NFI is judged to be appropriate at 0.8-0.9 or higher (Bentler and Bonett, 1980). PMR is judged to be appropriate at 0.08 or lower (Hair et al., 1998). In Figure 4, the numbers above the arrows indicate the estimate of each relationship, which were rounded to the third decimal place.

Cutting-edge was significant with $p < 0.001$ for user acceptance and has a positive correlation with the estimate of 0.33. Apprehensive was significant with $p < 0.001$ for user acceptance and has a negative correlation with the estimate of -0.28. Of the observed variables of cutting-edge, both ingenious and sophisticated were significant with $p < 0.001$, and both factors have a similar regression coefficient of 0.87 and 0.83, respectively. Of the observed variables of apprehensive, both uncomfortable and nervous were significant with $p < 0.001$, and had a regression coefficient of 1.16 and 1.09, respectively. Of the observed variables of user acceptance, intention to use, and WTP were significant with $p < 0.001$ and $p < 0.01$, respectively. Intention to use had a significant effect at the same level as overall satisfaction, yet the effect of WTP was relatively small with 0.38.

In conclusion, in the case of hypothesis H2a, cutting-edge, which was a typical positive emotion for Robo-taxi, was positively correlated with user acceptance, thus the hypothesis was accepted. In the case of hypothesis H2b, apprehensive, which was a typical negative emotion for Robo-taxi, was negatively correlated with user acceptance, thus the hypothesis was also accepted.

5.3 Model C: path analysis for overall satisfaction and service quality in each stage

We performed path analysis to find crucial evaluation factors by boarding stage that significantly affected overall satisfaction, which was a crucial factor for user acceptance.

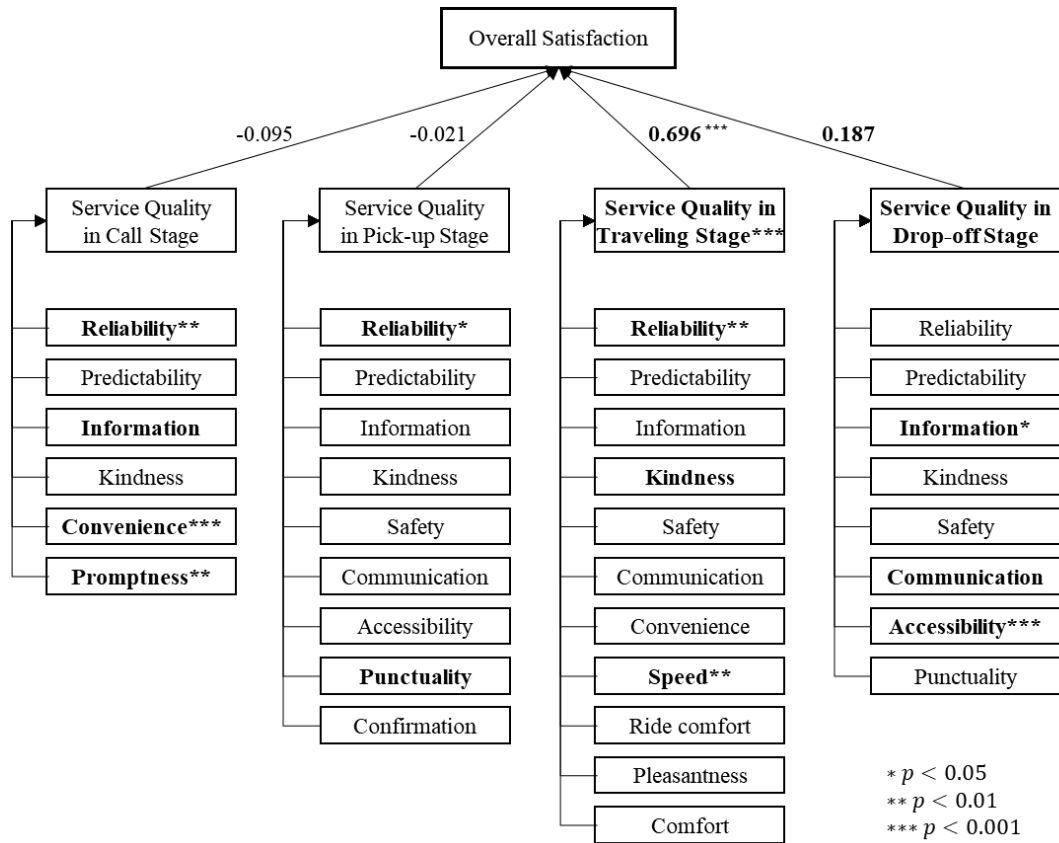


Figure 5. Path analysis model of overall satisfaction and service quality by service stage (Model C)

Figure 5 shows the results of path analysis. Evaluation factors in bold indicate significant, or less significant but still influential factors. Of the results, service quality in traveling stage was significant with $p < 0.001$, and service quality in drop-off stage was significant with $p < 0.1$. The estimate of service quality in traveling stage and in drop-off stage was 0.696 and 0.187, respectively. That is, the effect of service quality in the traveling stage was highest. Table 4 presents the path analysis results which were significant with $p < 0.1$.

Table 4. Boarding stage factors and overall satisfaction path analysis result

Path	Estimate	P	Label
Overall Satisfaction ← Service Quality in Traveling Stage	0.696	0.000	***
Overall Satisfaction ← Service Quality in Drop-off Stage	0.187	0.055	
Service Quality in Call Stage ← Reliability	0.290	0.001	**
Service Quality in Call Stage ← Information	-0.169	0.070	
Service Quality in Call Stage ← Convenience	0.569	0.000	***
Service Quality in Call Stage ← Promptness	0.252	0.006	**
Service Quality in Pick-up Stage ← Reliability	0.275	0.031	*
Service Quality in Pick-up Stage ← Punctuality	0.277	0.065	
Service Quality in Traveling Stage ← Reliability	0.258	0.008	**
Service Quality in Traveling Stage ← Kindness	0.149	0.056	
Service Quality in Traveling Stage ← Speed	0.157	0.004	**
Service Quality in Drop-off Stage ← Information	0.197	0.044	*
Service Quality in Drop-off Stage ← Communication	0.193	0.079	
Service Quality in Drop-off Stage ← Accessibility	0.292	0.000	***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In service quality in the traveling stage, reliability and speed were significant, and the effect was in the order of reliability and speed. In service quality in the drop-off stage, accessibility and information were significant. Of

these, the effect of accessibility was highest. Kindness in the traveling stage and communication in the drop-off stage did not satisfy $p < 0.05$ with a narrow margin but they were judged as important factors due to a large estimate.

The calculation results of the effect of the crucial factors on overall satisfaction in service quality in the traveling stage showed that reliability was 0.180 ($=0.258 \times 0.696$), speed was 0.109 ($=0.157 \times 0.696$), and kindness was 0.103 ($=0.149 \times 0.696$). In the drop-off stage, accessibility was 0.054 ($=0.292 \times 0.187$), information was 0.037 ($=0.197 \times 0.187$), and communication was 0.036 ($=0.193 \times 0.187$). Therefore, the factors that have the largest effect on overall satisfaction are in order of reliability, speed, kindness, accessibility, information, and communication. The fact that service quality in the traveling stage was significant was also true in model A of Section 5.1. However, path analysis revealed that reliability, speed, and kindness, which are the 2nd level evaluation factors, are crucial.

6. Discussion

We discuss the quantitative results derived from section 5 and analyze the qualitative results of the field test interviews to derive meaningful insights.

6.1. User experience and user acceptance

First, the results of the model A showed that positive experience with the Robo-taxi service had an effect on the improvement of user acceptance. This indicates that there is a need for a strategy that enables as many customers as possible to experience the service in advance at the beginning of the Robo-taxi service launch. Since user acceptance is high for those who have positive user experiences at the beginning of the service, they are highly likely to keep using the service. Therefore, it seems that various early marketing strategies such as free trial will be critical. Additional field test results also back up these results. Positive responses to questions about using Robo-taxi increased after the field test compared to before the field test. The interview results regarding intention to use Robo-taxi before and after the field test are as follows. Before the field test, 39% of the participants responded that they would use Robo-taxi as soon as it was commercialized and 61% responded that they would use it when it was considered to be safe enough after its commercialization. After the field test, 96% of the participants responded that they would use Robo-taxi as soon as it was commercialized while 4% responded that they had no intention to use it or only use it when it became safe after its commercialization. Previous study, Rödel et al. (2014), also found that the prior experience of self-driving vehicles had a positive effect on user acceptance and experience.

Second, in both Model A and Model C, the effect of the traveling stage experience was highest. The interview results also showed that the traveling stage was most crucial. After the field test, of the answers to the question “What was good about Robo-taxi compared to general taxis?,” the differentiation of the traveling stage between them was good and accounted for 97%. In particular, approximately 50% were about the convenience during traveling provided by unmanned services. They were satisfied with the service in that they did not have to talk to the driver, the environment is private, and there is no body or cigarette odor inside the vehicle. Some responses are quoted below.

“I loved being able to do whatever I wished with nobody around me.” (p05)

“I didn’t have to talk to the taxi driver and there was no burden.” (p63)

“I felt comfortable without emotional discomfort in the absence of the driver.” (p68)

Approximately 30% of the reasons why Robo-taxi was good were that AI was driving, thus driving was safe and riding quality was good.

“I felt safe because it followed the traffic rules. It was good to be quiet.” (p08)

“It was good to keep the appropriate distance from the car in front. I thought it was safe, and it seemed to follow the rules well.” (p53)

There were other views about freedom of action such as the possibility of consuming food, reclining and sleeping, and answering calls. This indicates that focusing on the development and improvement of the service for the traveling stage can greatly contribute to the improvement of technology acceptance.

Third, in Model A, of the variables representing user acceptance, WTP showed relatively low significance. Of the participants who responded positively to the intention to use, some indicated that they were willing to pay more because Robo-taxi was new technology whereas some felt that the fare should be lowered because there was no driver. Therefore, there were found to be different views regarding WTP. In fact, several previous studies argued that it was possible to reduce the transportation cost because there was no need for a driver, and accordingly the user expected the price advantage of Robo-taxi (Burns et al., 2013; Han and Ryu, 2009; Matzler et al., 2006). Some responses are quoted below.

“The fare initially seems to be similar to manned taxis. However, if a person drives directly, labor charges apply because it is a service job, thus Robo-taxi seems to have a different pricing policy because it simply uses machines.” (p44)

“I will use it more frequently when the fare is lowered and commercialized.” (p45)

“Just like expressway buses offering luxury or premium amenities according to the class, if Robo-taxi had such features, I would use it.” (p69)

6.2. Cutting-edge and user acceptance

In Model B, cutting-edge, which represent positive emotions, affects user acceptance. Cutting-edge can be explained by emotions such as trendy, ingenious, and sophisticated. With an increase in the newness (freshness) users feel when they experience Robo-taxi, user acceptance can increase. Therefore, the differentiation between the Robo-taxi and the traditional taxi service should be maximized.

The interview results revealed that the participants thought highly of the cutting edge of new technology itself. Although they felt that Robo-taxi was not perfect, they expected Robo-taxi to make them more comfortable in the future. Some responses are quoted below.

“I felt it was more convenient. It was good to automatically check if the seat belt was fastened.” (p11)

“I thought it was convenient and I would do more activities if unmanned taxis were commercialized.” (p50)

“Above all, I liked it because I didn't have to tell the driver about my destination, there was no refusal of passengers, and it was good to display the navigation paths on the big screen.” (p69)

6.3. Service apprehension and user acceptance

In Model B, of the negative emotions, we confirmed that apprehension for new technology had an effect on user acceptance. We defined apprehensive as emotions such as uncomfortable, afraid, and nervous. To increase user acceptance, service apprehension needs to be addressed first. The interview results revealed that there was some apprehension towards using Robo-taxi since it was new technology that the participants had never experienced before. In the early traveling stage, they felt uncomfortable about whether it worked well or was safe without a driver, but generally, in the later traveling stage, they responded that they felt relatively less uncomfortable, afraid, and nervous. Some responses are quoted below.

“I had doubt on how reliable this technology could be. I wondered if Robo-taxi could deal with unexpected situations.” (p47)

“I was terrified. I felt more uncomfortable because I was scared at the beginning.” (p65)

"I felt uncomfortable at the beginning, but I was okay from the middle of the service. If passengers are provided with a preliminary explanation/coping method for some specific situations before boarding an unmanned taxi, it will likely reduce discomfort." (p67)

6.4. Reliability, speed, and kindness while traveling

Model A showed that the traveling stage experience had a significant effect on technology acceptance. Reliability, speed, and kindness had a significant effect on the traveling stage experience in Model C. In previous research, reliability was regarded as the most crucial factor when experiencing Robo-taxi (Tussyadiah et al., 2017). In addition, as with the studies that demonstrated that the majority of experiment participants preferred the driving style of Robo-taxi to be similar to their driving style (Griesche et al., 2016), it is expected that user acceptance can be increased if the optimization of the user-customized speed increases satisfaction regarding the speed factor. In particular, reliability and speed were found to be related. Many users seemed to be very uncomfortable because they did not trust the new technology, and some users evaluated satisfaction according to speed. They felt differently even for the same speed, and some felt uncomfortable at high speed and vice versa. Some responses are quoted below.

"I felt a little discomfort as this was my first time experiencing an unmanned taxi. I had a feeling that the speed of the taxi was not completely consistent, and I noticed a bit of a sudden jerk when it changed lanes." (p13)

"The speed was reasonable, and it was comfortable and good like a normal taxi." (p55)

"The speed was a little slow compared to a normal car, and I felt a little discomfort about self-driving cars." (p7)

"It drove slowly in crowded alleys, so I felt safe." (p62)

Regarding the interview results related to kindness, some participants felt that the voice from the systemized machine was kind in the absence of a driver, whereas there were opposing views that since it was an efficient system that aimed to get to the destination from a departure point, they did not feel any kindness. Since kindness turned out to be crucial in the traveling stage, which was most important in the Robo-taxi service, the way that Robo-taxi could engage the user emotionally should also be considered. Some responses are quoted below.

"I didn't have to worry about the driver's mood, a chat with the driver, and uncomfortable things." (p61)

"I didn't have to unwillingly talk to the driver, and it was good that all communication was done by machine." (p56)

"I believe that kindness is such a thing that if there was a driver, the driver could have a humorous chat with me or could greet me, but I was not able to share the emotion of kindness with an unmanned taxi. I just got in the car, but I am not sure if there is any element of kindness." (p69)

6.5. Accessibility, information, and communication while dropping off

In Model C, in the drop-off stage, particular attention should be paid to accessibility, information, and communication to increase overall satisfaction. In the case of a manned taxi, the driver drops the passenger off flexibly by identifying traffic situations at their discretion. However, Robo-taxi drops the passenger off only at the designated safe stop. Therefore, there is a need to develop an HMI for flexible dropping off in terms of accessibility. Passengers have an approximate destination, but they should be able to specifically ask Robo-taxi exactly where to get out around the destination. In the same context, Robo-taxi should be able to offer passengers a safe place to be dropped off so that they can choose where to be dropped. The interview results also revealed that it was inconvenient in terms of the accessibility of where to get out and not being able to specify this through information and direct communication. Some responses are quoted below.

"I could not get out at the right place when I arrived. Voice recognition made it difficult for me to specifically control it." (p26)

"I felt uncomfortable when it stopped because of a car in front." (p12)

"It went smoothly. Before getting out, I asked the AI voice recognition for the expected time to be dropped off. I was satisfied with the accurate information provided." (p68)

"I was a little confused when to get out." (p23)

"In general, when I ask a taxi driver to be dropped off at a desired place, the driver drops me off. However, it seemed impossible for an unmanned taxi to drop me off flexibly. From the first call, it would be necessary to specifically determine the arrival place. It would be inconvenient if the drop-off place was set in advance." (p10)

"When I wanted to get off near my destination, I couldn't convey my message to Robo-taxi." (p37)

7. Conclusion

Unlike previous user experience studies on self-driving vehicles that mainly depended on surveys and simulators, this study was based on the survey and in-depth interview data obtained after participants experienced the Robo-taxi service operating in the actual city center. Based on the collected quantitative data, we built structural equation models and a path analysis model, and analyzed these by comparing them with the in-depth interview results, which were qualitative data. Furthermore, by analyzing the relationship between user experience and user acceptance, we suggested a way to further improve the Robo-taxi service.

First, the results of Model A, which showed the relationship between user experience and user acceptance, proved that user experience had a significant effect on user acceptance. Service quality in the traveling stage had the largest effect on user experience, and overall satisfaction had the largest effect on user acceptance whereas WTP had a relatively low effect. Second, the results of Model B, which analyzed 24 emotional factors and the relationship between these factors and user acceptance, showed that cutting-edge was selected as the typical emotion that had a positive relationship with user acceptance whereas apprehensive was selected as a typical emotion that had a negative relationship. Trendy, ingenious and sophisticated relate to cutting-edge and uncomfortable, afraid and nervous relate to apprehensive. Third, in Model C, we performed path analysis for the relationship between 34 evaluation factors by service stage and overall satisfaction. Service quality in the traveling and drop-off stages were found to have a significant effect on overall satisfaction. Reliability, speed, and kindness were found to be crucial factors in the traveling stage, and accessibility, information and communication were found to be crucial factors in the drop-off stage.

Based on the results, we also suggested Robo-taxi service design and marketing. Since the initial service experience turned out to be crucial, there is a need for a strategy of providing as many customers as possible with service experience in the early stage of Robo-taxi launch. Moreover, since cutting-edge has a significant effect on user acceptance, the differentiation between the Robo-taxi and conventional taxi services should be maximized. Apprehension, a negative emotion, also affects user acceptance, thus, the issue of low reliability should be addressed more than anything else. Since reliability, speed, and kindness were found to be crucial in the traveling stage, it is necessary to provide an optimized speed service for an individual user and for in-vehicle AI to approach the user emotionally. In the drop-off stage, since accessibility, information and communication are crucial, there is a need to develop an HMI for flexible drop-off (e.g., virtual stop (Kim et al. (2020))).

This study makes the following contributions. First, it conducts SEM analysis based on the survey data on Robo-taxi user experience. The findings of previous studies were mainly based on simple survey or simulator-dependent data, and there was a lack of SEM study cases based on real user experience. Second, we simultaneously analyzed quantitative SEM results and qualitative interview results. By identifying crucial relationships between the factors based on the SEM results and deriving the basis for them from the interview results, we improved the reliability of model analysis results and performed balanced analysis. Third, through the analysis results, we suggested guidelines for the design and marketing of the future Robo-taxi service.

The limitations of this study and future research directions are as follows. First, due to the physical limitations of the Robo-taxi field test, we had difficulty securing a statistically sufficient amount of user experience data. In future research, we will continue to increase the number of subjects with diverse backgrounds. Second, we will

collect the Robo-taxi service data by considering various environments. For example, we will take night service situations where the demand for Robo-taxi is high, and service environments for the socially disadvantaged such as the disabled and the elderly into account.

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