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Exploring Countermeasures from a Psychological Perspective to Create a Safe Driving Environment for Personal Mobility Devices

Suk-Hee Kim [1], Hyejin Lim [1] and Junghwa Kim [2,*]

[1] Department of Urban Space Research, Suwon Research Institute, Suwon 16429, Korea; sukheek@suwon.re.kr (S.-H.K.); hjlim@suwon.re.kr (H.L.)
[2] Department of Urban and Transportation Engineering, Kyonggi University, Suwon 16227, Korea
* Correspondence: junghwa.kim@kyonggi.ac.kr

Abstract: The personal mobility device (E-Powered Personal Mobility Vehicle) has recently been attracting attention as a viable method of transportation for first and last mile travel, primarily due to its portability and ease of mobility. Although the size of its market is increasing rapidly, the number of accidents is also increasing rapidly. Suwon city, in particular, has the highest rate of traffic accidents linked with personal mobility among all of the local governments in the Gyeonggi Province in Korea, as of 2019. The annual average rate of increase has been as high as 151.7% over the past three years. The objective of this study was to analyze the usage of personal mobility devices among Suwon citizens through a questionnaire, which was then analyzed using partial least square structural equation modeling (PLS-SEM). We then examined the impact of psychological attitudes on the future use of personal mobility, and then derived future policy directions from all of the gathered data. According to a survey of Suwon citizens, the ratio of users who had no experience in using the devices was higher than that of those who had some experience in using them. The results of the survey on citizens' satisfaction with the driving environment revealed that their overall satisfaction level was low, while the response rate regarding the need for safety equipment and systems was high, confirming that the current system had poor safety levels, which results in a very high risk of accidents. However, given that there were many positive responses regarding the users' intentions to use personal mobility devices in the future, it seems that it is necessary to establish a safer driving environment in order to better incorporate these personal mobility devices into the city.

Keywords: personal mobility; usage behavior; PLS model; driving environment; safety

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1. Introduction

The personal mobility device (E-Powered Personal Mobility Vehicle) has recently been attracting attention as a viable method of transportation for first and last mile travel, primarily due to its portability and ease of mobility. A personal mobility device is defined as any tool which an individual uses to move. Various terms, such as "smart mobility" and "micro mobility", are also used to describe personal mobility, as shown in Figure 1. In a more specific sense, the term "one to two-seater personal motor" has also been used in different contexts. Personal mobility features can be divided into five categories: Portability, Mobility, Eco-friendly, Next-generation means of transportation, and Leisure [1]. First, they are portable, as they are designed to be folded so that they are able to be easily carried and stored. They are also portable within other transportation modes, as users are also able to take them onto commuter vehicles without worrying about parking. Second, they provide a high level of mobility. Personal mobility has often been seen as an emerging solution to the last mile problem, as it can make medium and short-distance travel easier, by driving at a speed of about 10 to 20 km/h. Third, they are eco-friendly, as most personal mobility devices are powered by electricity, thus producing lower carbon dioxide emissions and greatly reducing energy consumption when compared to modes of transportation which use internal combustion engines. Fourth, they are the next generation of transportation. The physically weak and the elderly, who are unable to move easily, can move comfortably throughout different terrains with the use of a personal mobility device. Finally, they present a strong image of leisure. Rental activities, such as leisure electric scooters and Segways, can be actively used around parks, and tourism products making use of Segways have already been released overseas.

Figure 1. Types of personal mobility device.

Under the current laws in Korea, a personal mobility device is classified as a motorized bicycle that can be driven on the road. However, with the revision of relevant laws (10 December 2020), the definition and specifications of personal mobility devices have been newly defined, and conditions for their usage have been eased. The number of users is expected to increase rapidly as bikeways become available for use without the requirement to obtain a driver's license. Therefore, as the number of users of personal mobility devices increases, accidents are also set to increase rapidly. Safety issues such as traffic accidents are expected to continue to rise in Korea if the demand for personal mobility use continues to increase amid a lack of relevant legal systems and policies. Therefore, it is necessary to create improvement measures for a safe and pleasant driving environment in the future, mainly through the analysis of the current circumstances surrounding personal mobility. In Korea, an electric kickboard is a representative personal mobility device; it should not be driven on a pedestrian path and can be driven in the rightmost lane of the road. However, from December 2020, the law was revised so that these devices could be operated on some bikeways, in order to ensure safety. Due to this revision, the need to identify the user's point of view on how to improve the environment's operational safety and infrastructure has become essential. This study has developed a model that utilizes partial least square structural calculation modeling (PLS-SEM) when analyzing the usage patterns of electric kick scooters, which are the most widely used personal mobility devices in Korea among those shown in Figure 1. Through this developed model, this study aims to contribute to the improvement of the safety of driving infrastructure for driving as well as the overall reduction of traffic accidents, by presenting policy directions for the usage of personal mobility devices which are specifically targeted at the city of Suwon in South Korea.

2. Literature Review

Up until this date, academic research on e-powered personal mobility vehicles has not been widely conducted, although some prior studies have studied the subject in various ways, mainly through experiments which estimate the cognitive response time of users and car-following models, among others. The location and extent of injuries which occurred during collision events through a collision simulation experiment involving personal mobility devices and other transport modes [1]. To determine the degree of injury caused by the collision between personal mobility devices and other road transport modes, such as vehicles, pedestrians, and bicycles, the degree of injury was analyzed through frontal, lateral, and rear impact tests. The effect of wearing a helmet on the safety of a crash was analyzed by comparing the degree of injury caused by a collision before wearing a helmet and after wearing the helmet. This study derived the following results and implications: (1) Pedestrian injury risk with a personal mobility device was high; (2) Users should wear a helmet for shock absorption and safety in case of a collision; and (3) Personal mobility devices without buffers were found to result in a high risk of injury to the driver in the event of a collision. Improvement plans for existing bicycle roads by taking into consideration different characteristics of personal mobility have been studied [2]. A focus group interview (FGI) was performed for those who were currently using personal mobility in order to derive practical ways to improve bicycle paths. As a result of the interview, it was found that personal mobility devices were very sensitive to varying road conditions due to their small wheels. Thus, it is necessary to maintain the good conditions of roads. If a personal mobility device is allowed to be used on a road, there should be a posted road sign, in addition to markings on the road in order to prevent conflicts between bicycles and pedestrians The characteristics of personal mobility users and their cognitive response times was analyzed [3]. Their study suggested a methodology for extracting cognitive response times of pre-stop speed by videotaping driving and stopping processes during the alert and non-alert states of electric scooters [3]. The experiment for the response times of a personal mobility device showed that the non-alert state was 1.12 seconds for the 85th percentile of subjects, and that the alert state was 0.93 seconds. The cognitive response time of 2.5 seconds presented in AASHITO's bicycle facility development guidelines resulted in a margin of more than 1 second.

The two research projects in order to evaluate the driving safety of Segways were conducted [4]. In the first experiment, technology evaluation, ergonomic evaluation, and user group evaluation were conducted through test drives after the participants learned to drive in a controlled environment, using both the Segway and an electric scooter. The second experiment was conducted using a questionnaire which was given to the participants after they drove the Segway on the actual roads. As a result of the study, first, considering that the Segway holds very positive environmental benefits with minor negative impact, the use of Segways in urban corridors was allowed broadly, except in situations where they may result in disruptive behaviors in India. Second, local governments need the authority to restrict the use of Segways for a time or period that is deemed inappropriate. Third, local governments should establish guidelines in order to provide information on ways to safely use electric powered personal mobile devices within their jurisdiction. Fourth, a public campaign should be implemented in order to alleviate the fear and anxiety of pedestrians regarding electric assisted mobility devices that are being used on sidewalks, in addition to raising greater awareness to the environmental benefits of using motorized assisted mobility devices. It was stated that the operation of electric and non-motorized transportation means that many US state governments have adopted is the AASHTO's bicycle facility guide as a standard to govern public roads and non-powered transportation [5]. To establish newly designed standards for road facilities which ensure safety, the operation characteristics of transportation users were compared and studied. Their study analyzed the movements of users through image capturing in a place where the physical values, at a specific point of a facility, can be measured through the configuration of various road conditions for 14 different types of electric and non-motorized transportation methods. As a result of their study, there was a difference in driving characteristics on the road according to the type of user. Segways had the second shortest braking distance, the highest eye level, the narrowest occupied area, and the shortest perceptual response time, and complied with all of the recommendations of the American Transportation Authority's Guide to the Construction of Bicycle Facilities. A research project to test the Segways at the initiative of the manufacturer in order to conduct an empirical experiment that examines the interactions of Segways and other road users was done [6]. The experiment was conducted before and after the trial run, and also included a braking experiment. Interviews were conducted with test participants three weeks after the start of the experiment, as well as after the end of the experiment. Images were taken during the course of the entire pilot study. The odometer consistently recorded at random intervals during the preliminary study. As a result of the research, the Segway was found to be easy to handle, intuitively designed, and easy to use. It was found that long-term usage should be limited and that its usage should be particularly restricted during bad weather. In addition, it was verified that the functioning noise of the Segway was too low to give an appropriate warning signal. Sufficient lighting facilities are also needed in order to ensure visibility when Segway users are moving at night. Collision tests with pedestrians and vehicles in order to evaluate vehicle safety characteristics that would then permit the licensing of Segways or electric scooter usage as a means of public transportation was tested [7]. In the experiment, the impact was measured when a Segway rider drove at a speed of 15 km/h and collided with an immobile pedestrian or car. As a result of the study, it was found that a Segway must only be driven after the user has received training, and that it should only be used on bicycle roads, and it is recommended that it should not be used on other roads. Second, the recommended driving speed should be limited to 9 km/h. Third, Segways should be treated like bicycles, in that they should have lights, horns, stands, and time switches. Fourth, Segway drivers must wear a hard hat and be guaranteed insurance. A risk perception model was developted in order to properly evaluate personal means of transport from a safety perspective, before allowing them to share an environment with pedestrians in the near future [8]. The model was inspired by the concept of social force, and a safety index was estimated which is referred to as the subjective risk index (SDI). As a result of the study, two important characteristics of the subjective risk of pedestrians were found. First, pedestrians' sense of distance between themselves and the personal means of transportation was higher when they were in front of them than when they were behind them. Second, when the distance between the pedestrian and the personal means of transport was relatively large, the pedestrians perceived that when the personal means of transport was approaching, it was more dangerous when approaching from the back than when approaching from the front. However, if the distance between the pedestrian and the personal means of transportation was relatively low, it was perceived as more dangerous when approaching from the front.

3. Data

3.1. Descriptive Statistics of Respondents

This study surveyed 432 people in order to present future policy directions for the establishment of a safe road environment for Suwon citizens, including 161 users and 271 non-users (Since the population of Suwon is currently 1.2 million, a sample size exceeding 385 respondents seems to be enough to get statistical significance, at a confidence level of 95% and a margin of error of 5%.) The survey was conducted over the course of four days in July 2020 through an online survey. As shown in Table 1, the survey outline is as follows. Survey items included a total of 55 questions related to ▲ the general information of respondents, ▲ the experience of using personal mobility devices, ▲ the characteristics of driving, and ▲ the experience of personal mobility accidents. The survey collected valid responses from a total of 432 people (49.1% males and 50.9% females), with similar proportions of males and females. In terms of age, people in their 20s and 30s accounted for the highest proportion (55.3%). In terms of residence, 31.7% of respondents who resided in Gwonseon-gu, 27.5% in Yeongtong-gu, 26.9% in Jangan-gu, and 13.7% in Paldal-gu participated in the survey. In terms of occupation, office workers accounted for the highest percentage, at 58.3%, followed by students, at 15.7%. In terms of whether or not the participants owned a personal vehicle, 57.2% were owners and 42.8% were non-owners.

Table 1. Survey items.

Item	Contents
Respondents	- Sex and Age, - Occupation, - Residence, - Possession of Vehicles
Psychological Perspectives for PM Device Driving	- Perception of personal mobility device - Satisfaction with the driving environment of personal mobility device (infrastructure, ease of use, relevant laws, and systems) - Necessity for the driving environment (Safety equipment and system) - Intention of using personal mobility device in the future

3.2. *Psychological Perspectives of PM Device Driving*

As shown in Table 2, among the respondents, 84% answered "Personal mobility device is well known transportation mode", 60.7% said "it is useful as a transportation mode", and 61.8% answered "it is an eco-friendly transportation mode". The number of respondents saying "It is easy to drive and handle" was 55.5% of the total, and we identified that more than half of the respondents showed positive responses to the personal mobility device. As shown in Figures 2–4, it could be said that the satisfaction level of Suwon's overall driving environment was low, given that 40.5% answered "unsatisfied" and 13.9% said "satisfied". Specific driving environment was divided into three categories (infrastructure, ease of use, and relevant laws and systems) to analyze satisfaction. For infrastructure, satisfaction surveys were conducted for a total of seven items, with a high percentage of responses being "unsatisfied". Among these items, "personal mobility auxiliary facilities of personal mobility" had the highest level of dissatisfaction rate, followed by "bicycle road connectivity". For the ease of use, satisfaction surveys were conducted for a total of four items. Among these items, "connectivity to other means of transportation" and "availability to carry in public transportation" were found to be unsatisfactory, while more respondents were satisfied with the factor of "economic feasibility of personal mobility" than the proportion of those who said they were dissatisfied. In the case of relevant legal systems, as a result of conducting a satisfaction survey for a total of four items, the response rate to dissatisfaction was high for all items. Among them, the dissatisfaction rate of the "relevant insurance system" was the highest, at 56.4%. The majority of respondents said they were unsatisfied with "bicycle road control and maintenance" and "incentive system".

Depending on the driving environment, the necessity of three items of safety equipment and a total of five items of systems were investigated as shown in Table 3. As a result of surveying a total of three safety equipment items (speed limiter, safety helmet, headlight) and their varying levels of necessity, a majority of respondents answered "necessary" for all items. Among them, the response rate to the level of necessity was high regarding "headlight", "safe helmet", and "speed limiter". In terms of the level of necessity of the safety system as shown in Table 4, a total of five items (operation of the exclusive license system, mandatory completion of safety and driving education, mandatory wearing of safety equipment for users, mandatory signing of insurance for users, and age restrictions) were investigated. The majority of respondents answered "necessary" for all items. Among various items, the "mandatory wearing of safety equipment for users" had the highest response rate, followed by the "mandatory completion of safety and driving training".

Furthermore, in response to the "intention to use in the future", 47.9% said yes, 23% said no, and 43.5% said "willing to reuse". As much as 34.9% of respondents said "I will recommend it to others", while 25.5% said that they would not as shown in Figure 5. To the question of whether they would be willing to promote the device, 27.4% of respondents answered "No". This indicates that a review of public relations measures would be needed in order to revitalize personal mobility device usage.

Table 2. Response status regarding the perception of the PM device.

Category		Strongly Yes	Yes	Neutral	No	Strongly No	Total
Well-known transport mode	N	101	262	62	7	0	432
	%	23.4	60.6	14.4	1.6	0	100.0
Useful as transport mode	N	47	215	126	37	7	432
	%	10.9	49.8	29.2	8.6	1.6	100.0
Eco-friendly transport mode	N	56	211	140	23	2	432
	%	13.0%	48.8%	32.4	5.3	0.5	100
Safe transport mode	N	8	23	108	214	79	432
	%	1.9	5.3	25.0	49.5	18.3	100.0
Easy to drive/handle	N	29	211	162	28	2	432
	%	6.7	48.8	37.5	6.5	0.5	100.0
Low-cost transport mode	N	22	174	172	56	8	432
	%	5.1	40.3	39.8	13.0	1.9	100.0

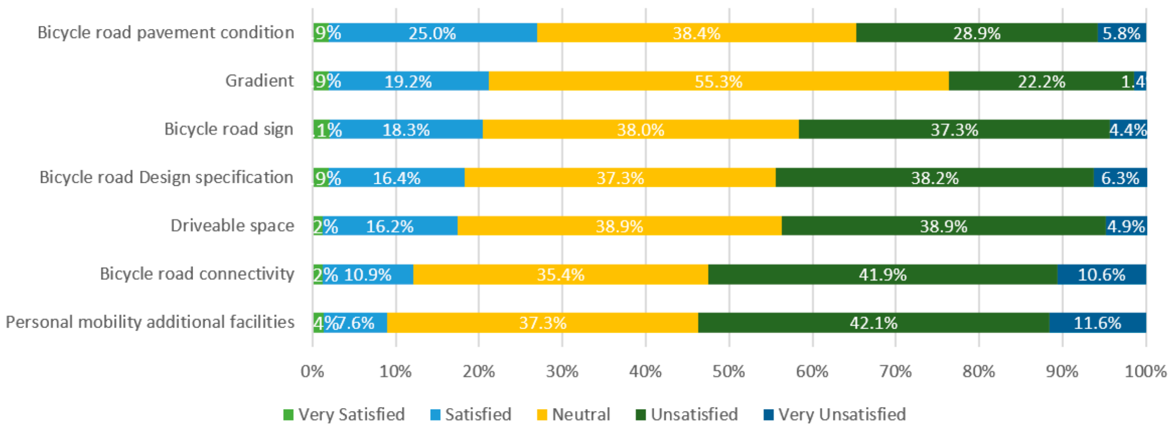

Figure 2. Levels of satisfaction with PM driving environment (Infrastructure).

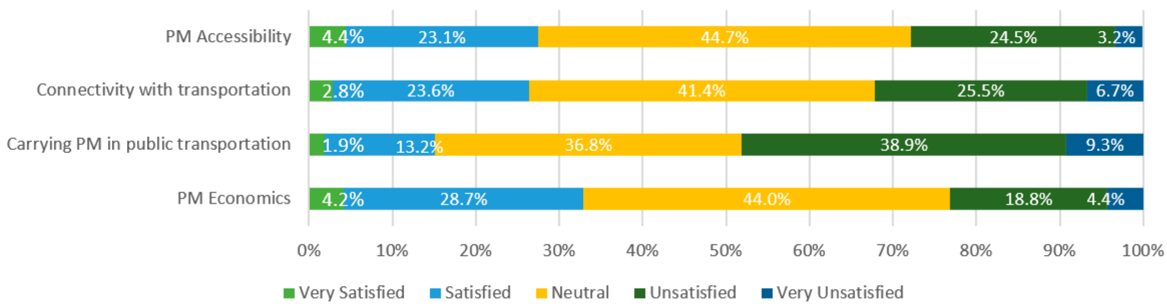

Figure 3. Levels of satisfaction with PM driving environment (Convenience of use).

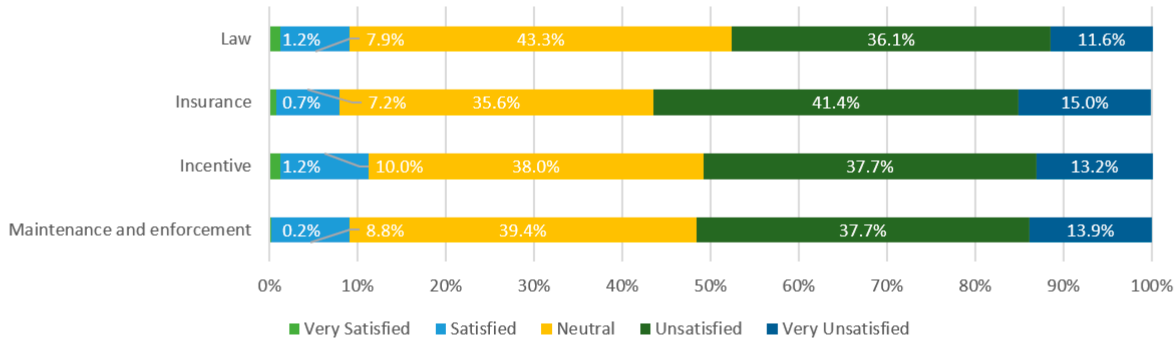

Figure 4. Levels of satisfaction with PM driving environment (Legal system).

Table 3. Level of necessity for the driving environment (Safety equipment).

Category		Very Necessary	Necessary	Usually	Unnecessary	Very Unnecessary	Total
Speed limiter	N	172	191	53	15	1	432
	%	39.8	44.2	12.3	3.5	0.2	100.0
Helmet	N	220	141	50	19	2	432
	%	50.9	32.6	11.6	4.4	0.5	100.0
Headlight	N	225	166	35	6	-	432
	%	52.1	38.4	8.1	1.4	-	100.0

Table 4. Level of necessity for the driving environment (Safety system).

Category		Very Necessary	Necessary	Usually	Unnecessary	Very Unnecessary	Total
Operation of exclusive license system	N	110	171	101	45	5	432
	%	25.5	39.6	23.4	10.4	1.2	100.0
Mandatory completion of safety and driving training	N	148	173	74	30	7	432
	%	34.3	40.0	17.1	6.9	1.6	100.0
Mandatory wearing of safety devices	N	193	159	59	17	4	432
	%	44.7	36.8	13.7	3.9	0.9	100.0
Mandatory insurance subscription	N	141	167	94	24	6	432
	%	32.6	38.7	21.8	5.6	1.4	100.0
Age limit	N	162	168	79	17	6	432
	%	37.5	38.9	18.3	3.9	1.4	100.0

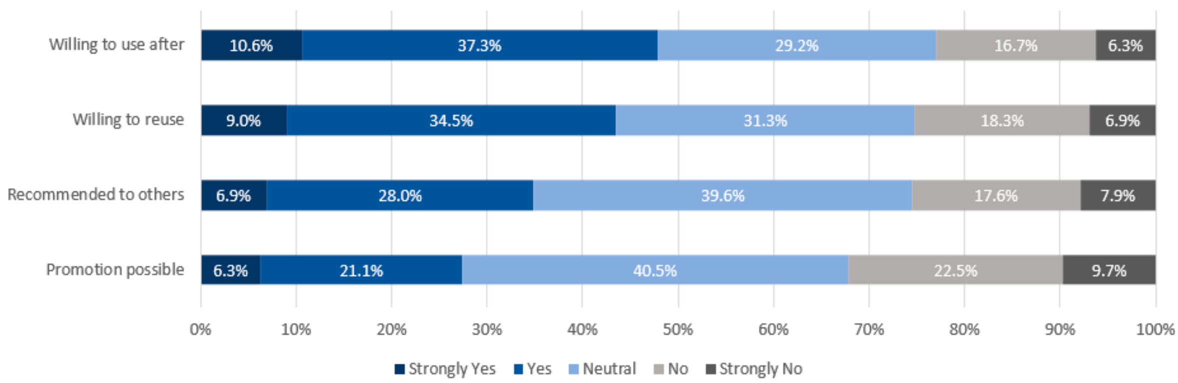

Figure 5. Intention to use personal mobility devices.

4. Analysis

4.1. Reliability Analysis

To check the validity and reliability of the configuration system of measured items used in this study, principal component analysis, internal consistency (Cronbach's α), and composite reliability (DG's ρ values) were performed or derived as shown in Table 5 and Figure 6. A total of seven components were derived from the results of the principal component analysis. As a result of checking which components were in items with a factor loading value of 0.4 or higher, "perception of personal mobility", "infrastructure", "ease of use", "relevant laws and systems", "safety equipment", "system", and "intention of the future use" were identified. The reliability analysis based on validated questions showed that all components had Cronbach's α values of at least 0.766, and composite reliability DG's ρ values of at least 0.847, showing high reliability. In addition, the average variance extraction (AVE) was found to be at least 0.466 or higher for all components. It was found that the perception of personal mobility devices was heavily influenced by "usefulness to means of transportation". In terms of satisfaction with the driving environment, it was found that the infrastructure was much influenced by the "support of designing bicycle road", and the ease of use was influenced by "accessibility to personal mobility", while relevant laws and systems were influenced by "relevant insurance systems". For the level of necessity, it was found that safety equipment was highly influenced by "speed limiters" and that the system was highly influenced by the "mandatory completion of safety and driving training". Finally, it was found that the intention of future use was greatly influenced by the users' "intention to recommend to others".

4.2. Model Estimation

As shown in Table 6, this study identified the correlation between the measured factors of questions that secured validity and reliability through principal component analysis and reliability analysis. Before model estimation, we identified the correlation coefficient r value, which was then compared with the square root of the average variance extracted ($\sqrt{\text{AVE}}$) value in order to confirm the discriminative validity. Results for the discriminant validity are shown as follows. As a result of the correlation analysis, the perception of personal mobility showed positive (+) correlations with "infrastructure", "ease of use", and "relevant laws and systems", as subfactors of driving satisfaction with personal mobility in Suwon. The perception of personal mobility also showed negative (−) correlations with "safety equipment" and "system" as subfactors of the level of necessity. Similarly, "infrastructure", "ease of use", and "relevant laws and systems" as subfactors affecting the driving satisfaction with personal mobility in Suwon had negative (−) correlations with "safety equipment" and "system" as subfactors of the level of necessity. The relative coefficient r was then compared to the square root of the average variance extracted ($\sqrt{\text{AVE}}$) value in order to check the discriminative validity, resulting in "$r < \sqrt{\text{AVE}}$", indicating that there was discriminative validity among all components.

We used partial least square structural calculation modeling (PLS-SEM), which is now widely applied in many social science disciplines [9–19]. The suitability of the estimated model was found to be as follows. Values representing the explanatory power of endogenous variables were 0.086 to 0.090 for "infrastructure", "ease of use", and "relevant laws and systems" as subfactors of satisfaction with the driving environment. These values were 0.112 and 0.114 for "safety equipment" and "system" as subfactors of the level of necessity. The value for the intention to use in the future was 0.338. The Goodness of Fitness (GOF)* value, meaning the fitness of the whole model, was 0.291, exhibiting high fitness as shown in Table 7.

Table 5. Metrics organization of reliability and validity.

Factor		Category	PM Recog.	Infra	Conv.	Legal	Safety Device	System	Intent. to Use
Perception of PM device		①Well-known transport mode	**0.424**	0.061	0.138	−0.065	0.140	0.083	0.339
		②Useful as transport mode	**0.790**	0.168	0.189	0.175	−0.168	−0.174	0.536
		③Eco-friendly transport mode	**0.737**	0.186	0.213	0.173	−0.095	−0.095	0.480
		④Safe transport mode	**0.757**	0.326	0.141	0.366	−0.340	−0.350	0.376
		⑤Easy to drive/handle	**0.622**	0.196	0.213	0.124	0.036	−0.019	0.336
		⑥Low-cost transport mode	**0.698**	0.171	0.268	0.157	−0.035	−0.024	0.316
Satisfaction level of driving environment	Infrastructure	①Gradient	0.248	**0.600**	0.290	0.304	−0.052	−0.092	0.189
		②Bicycle road sign	0.250	**0.784**	0.386	0.447	−0.147	−0.173	0.103
		③Bicycle road Design specification	0.251	**0.823**	0.399	0.451	−0.141	−0.149	0.168
		④Bicycle road pavement condition	0.140	**0.715**	0.329	0.364	−0.047	−0.109	0.045
		⑤Bicycle road connectivity	0.193	**0.778**	0.433	0.444	−0.132	−0.160	0.110
		⑥Drivable space	0.243	**0.772**	0.470	0.503	−0.109	−0.139	0.195
		⑦Personal mobility additional facilities	0.186	**0.686**	0.564	0.570	−0.105	−0.146	0.075
	Convenience of use	①PM Accessibility	0.206	0.490	**0.833**	0.388	−0.035	−0.062	0.174
		②Connectivity with transportation	0.140	0.400	**0.732**	0.353	−0.032	−0.014	0.062
		③Carrying PM in public transportation	0.157	0.457	**0.774**	0.446	−0.118	−0.088	0.049
		④PM Economics	0.294	0.338	**0.714**	0.297	0.027	−0.011	0.124
	Legal system	①Law	0.294	0.519	0.478	**0.872**	−0.247	−0.262	0.136
		②Insurance	0.269	0.497	0.371	**0.884**	−0.274	−0.269	0.174
		③Incentive	0.155	0.453	0.415	**0.796**	−0.161	−0.147	0.032
		④Maintenance and enforcement	0.239	0.556	0.404	**0.847**	−0.262	−0.244	0.172
Necessity	Safety device	①Speed limiter	−0.186	−0.157	−0.106	−0.269	**0.876**	0.535	−0.133
		②Helmet	−0.195	−0.114	−0.007	−0.226	**0.874**	0.666	−0.188
		③Headlight	−0.118	−0.091	0.006	−0.232	**0.783**	0.571	−0.047
	System	①Operation of exclusive license system	−0.185	−0.142	−0.062	−0.208	0.497	**0.791**	−0.195
		②Mandatory completion of safety and driving training	−0.237	−0.203	−0.077	−0.217	0.608	**0.895**	−0.229
		③Mandatory wearing of safety devices	−0.184	−0.147	−0.039	−0.237	0.706	**0.861**	−0.124
		④Mandatory insurance subscription	−0.156	−0.120	−0.041	−0.229	0.511	**0.789**	−0.176
		⑤Age limit	−0.096	−0.143	−0.021	−0.268	0.460	**0.684**	−0.087

Table 5. *Cont.*

Factor	Category	PM Recog.	Infra	Conv.	Legal	Safety Device	System	Intent. to Use
Intention to use in the future	①Willing to use after	0.488	0.123	0.081	0.094	−0.110	−0.185	**0.906**
	②Willing to reuse	0.524	0.154	0.128	0.132	−0.103	−0.172	**0.926**
	③Recommended to others	0.565	0.198	0.171	0.196	−0.182	−0.220	**0.938**
	④Promotion possible	0.519	0.177	0.127	0.165	−0.159	−0.180	**0.901**
Cronbach's alpha		0.782	0.861	0.766	0.875	0.806	0.865	**0.938**
DG.rho		0.847	0.895	0.851	0.914	0.886	0.903	0.956
AVE		0.466	0.548	0.584	0.723	0.715	0.652	0.842

Bold: composite reliability results which shows the items could be considered as same factor.

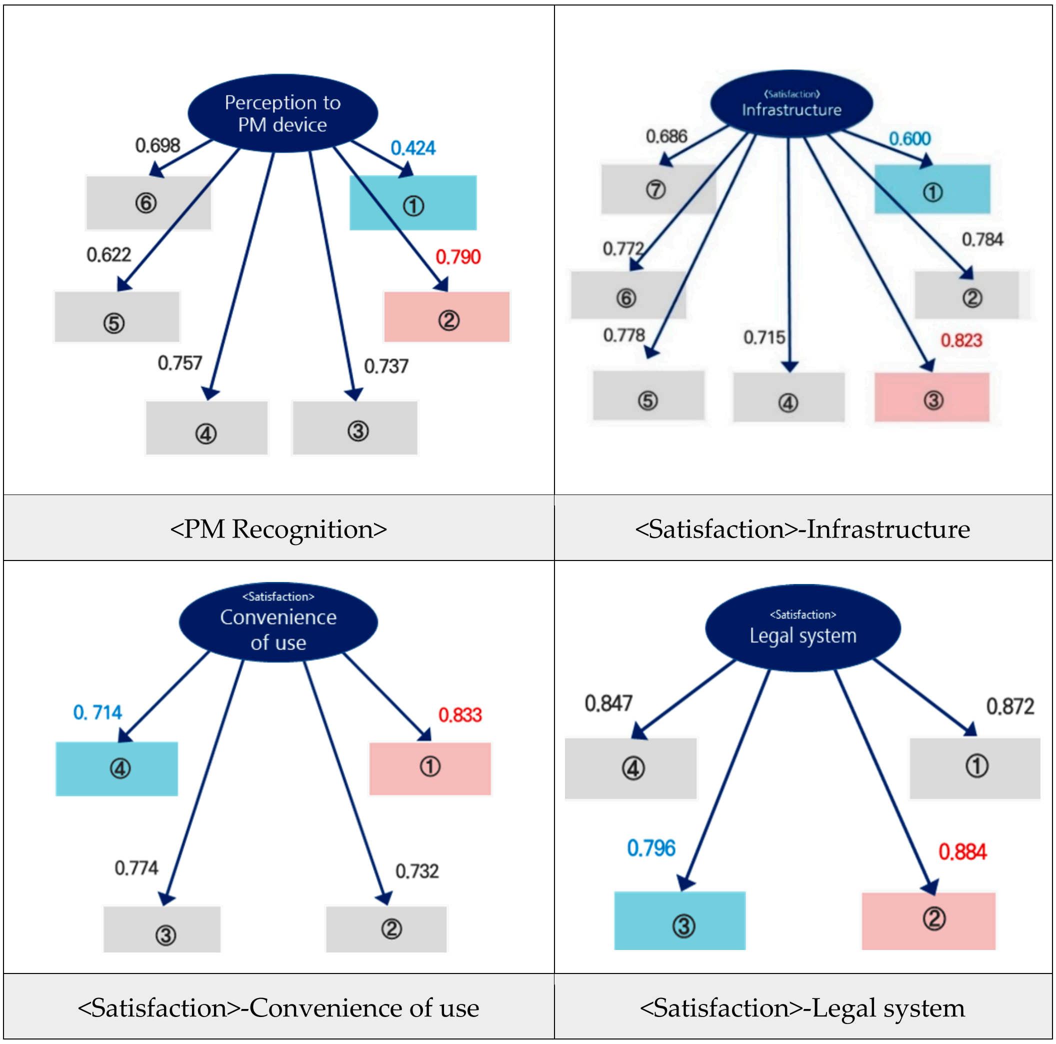

Figure 6. *Cont.*

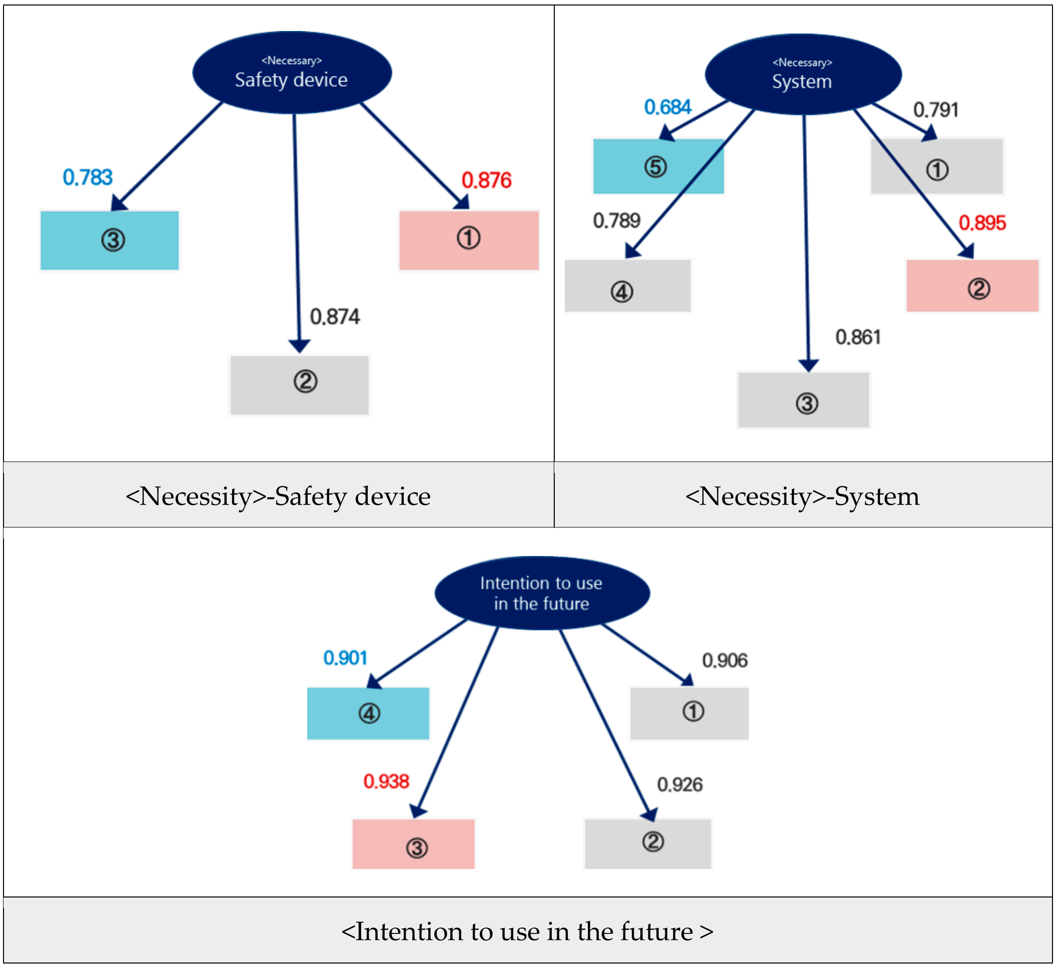

Figure 6. Results of the reliability test.

Table 6. Results of Correlation Analysis.

Var.		1	2(a)	2(b)	2(c)	3(a)	3(b)	4	√AVE
Perception of PM device		1							0.683
Satisfaction of PM driving environment	(a) Infrastructure	0.30	1						0.740
	(b) Convenience of use	0.27	0.56	1					0.765
	(c) Legal system	0.29	0.60	0.49	1				0.851
Necessity level for driving environment	(a) Safety equipment	−0.20	−0.15	−0.05	−0.29	1			0.845
	(b) Safety system	−0.22	−0.19	−0.06	−0.28	0.69	1		
Intention to use in the future		0.57	0.18	0.14	0.17	−0.16	−0.21	1	0.918

In Table 8 and Figure 7, among the results of the structural estimation modeling analysis of the direct effects between exogenous and endogenous variables, there were six positive (+) paths and four negative (−) paths that had significant effects at the threshold level, as follows:

Positive Path (+):

"Perception of PM device → Infrastructure" (B = 0.3, t = 5.973 **)
"Perception of PM device → Easy to drive/handle" (B = 0.267, t = 5.441 **)
Perception of PM device → Legal system" (B = 0.293, t = 6.479 **)
"Perception of PM device → Intention to use in the future" (B = 0.561, t = 14.28 **)
"Easy to drive/handle → Safety equipment" (B = 0.135, t = 2.161 *)

"Easy to drive/handle→ Safety system" (B = 0.146, t = 2.436 *)

Negative Path (−):

"Perception of PM device → Safety equipment" (B = −0.15; t = −2.818 **)
"Perception of PM device → Safety system" (B = −0.161, t = −3.335 **)
"Legal system → Safety equipment" (B = −0.315, t = −5.071 **)
"Legal system → Safety systems" (B = −0.27, t = −4.496 **)

It was found that both the perception of personal mobility and the satisfaction level of the driving environment had positive effects. However, the level of necessity had a negative effect. The only factor that significantly affected the intention to use a personal mobility device in the future was the "perception of the personal mobility device".

Table 7. Fitness of the PLS structure equation model.

Variables		R^2	GoF
Satisfaction level of driving environment	Infrastructure	0.090	0.291
	Convenience of use	0.071	
	Legal system	0.086	
Necessity level for driving environment	Safety equipment	0.112	
	Safety system	0.114	
Intention to use in the future		0.338	

Table 8. Model estimation results.

Category	B	s.e	t	*p*
Perception of PM device → Infrastructure	0.300	0.050	5.973	0.000 ***
Perception of PM device → Convenience of use	0.267	0.049	5.441	0.000 ***
Perception of PM device → Legal system	0.293	0.045	6.479	0.000 ***
Perception of PM device → Safety equipment	−0.150	0.053	−2.818	0.005 **
Perception of PM device → Safety system	−0.161	0.048	−3.335	0.001 **
Perception of PM device → Intention to use in the future	0.561	0.039	14.280	0.000 ***
Infrastructure → Safety equipment	0.011	0.061	0.176	0.860
Infrastructure → Safety system	−0.061	0.057	−1.080	−0.720
Infrastructure → Intention to use in the future	0.017	0.054	0.323	0.253
Convenience of use → Safety equipment	0.135	0.062	2.161	0.031 *
Convenience of use → Safety system	0.146	0.060	2.436	0.015 *
Convenience of use → Intention to use in the future	−0.009	0.064	−0.139	−0.111
Legal system → Safety equipment	−0.315	0.062	−5.071	0.000 ***
Legal system → Safety system	−0.270	0.060	−4.496	0.000 ***
Legal system → Intention to use in the future	−0.028	0.066	−0.428	−0.331
Safety equipment → Intention to use in the future	0.029	0.063	0.465	0.642
Safety system → Intention to use in the future	−0.110	0.069	−1.602	−0.891

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

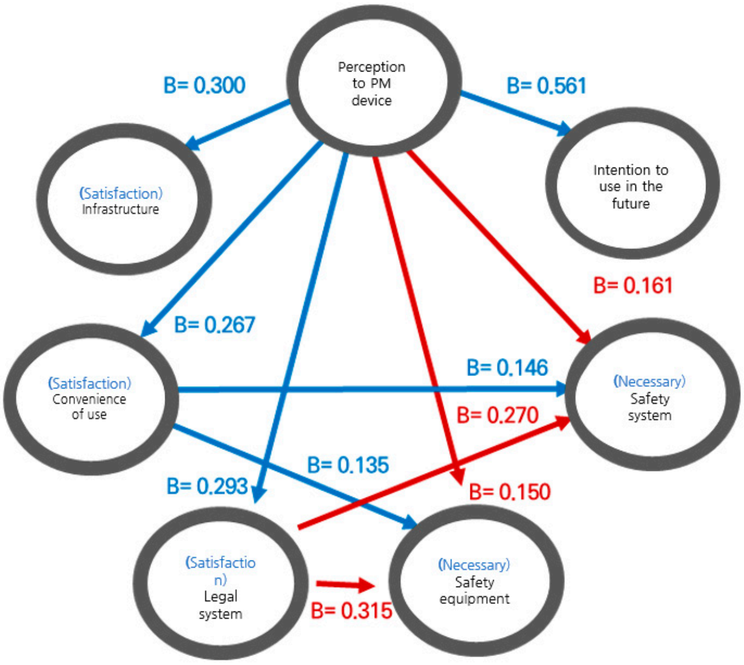

Figure 7. Paths showing significant direct effects.

As shown in Table 9, in the partial least square structural calculation modeling (PLS-SEM), a total effect analysis was conducted in order to determine whether perceptions of personal mobility could affect future use intentions through the subfactors of driving satisfaction (infrastructure, ease of use, relevant laws and systems) and the subfactors of necessity (safety equipment, system). Results indicated that the only factor that had a significant impact on the intention of future use was the perception of the personal mobility device. In other words, since the subfactors of satisfaction with driving environment and the level of necessity did not have a significant effect on the intention of future use, the direct effect of the perception of personal mobility device (B = 0.451, t = 14.280 **) accounted for the majority of the effects among the total effects (B = 0.574, t = 17.032 ***) on the intention of future use. In addition, it is shown that the perception of personal mobility had positive (+) effects on subfactors of all driving environment satisfaction and negative (-) effects on subfactors of the level of necessity. Additionally, the ease of use among the subfactors of driving environment satisfaction had a positive effect (+) on relevant laws and systems but a negative effect (−) on the subfactors of the level of necessity.

Table 9. Total effect analysis results.

Path	B	s.e	t	*p*
Perception to PM device → Safety equipment	−0.203	0.049	−4.109	0.000 ***
Perception to PM device → Safety system	−0.219	0.049	−4.494	0.000 ***
Perception to PM device → Intention to use in the future	0.574	0.034	17.032	0.000 ***
Infrastructure → Intention to use in the future	0.025	0.053	0.463	0.643
Convenience of use → Intention to use in the future	−0.021	0.061	−0.343	−0.269
Legal system → Intention to use in the future	−0.008	0.061	−0.123	−0.098

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

5. Discussion

Model development and analysis were conducted in this study using partial least square structural calculation modeling (PLS-SEM) in order to determine the effects of different perceptions of personal mobility devices, the satisfaction with the driving environment, and the necessity of safety equipment or system safety measures on the intention of future usage of personal mobility methods. A total of seven components were derived as a result of the principal component analysis. Differing levels of importance and priority were then derived by identifying factors that had important effects on each component. It was found that: (1) "perceptions of personal mobility devices" should be strengthened in order to increase their "usefulness as [a] transport mode;" (2) "infrastructure" should receive additional support through better bicycle road design; (3) "ease of] driving/handling" should focus on the accessibility of personal mobility devices, and (4) "legal systems" should be improved through better insurance systems. In addition, it was found that "perceptions of personal mobility devices" was the only factor that affected the "intention to use them in the future". It can be said that measures to improve public awareness through promotions/campaigns/policies and road environment improvements are needed in order to vitalize the usage of personal mobility devices in the future.

The findings derived the priority of different improvement and policy directions in order to promote the usage of personal mobility devices in Suwon and create a safe driving environment in the future. First of all, it is necessary to improve the perception of personal mobility devices. The partial least square structural calculation modeling revealed that the "perception of personal mobility devices" was the only factor which affected an individual's intention to use a personal mobility device. Survey results showed that the "intention to use in the future" was high, but 67.8% of the respondents answered "No" to the question "Is a personal mobility device a safe transport mode?" Therefore, it is necessary to construct a safe driving environment through various measures, such as policies, campaigns, public relations strategies, and public-private cooperative governance, so that positive changes can be made to improve the perceptions of personal mobility. In addition, a plan for personal mobility education and a public relations program is necessary, based on the psychological factors considered in this study. Personal mobility devices are easy to drive and handle, and thus users must learn only simple operational methods when using them. However, many accidents are caused by poor operation. Additionally, if bike paths become accessible, the number of accidents caused by conflicts between existing cyclists and pedestrians will increase even further. Therefore, education and public relations programs are necessary in order to transform potential demand into real demand, along with the creation of a safe culture of use.

Moreover, at the current time, shared personal mobility devices operated by private companies are very active in Korea. In the case of shared personal mobility devices, the user can determine the time and space very flexibly when parking and returning the personal mobility device, so there is no need to carry the personal mobility device on board when using public transportation, such as buses and urban railways. The Korean government intends to implement a policy to install indoor cabinet-type parking lots at major transit points, such as subways stations, in order to address the needs of users of privately owned personal mobility devices. Carrying a personal mobility device when using public transportation is not yet legally defined, and therefore further research would be required on this issue. In addition, a law that allows for the use personal mobility devices weighing less than 30 kg and with a speed ability less than 25 km/h on bicycle roads was established in Korea in December 2020. Therefore, the establishment of a driving environment where personal mobility devices are safely used would be the most important policy task, and it is also important to construct related road facilities which reflect the needs of personal mobility device driving. This study has limitations in its model estimation through the integration of the response data of personal mobility devices' users and non-users. We believe that future research may be able to derive more meaningful policy implications by estimating the model separately for both the user group and the non-user group.

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References

1. Shin, H.; Jung, K.; Lee, J.; Park, S.; Kim, S.; Yang, S. *Support Project for Micro Mobility Transport Policy*; The Korea Transport Institute: Sejong, Korea, 2017.
2. Ji, W.; Park, K.; Yoon, J. *Bicycle Lane Enhancement Measures for Increasing Use of Personal Mobilities*; Gyeonggi Research Institute: Suwon, Korea, 2018.
3. Song, J.; Ryu, I.; Lee, S.; Choi, K. A Study on Personal Mobility User Characteristics and Cognitive Response Time. In Proceedings of the Korean Society of Transportation Academic Conference, Seoul, Korea, 10 November 2019.
4. CEVEQ. *Centre for Electric Vehicle Experimentation in Quebec. Pilot Project for Evaluating Motorized Personal Transportation Device: Segways and Electric Scooters*; CEVEQ: Montreal, QC, Canada, 2004.
5. Landis, B.W.; Theodore, A.P.; Herman, F.H. *Characteristics of Emerging Road and Trail Users and Their Safety*; The Federal Highway Administration (FHWA) Research, Development, and Technology Turner-Fairbank Highway Research Center: McLean, VA, USA, 2004.
6. Darmochwal, A.; Topp, H.H. *Segway in Public Spaces: Evaluation of the Saarland Pilot Trial with Regard to the Usage Compatibility and the Road Traffic Regulatory Handling of These Special Transport Devices*; Institute for Mobility & Transport: Lisbon, Portugal, 2006; Available online: https://www.ft.dk/samling/20061/almdel/tru/bilag/560/392826.pdf (accessed on 20 February 2021).
7. Kühn, G. *Assessing the Safety Characteristics of the Segway*; German Insurance Association: Berlin, Germany, 2009.
8. Yu, H. Modeling pedestrians' subjective danger perception toward personal mobility vehicles. *Transp. Res. Part F Traffic Psychol. Behav.* **2018**, *56*, 256–267.
9. Sosik, J.J.; Kahai, S.S.; Piovoso, M.J. Silver bullet or voodoo statistics? A primer for using the partial least squares data analytic technique in Group and Organization Research. *Group Organ. Manag.* **2009**, *34*, 5–36. [CrossRef]
10. Ringle, C.M.; Sarstedt, M.; Straub, D.W. A critical look at the use of PLS-SEM in MIS quarterly. *MIS Q.* **2012**, *36*, iii–xiv. [CrossRef]
11. Peng, D.X.; Lai, F. Using partial least squares in operations management research: A practical guideline and summary of past research. *J. Oper. Manag.* **2012**, *30*, 467–480. [CrossRef]
12. Hair, J.F.; Sarstedt, M.; Pieper, T.M.; Ringle, C.M. The use of partial least squares structural equation modeling in strategic management research: A review of past practices and recommendations for future applications. *Long Range Plan.* **2012**, *45*, 320–340. [CrossRef]
13. Hair, J.F.; Sarstedt, M.; Ringle, C.M.; Mena, J.A. An assessment of the use of partial least squares structural equation modeling in marketing research. *J. Acad. Mark. Sci.* **2012**, *40*, 414–433. [CrossRef]
14. Kaufmann, L.; Gaeckler, J. A structured review of partial least squares in supply chain management research. *J. Purch. Supply Manag.* **2015**, *21*, 259–272. [CrossRef]
15. Richter, N.F.; Sinkovics, R.R.; Ringle, C.M.; Schlägel, C.M. A critical look at the use of SEM in international business research. *Int. Mark. Rev.* **2015**, *33*, 376–404. [CrossRef]
16. Nitzl, C. The use of partial least squares structural equation modelling (PLS-SEM) in management accounting research: Directions for future theory development. *J. Account. Lit.* **2016**, *37*, 19–35. [CrossRef]
17. Ali, F.; Rasoolimanesh, S.M.; Sarstedt, M.; Ringle, C.M.; Ryu, K. An assessment of the use of partial least squares structural equation modeling (PLS-SEM) in hospitality research. *Int. J. Contemp. Hosp. Manag.* **2018**, *30*, 514–538. [CrossRef]
18. Ringle, C.M.; Sarstedt, M.; Mitchell, R.; Gudergan, S.P. Partial least squares structural equation modeling in HRM research. *Int. J. Hum. Resour. Manag. Forthcom.* **2019**, *31*, 1617–1643. [CrossRef]
19. Hair, J.F.; Rosher, J.J.; Sarstedt, M.; Ring, C.M. When to use and how to report the results of PLS-SEM. *Eur. Bus. Rev.* **2019**, *31*, 2–24. [CrossRef]