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Research article

Differences in perception of safety in driving environment according to shared PMD user experience through multi-criteria analysis

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A R T I C L E I N F O

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A B S T R A C T

A shared personal mobility device (PMD) is a transportation model that rents personal transportation devices, such as bicycles and kickboards, through a sharing platform. The use of shared PMD has increased, but related complaints and traffic accidents are doubling with it every year. This study applied an analytic network process (ANP) methodology for the multi-criteria analysis. A survey including normal citizens was conducted to evaluate the importance of safety regarding shared PMD experience.

The evaluation factors differ according to the experience of using the shared PMD device, although 'driving continuity' and 'separation of sidewalks and roadways' were the most important. PMD users gave greater priority to 'removal of the road gap', 'traffic safety signs', 'dedicated parking area' and 'management of obstacles' compared to non-users. On the other hand, for non-PMD users, 'bicycle lane width', 'strengthening enforcement', and 'user safety education' were more important. The results showed that importance differed depending on the participant's experience of using a shared PMD or the lack of it. In the case of users, factors that have a direct effect on driving were prioritised, and in the case of non-users, auxiliary operations and management, such as crackdowns and education, were prioritised.

1. Introduction

As urbanisation has accelerated the concentration of human populations in cities, traffic congestion caused by densely populated urban areas has significantly affected the life satisfaction of urban residents [1,2]. Under these environmental circumstances, shared personal mobility devices (PMDs), which are low-speed vehicles such as E-bicycles and electric kick scooters, have received a lot of attention as innovative means of transport that multiple users share to travel short distances [3,4]. Shared PMDs show mixed characteristics of both pedestrian movement and vehicle-based movement and are used as an optimal means of transport from a public transfer station (first mile) to the final destination (last mile) [5–8].

Countries have recently witnessed a decrease in the number of public transport users due to the COVID-19 pandemic, while the number of shared PMDs has increased [9]. Based on this, researchers have examined the sustainability of shared PMDs [4,10,11]. The advantages of shared PMDs have contributed to the rapid growth of the shared PMD market [3,12]. However, the growth of the shared

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PMD market has also been accompanied by a gradual increase in the number of relevant traffic accidents [13]. The South Korean government has analysed data on PMD-related traffic accidents and found that the number of PMD-related traffic accidents has increased from 244 cases in 2017 to 897 cases in 2020; concurrently, the number of deaths caused by PMD-related traffic accidents has increased from 4 deaths in 2017 to 17 deaths in 2020 [14,15].

As a result, PMD users tended to drive on sidewalk as it provides convenient and safe driving conditions. Nevertheless, the South Korean government clearly prohibited using PMDs on sidewalks as it posed a threat to pedestrians. Shared PMDs, which can be borrowed and returned as service items, inevitably intrude on pedestrian walkways and driving roads at the time of parking and thereby cause safety issues. Shared PMD users are therefore faced with a restricted driving environment that cannot cope with the growing market, the increasing number of shared PMD users, and other obstacles that prevent the establishment of a shared PMD-friendly driving environment.

The aforementioned problems have deprived PMD users of their right to safe driving conditions and put pedestrians and vehicle drivers at risk [16–19]. For this reason, negative perceptions towards PMD-related issues, such as an increasing number of PMD-related accidents, have inhibited the growth of PMD sharing platforms and the use of PMDs [20].

This study focuses on shared PMD-related safety issues and conditions caused by a limited driving environment, which prioritises the safety of pedestrians and motorists over the safety of shared PMD users [21]. For this reason, the background of the study was focused on the difference in safety awareness of the driving environment, which differed depending on the use of shared PMDs. A survey was conducted to examine the priorities of PMD users and non-PMD users on the subject of improving the driving environment for PMDs, which differ according to the level of their needs. The survey results were then analysed to establish the importance of improvement to the driving environment for shared PMDs. Thus, this study expands the scope of existing research on shared PMD driving environment by comparing the differences in the priorities of PMD users and non-PMD users, according to their experiences when using shared PMDs. It also highlights the wide range of evaluation factors that should reflect in the public decision-making process.

2. Regional context and literature review

2.1. Regional context

The implementation and rapid development of shared PMDs have introduced administrative problems in cities throughout the world [5,22,23]. When shared PM companies initially enter a market and provide PMDs, local governments may choose to intervene and restrict the number of PMDs. South Korea allows shared PM companies to operate shared PM services without limiting their power as long as the companies are registered with the local governments [16,24]. As a result, an excessive number of shared PM companies and electric kick scooters have entered the market in major cities throughout South Korea. In other words, South Korea clearly shows a weakness in the management of shared PM companies, PMDs, and relevant regulations compared to other countries that empower local governments to regulate shared PM companies and PMDs. This has created a blind spot where shared PM Service users are not protected with regard to insurance and responsibility in case of an accident [25].

Considering the driving environment, in Korea, the Road Traffic Act on PMD has been revised twice (see Table 1). The initial method of passage implemented without a clear definition was ineffective. This misled users, and driving on the sidewalk was often seen. Since the legal status of PMD was defined through the revision, the PMD method of passage has been expanded to bicycle lanes as well as the edge of the road, but sidewalk driving is still frequently observed [26]. This is why the Act still puts PMD users in a dangerous environment on roads full of cars and cyclists, and there is a need for active revision in terms of PMD use [27].

The rapid increase in shared PMD usage by city further caused traffic congestion in the city. In order to prevent the risk of collision, PM users are required to use the edge half area of car lane and bicycle lane, but it is far from reality due to the recognition of the edge half and the limitation of the spread of bicycle lane [28]. This still led to widespread driving in sidewalk. As a result, PMD users are also in a position to pose a safety risk to pedestrians due to an unsecured driving environment [18,21,29].

Different regulations are applied to shared PMDs driving roads in consideration of PMDs driving environment in each country. In the case of South Korea, shared PMDs was able to drive only on car roads in the beginning. However, these regulations were ineffective and confusing and failed to prevent PMD users from driving their PMDs on sidewalks. The revised shared PMDs a legal status, and the range of roads that could accommodate PMDs was expanded from the bicycle roads. Nevertheless, several people still drive PMDs on the sidewalk [26] (Fig. 1).

Other countries have implemented different regulations based on the legal status of PMDs [17,30]. Japan's Road Traffic Act defines PMDs as motorised bicycles, similar to South Korea's Road Traffic Act, but without providing a specific definition of PMDs. Accordingly, PMD users in Japan are obliged to adhere to the driving regulations for motorised bicycles. Electric scooters should

Table 1
PM on the driving environment (the road traffic Act).

Section	Before the enactment	First revision	Second revision
Time of implementation	–	20.12.10	21.05.13
Definition	Motorised bicycle	PM	PM
User's qualification	No need	No need	Need
Roadway	Car lane	Car lane, Bike lane	Car lane, Bike lane

Fig. 1. Driving environment of shared PMDs.

essentially be driven on low-speed roads (e.g., bicycle lanes), and users who possess a licence for motorised vehicles can also drive electric scooters on public roads. However, driving PMDs on the sidewalk is prohibited [26]. The Japanese government has also designated and operated zones for driving PMDs in major parks. This approach of the Japanese government (MLIT) contrasts with that of the South Korean government, which has banned driving PMDs in public spaces such as parks.

The status of PMDs and relevant regulations in Germany are similar to those in Japan. The German government allows PMD users to drive on bicycle roads and accepts conditional driving of PMDs on the sidewalk, for which PMD users require special permission. The regulations prioritise pedestrians on roads and protect them from being threatened or disturbed in their movement while using roads. The German government operates exclusive roads for electric bicycles where PMD users are allowed to pass bicycle users [31]. The United States classifies PMDs that can be driven at 32 km/h as low-speed vehicles, and local governments allow PMD users to drive on bicycle roads, sidewalk pavements, and public roads (approved in 22 states) according to the characteristics of the PMDs [32]. As described above, countries have formulated laws on driving spaces, speed limits, and the licencing of PMDs according to their unique legal standards and environment.

2.2. Literature review

Studies on shared PMDs are classified into those that analyse shared PMDs in a comprehensive way and those that focus intensively on specific PMDs, such as electric kick scooters, electric scooters, and electric bikes [33]. Although the concepts and names of shared PMDs differ by country, it is obvious that an increasing number of studies on shared PM have been conducted recently. Considering the increasing use of shared PMDs as the primary cause of various traffic issues, researchers have examined a wide range of research fields related to shared PMDs, including system analyses and market comparisons. Researchers have mainly conducted declaratory studies on evaluating the physical driving environment for PMDs, analysing PM-related cases observed in South Korea and other countries, and investigating measures for legal and system improvements. Surveys have been conducted to evaluate the environment from a user perspective [34]. Hardt and Bogenberger evaluated the usability of shared PMDs in cities by conducting a survey based on a Likert scale to identify the motivations for using shared PMDs and found that people's environmental values indirectly affected their intention to use PMDs [35]. Eccarius and Lu also found that parking convenience was the most obvious advantage of PMDs, and the intention of using PMDs was also influenced by administrative regulations, such as limitations in the use and maximum speed of PMDs according to road types [36]. In addition, Almannaa et al. analysed the lack of exclusive roads for electric scooters as the most serious obstacle for the use of PMDs [37].

With regard to existing studies on the safety of shared PMDs, Turoń et al. defined the safety of shared PMDs by classifying the concept into vehicle safety, infrastructure safety, and mobility management [38]. There are policies/legislations that address the promotion of education and training for PMD use [39–44]. Sund and Brandt developed a traffic simulation model and derived a risk index related to the physical environment of PMDs based on a linear regression model [45]. Oh and Kim verified the seriousness of traffic accidents caused by PMDs by applying a logistic regression model and variables on road characteristics to cases of PMD accidents [46]. Reck and Axhausen investigated data on the paths used by shared PMDs to estimate a mode selection model. They found that precipitation and approach distance were essential factors for mode selection and that PMD users were willing to walk a maximum of 200 m to access PMDs [6]. Maiti et al. analysed data on collisions between shared PMDs and pedestrians on a university campus to identify elements that could affect the safety of pedestrians [47]. Jiao and Choi examined data on traffic accidents caused by PMDs and derived Moran's I by considering spatial autocorrelation; they verified a spatial correlation between traffic accidents caused by the collision between shared PMDs [48]. Specifically, traffic accidents caused by shared PMDs were more likely to occur on primary street due to traffic signals than general traffic accidents. To prevent accidents, it is necessary to establish a system that increases the visibility of traffic signals.

Numerous studies have examined the mobility and movement patterns of PMDs to develop strategies for optimised sharing of PMDs [6,47]. However, little research has been conducted to investigate decision-making processes for solving urban problems and complaints related to shared PMDs [39,40]. Altintasi and Yalcinkaya used analytic hierarchy process (AHP) methodology to consider environmental factors for the location of charging stations and to promote decision-making on the determination of optimal locations for charging stations for shared PMDs [41]. Deveci et al. proposed a decision-making model based on the q-rung Orthopair fuzzy set to determine the priority of safety-related factors [10]. They introduced strategies for the safe use of PMDs based on the placement of infrastructure, user behaviours, and connections with other modes of transport. They also presented an efficient decision-making model to solve the problem of determining alternative methods for the operation of PMDs. They selected safety, infrastructure, cost, and sustainability as the top evaluation factors and divided solutions into infrastructure, safety education, and safety operation. Their results suggest the enhancement of infrastructure is the most important among the solutions related to infrastructure, safety education, and driving regulations.

Few studies have examined the driving environment for shared PMDs and verified quantitatively the effect of road or driving characteristics on traffic accidents, and that policies are needed to enhance the driving environment for shared PMDs. Research that analysed the driving environment of existing shared PMDs suggested only limited improvement factors depending on the usage characteristics and travel behaviour of shared PMDs [42]. It addresses psychosocial and behavioural risks in interactions with other means and argues for effective regulatory introduction to reduce the possibility of collision [27], and suggests that regulations and improvements are needed as both cyclists and PMD drivers prefer infrastructure to feel safe [43]. In this respect, this study attempted to determine the dependencies between evaluation factors and evaluate the priorities of the factors by synthesising the proposed regulations and infrastructure improvement. Accordingly, the public decision-making process requires a quantitative analysis of the causal relationship between factors and a qualitative evaluation that considers experience in using PMDs. Studies are increasingly using the multi-criteria decision-making (MCDM) methodology to investigate the traffic environment for shared PMDs. Nevertheless, researchers have not yet analysed the importance and priority of evaluation factors for the safety of the shared PMD driving environment, despite an increasing number of complaints and accidents related to shared PMDs. Particularly, as studies on analysing shared PMDs based on decision-making methods only target a few experts, these studies cannot be effectively used for the decision-making process for practical policy enactment [10].

In addition, as a result of reviewing previous studies that surveyed PMD, there was a study on the difference in perception of risk between users and non-users according to user experience for actual shared PMD. It was investigated by classifying into various characteristics such as risk perception and use inhibition for PMD [49–52]. The novelty of this study is that it focuses on how these differences in perception actually differ in priorities for improving the driving environment. In fact, these differences show that various improvements such as regulation and legislation, training, and road infrastructure should be improved, but it is necessary to discuss how opinions vary depending on the user experience. Even in decision-making regarding PMDs, it is difficult to reflect the opinions of actual citizens, and it is difficult to prioritise between improvement factors. This study presents the need to consider the limitations of previous studies and differences in perception in decision-making, and adopted the multi-criteria analysis for efficient decision-making.

This study's significance lies in the fact that it analyses the importance of evaluation factors by conducting surveys based on the experiences of both shared PMD users and non-users. This study also has political significance in that it identifies the priority of evaluation factors for the shared PMD driving environment according to the experience of survey participants in using shared PMDs; moreover, it derives significant findings that can be effectively used to implement relevant policies and establish enhancement plans.

3. Methodology

Analytic network process (ANP) analysis, a multi-criteria method, is an empirical decision-making method that considers various correlations between factors by expanding, considering only the vertical relationship. In the case of AHP, there is a limit to considering all of these actual influences in environmental evaluation, whereas ANP is a useful methodology as it considers multicollinearity correlations between evaluation factors that occur in actual urban and traffic environment evaluation. Therefore, in order to reflect various needs and opinions of city people, this methodology is applied when evaluating priorities for the introduction of infrastructure that requires discussion between citizens. PMDs should further consider various environmental conditions; the distribution of related laws and infrastructure is different for each country. In order to improve the driving environment, optimal decisions can be made only by considering the correlation between evaluation factors. As a result of ANP, the importance of evaluation factors was different depending on user experience, and it is believed that this evaluation can be used for decision making and reflected according to the environment. This study should be introduced in consideration of demographic characteristics of usage and target in the actual urban environment as well as opinions among policymakers, and this study can be used to help decision-making to some extent.

Prior to analysing priorities in the driving environment for PMDs, this study first derived the evaluation factors, and formulated questionnaires to collect survey data for the analysis. Expert discussions were conducted based on the selected evaluation factors to perform a *t*-test on the evaluation items and evaluate the complex relationships among the selected evaluation factors. Next, the selected evaluation factors were categorised according to the primary factors and designed into a network system. This study conducted a pairwise comparison between shared PMD users and non-users to measure the comparative significance of the driving environment for PMDs. Subsequently, it calculated the weights for the collected survey data by applying the analytic network process

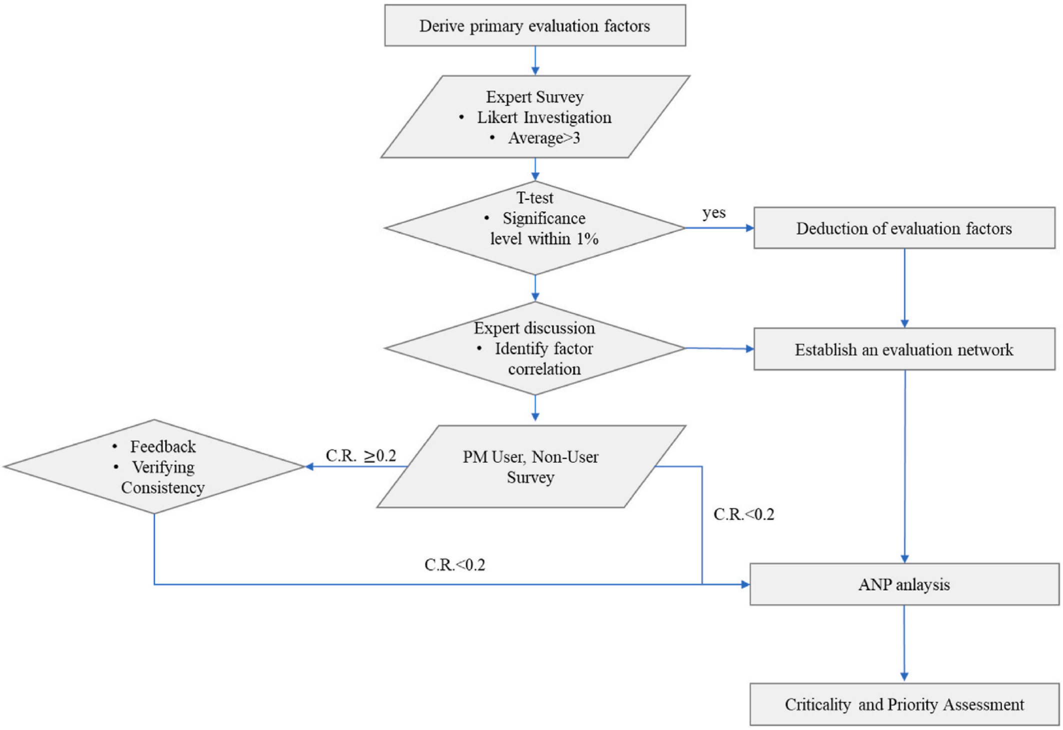

Fig. 2. Research flow.

(ANP) and numerically presented the significance of the driving environment for PMDs along with the priority of such significance according to the calculated weight (Fig. 2.).

3.1. Data sources

According to the flow of the research, in order to synthesise expert opinions for selection of evaluation factors prior to the survey, the researcher in the field of planning city and transportation was contacted by phone and e-mail to conduct the survey. In order to evaluate the suitability of the evaluation factors before the survey, an expert survey, consisting of a 5-point Likert scale, was conducted on 31 urban transportation experts. A single *t*-test test was conducted to determine the significance of the suitability evaluation. For significant verification, the sample size was decided to be more than 30, assuming that it follows the normal distribution. The final index was derived by determining that the response above average (3 points) was appropriate and restructured into an evaluation item that satisfies an average of 3 points or more under the significance level. As a result of the *t*-test, the evaluation indicators show that the p-value does not satisfy the significance level of 1% including 'Mounting composition', 'Backward driving prevention guide', and 'Visual guidance facilities'. The above three factors are characterized by safety facilities that are valid only in specific conditions, and the average is also lower than the evaluation factors. Thus, based on these results, they are not suitable for the final evaluation factor. In addition, the items were unified and simplified to prevent participant fatigue caused by excessive questions. Fifteen evaluation elements were derived as the final evaluation index. Next, an expert discussion was conducted to analyse the correlation of the derived evaluation factors. Correlation analysis was conducted on 9 experts who participated in the selection of evaluation factors. Experts were recruited mainly from those who obtained master's or higher degrees as urban and transportation majors or who worked at related agencies. In consideration of the COVID-19 situation, a meeting was held in May to combine hybrid methods, and experts who were unable to attend face-to-face attended through Zoom. After explaining the outline of ANP and the network diagram process, the evaluation paper was prepared, and the dependencies between the evaluation factors were evaluated based on these results. After that, not only experts but also citizens were recruited to examine the differences in perception of the evaluation factors of the built driving environment. As many experts do not have any experience with using shared PMDs, this study recruited experts who were familiar with PM to obtain reliable data. To recruit the experts, the Shared Personal Mobility Alliance (SPMA)—the largest representative body for the PM industry—was contacted and questionnaires were distributed to experts from SPMA by email. Then a platform called 'Involve.me' was used for investigation based on the constructed questionnaire. In 'Involve.me', questions can be structured more sophisticatedly than Google Survey or other sites. In particular, for the analysis of ANP, it was randomly recruited for two weeks in May

Table 2
Overview of the survey.

			Number		Ratio (%)	
Sex	Man		114		49.1	
	Woman		118		50.9	
Ages	20s		122		52.6	
	30s		76		32.8	
	40s		24		10.3	
	50s		8		3.4	
Shared PMD experience	Yes	Electric-scooter	168	86	72.4	51.2
		Electric bicycle		25		14.9
		Both		57		33.9
	No		64		27.6	
Career	Student		50		21.55	
	Worker		127		54.74	
	city and transportation officials		10		4.31	
	city and transportation researcher		27		11.64	
	PMD-related workers		5		2.16	
	ETC		13		5.60	
level of education	high school		43		18.53	
	Undergraduate		143		61.64	
	a master's degree		38		16.38	
	Doctor's degree		8		3.45	
Overall			232		100.0	

using an online bulletin board to recruit participants regardless of their shared PMD usage. This study was performed in accordance with the Institutional Review Board of Seoul National University (Korea; SNU IRB No. 2205/002-002). Participants were free to stop participating in the test at any time without any disadvantages. Informed consent was obtained from all participants for our experiments. The testing procedure for adolescents was approved by the Ethics Committee of the "SNU IRB". During the recruitment period, 237 cases were collected, and consistency analysis was conducted to acquire and verify valid surveys. Since the consistency ratio (CR) of 0.2 or more is not valid, only the questionnaire of 0.2 or less was used. As a result, 112 cases were analysed (see Table 2).

Before recruiting participants, it is necessary to examine the demographic distribution of PMD users. Statistical data on the use of shared PMDs in the country have not been investigated so far, and access is limited because the spatial operating range and usage of each shared PM company are very different. Considering these points, it is possible to estimate the distribution and sociological characteristics of users in related studies conducted previously. PMDs are generally used for short journeys, and it was found that they are popular in young age groups living in cities, and that men used them more than women [27]. In this survey, responses were collected by academic communities and online bulletin boards to sample respondents regardless of user experience. It was found that the ratio of men and women was similar, and the respondents who had experience using PMD were slightly higher for men. In addition, 86% of the users were in their 20s and 30s, and their educational background was found to be undergraduate or higher for more than 70% users. This showed similar statistical characteristics as were generally investigated in previous studies, and these response results were used as data for this study. This study recruited survey participants regardless of their experience in using shared PMDs, given that the purpose of the study was to compare the significance of the evaluation items based on participants' experience in using shared PMDs. Shared PMD users and non-users accounted for 70% and 30% of the sample, respectively (Table 2). Among 232 respondents, data satisfying CR of 0.2 or less were constructed to use only data with proven consistency as analysis data. Of the 232 copies of responses collected in this study, the number of questionnaires used for importance analysis through consistency verification was limited to 122 copies. Among the 122 copies, 89 were users and 33 were non-users.

$$C.I. = \frac{\lambda_{max} - n}{n-1} C.R. = C.I. \Big/ R.I.$$

3.2. Methodology

This study applied the ANP methodology to reflect the correlation between evaluation factors and complex dependence in the decision-making process related to the traffic environment. As the ANP considers both internal and external dependence between hierarchies and relationships among hierarchies by reflecting the dependency, this methodology based on an accurate structure map is used to implement policies or to make decisions. With regard to the application of an analytic method for traffic facilities, a decision-making process on benefits and driving evaluations evaluates the significance of the target items based on a complex network structure between elements instead of a top-down vertical structure.

The ANP methodology is appropriate for evaluating the significance of a driving environment for PMDs in terms of safety and investigating the practical implementation of an enhanced driving environment for PMDs. Furthermore, this study uses evaluation factors for both the physical and non-physical environments as it is crucial to accurately identify correlations between these factors and

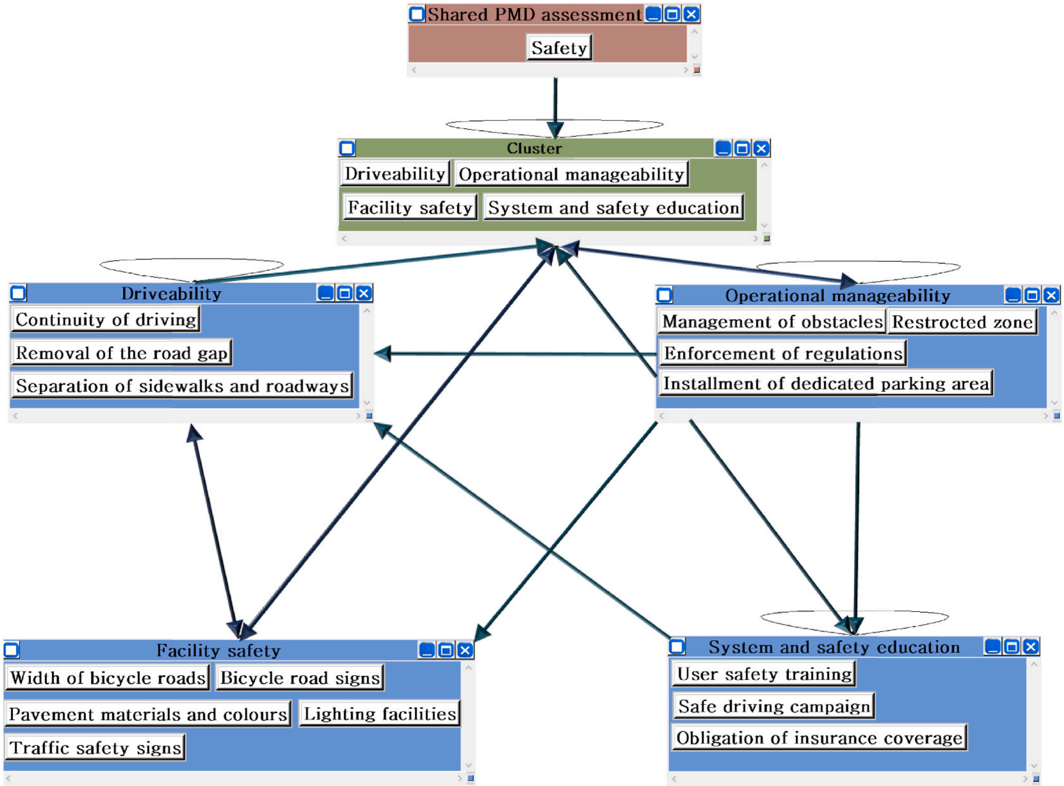

Fig. 3. Diagram of ANP survey network (Super Decisions ver. 2.10).

their network structure.

A preliminary study and an expert survey were conducted to derive the evaluation factors. A *t*-test on the derived factors was performed to select the ultimate significant factors. An expert discussion was carried out to verify the evaluation factors and the correlations between the selected evaluation factors. The correlations, which were confirmed by two-thirds of the experts who had joined the expert discussion, were reviewed and used to establish networks of evaluation factors. The Super Decisions (ver. 2.10) software programme was used to perform the modelling of the established networks in the form of a diagram. Surveys were conducted among PMD users and non-users to evaluate the significance of the driving environment for PMDs and the priority of each environment based on the collected survey data. The safety-focused driving environment for shared PMDs was extensively analysed, which was not examined in previous studies. The initial evaluation factors were selected after considering the evaluation factors used in previous studies and reflecting on the characteristics of the driving environment for shared PMDs. To verify the fitness of the evaluation factors, this study surveyed 31 South Korean experts who evaluated the factors based on a five-point Likert scale. The survey's participants included currently employed workers, researchers, and professors who had obtained a master's degree or higher in urban or traffic studies and had expertise in the assessment of evaluation factors.

The 26 initial evaluation factors were sorted and classified based on the driving environment for PMDs. Subsequently, a sample *t*-test was conducted to determine the fitness of the initial evaluation factors. Responses of 3 (neutral) or higher points on the Likert scale were evaluated to satisfy the fitness level and were restructured as the evaluation factors. Evaluation factors that did not meet this criterion were excluded from the final selection of evaluation factors. Moreover, this study integrated and simplified evaluation factors to prevent survey participants from becoming fatigued due to an excessive number of questions in the pairwise comparison process. The final selection of 15 evaluation factors was divided into four top factors according to their functions, as shown in Fig. 3. Next, expert interviews were conducted to evaluate correlations between the 15 factors and show the factors' networks in the form of a diagram. Nine researchers and professors in the field of urban studies verified the correlation between the evaluation factors. In the correlation evaluation process, the experts were asked to indicate 'O' when they thought a certain evaluation factor affected the other factors, respectively. Based on this assessment method, this study intuitively analysed correlations between the evaluation factors. It considered only correlations of evaluation factors that were confirmed by a majority (six or more) of the participants. It developed a network syntax by reflecting the identified correlations of evaluation factors, as depicted in Fig. 3.

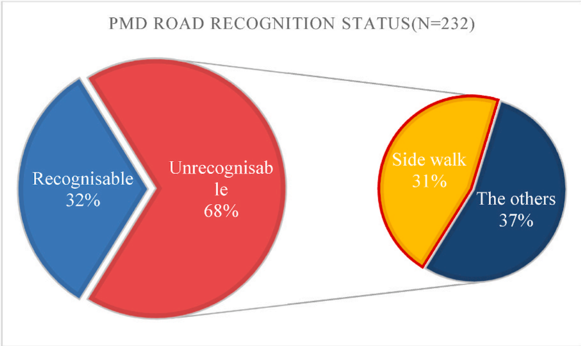

Fig. 4. PMD road type recognition.

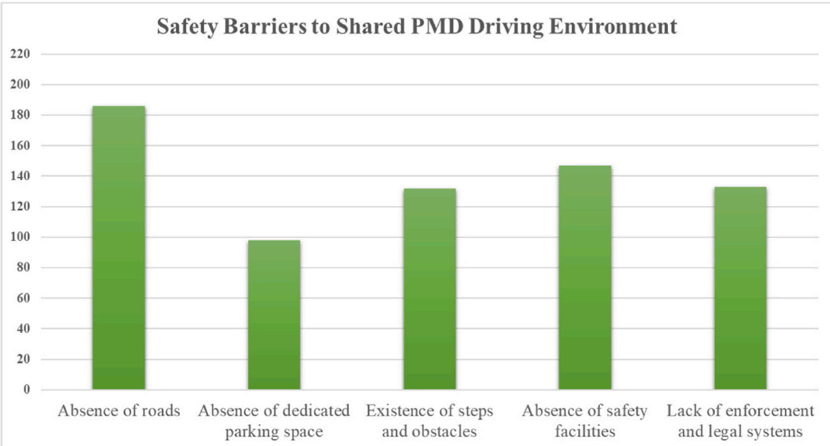

Fig. 5. Barriers to shared PMD safety.

4. Results

4.1. Survey overview

This study conducted surveys based on the views of urban and traffic experts and ordinary citizens. As many experts do not have experience in using shared PMDs, this study recruited experts related to PM to obtain reliable data. Survey participants in their 20s accounted for the largest proportion of the sample. In addition, 72% of the participants responded that they had experience of using shared PMDs; 52% of the PMD users used electric kick scooters; 14% used electric bicycles; and 34% used both electric kick scooters and electric bicycles. As for awareness of roads for PMDs, only 32% of the respondents correctly knew that PMDs could be used in both bicycle and car lanes. A noteworthy result was that 31% of the respondents incorrectly identified sidewalk pavements as drivable for the PMDs. This ratio was similar to that of respondents who correctly recognised drivable roads for PMDs (Fig. 4).

Users have difficulty in accurately recognising policies on the operation of PMDs due to the frequent revisions of the law over a short period and the approval of driving PMDs on bicycle roads, which was approved within two years of the promotion of PMDs. Moreover, the PMD driving environment in South Korea makes it difficult for people to use PMDs on bicycles and public roads. As a result, they frequently resort to driving their PMDs on the sidewalk pavement, which confirms the validity of the current survey's results. In terms of barriers to the driving environment for shared PMDs, the absence of suitable roads was selected as the most problematic barrier. In other words, most respondents considered the lack of infrastructure in the physical driving environment for shared PMDs to be a significant safety risk. The second most problematic barrier was an absence of safety facilities, followed by steps and other obstacles, and a lack of enforcement and a legal system. The absence of a dedicated parking space was the least problematic barrier (Fig. 5).

As for barriers against use of shared PMDs, most respondents selected poor driving environment as the most problematic barrier, followed by a preference for other transport modes, PM driving inexperience, rate system dissatisfaction, and service areas that are not suitable. Unsuitable service areas were the least problematic barrier because the promotion of shared PM resulted in a wide range of services for the use of PMDs in cities. The poor driving environment, which was selected as the most problematic barrier, indicates that the level of relevant infrastructure was lower than the availability of shared PMDs (Fig. 6).

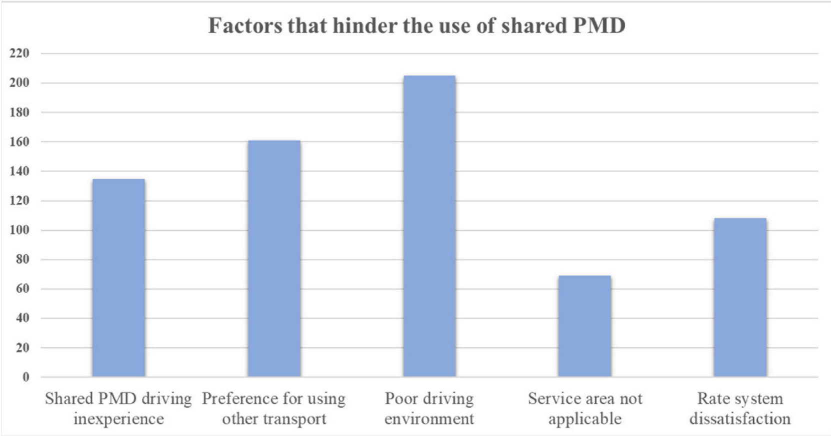

Fig. 6. Hinder the use of shared PMD.

4.2. ANP analysis

This study analysed the importance of evaluation factors for the PMD driving environment based on a modelled network map. It presented the analytic results according to the experience of survey participants in using shared PMDs to examine the difference in the importance of driving environment factors according to the status of the use of shared PMDs. Table 3 shows the responses of shared PMD users. Prior to important analysis, the sum of the top factors in analytic results becomes 1. Likewise, the sum of the evaluation factors that belong to the same top factor also becomes 1. Weight to a top factor affects evaluation factors that belong to the top factor. A limiting cluster is used to calculate the overall weight and determine the ranking of evaluation factors based on their calculated weight. The analytic results of the importance of evaluation factors indicated that driveability had the highest importance value (0.55479), followed by facility safety (0.35149), operational manageability (0.06755), and system and safety education (0.02618). With regard to driveability, continuity of driving had the highest important value, followed by separation of sidewalks and roadways and removal of the road gap.

In terms of the overall order of priority, evaluation factors that were associated with driveability were ranked 1, 2, and 3 because driveability exhibited great internal and external dependence due to evaluation factors that belonged to other clusters and feedback effects. Evaluation factors that were associated with facility safety were ranked 4, 5, 6, 7, and 8 because the survey's participants placed a higher priority on the enhancement of the physical environment than on operational management and system and safety education. Table 4 shows the analytic results of the importance of the evaluation factors for the PMD driving environment based on respondents who had never used shared PMDs. The results show that the weight of the top factors for non-users was similar to that of shared PMD users. Driveability and facility safety showed high importance values of 0.55104 and 0.33868, respectively. This result was derived because these top factors influenced other factors due to internal and external dependence on the network map.

Table 3
Importance value for shared PMD user (Super Decisions ver. 2.10).

Top factor	Normalised by cluster	Assessment factor	Normalised by cluster	Limiting	Inter priority	Priority
Driveability	0.55479	Continuity of driving	0.45649	0.2533	1	1
		Removal of the road gap	0.17195	0.0954	3	3
		Separation of sidewalks and roadways	0.37155	0.2061	2	2
Facility safety	0.35149	Width of bicycle roads	0.19241	0.0676	3	6
		Pavement materials and colours	0.24184	0.0850	2	5
		Bicycle road signs	0.18580	0.0653	4	7
		Lighting facilities	0.12078	0.0425	5	8
		Traffic safety signs	0.25917	0.0911	1	4
Operational manageability	0.06755	Management of obstacles	0.17999	0.0122	4	12
		Enforcement of regulations	0.26861	0.0181	2	10
		Restricted zones	0.22556	0.0152	3	11
		Installment of dedicated parking area	0.32583	0.0220	1	9
System and safety education	0.02618	User safety training	0.45745	0.0120	1	13
		Safe driving campaign	0.17832	0.0047	3	15
		Obligation of insurance coverage	0.36424	0.0095	2	14
	1.0000			1.0000		

Table 4
Importance value for shared PMD non-user (Super Decisions ver. 2.10).

Top factor	Normalised by cluster	Assessment factor	Normalised by cluster	Limiting	Inter priority	Priority
Driveability	0.55104	Continuity of driving	0.46544	0.2565	1	1
		Removal of the road gap	0.11813	0.0651	3	6
		Separation of sidewalks and roadways	0.41643	0.2295	2	2
Facility safety	0.33868	Width of bicycle roads	0.24352	0.0825	2	4
		Pavement materials and colours	0.24803	0.0840	1	3
		Bicycle road signs	0.18258	0.0618	4	7
		Lighting facilities	0.11283	0.0382	5	8
		Traffic safety signs	0.21304	0.0722	3	5
Operational manageability	0.07572	Management of obstacles	0.15899	0.0120	4	13
		Enforcement of regulations	0.32307	0.0245	1	9
		Restricted zones	0.21999	0.0167	3	12
		Installment of dedicated parking area	0.29795	0.0226	2	10
System and safety education	0.03457	User safety training	0.5323	0.0184	1	11
		Safe driving campaign	0.1385	0.0048	3	15
		Obligation of insurance coverage	0.32919	0.0114	2	14
	1.0000			1.0000		

Operational manageability and system and safety education showed importance values of 0.07572 and 0.03457, respectively. Based on these values, non-users applied greater weight to system and safety education than shared PMD users.

Fig. 7 shows the ANP results for driveability and facility safety based on experience in using shared PMDs. As for driveability, shared PMD users placed the greatest importance on continuity of driving, followed by the separation of sidewalks pavements and roadways, and resolving the road gap. Non-users also ranked the evaluation factors associated with driveability in the same order; however, the importance value (0.0651) of resolving the road gap was significantly lower than other evaluation factors. In terms of facility safety, both users and non-users selected pavement materials and colours as the most important evaluation factors. Traffic safety signs, which showed a similar importance value to pavement materials and colours, were selected as the most important evaluation factor for shared PMD users. Bike lane width was determined as the second most important factor for non-users.

As for operational manageability, the importance of evaluation factors clearly varied between shared PMD users and non-users. Shared PMD users placed the greatest importance on dedicated parking areas (0.32583), whereas non-users prioritised enforcement of regulations (0.32307). This result indicates that shared PMD users considered the expansion of infrastructure for PMDs more important for safety. Non-users regarded the enforcement of regulations as more important than other evaluation factors as they contributed to the development of a safe environment for the operation of PMDs. Both shared PMD users and non-users selected the management of obstacles as the least important evaluation factor. Furthermore, non-users gave less weight to the management of obstacles than shared PMD users (Fig. 8).

As for system and safety education, there was no significant difference between shared PMD users and non-users. Specifically, both shared PMD users and non-users placed the least importance on system and safety education among the top importance factors, regardless of their experience in using shared PMDs. User safety training had the highest importance value, followed by the importance

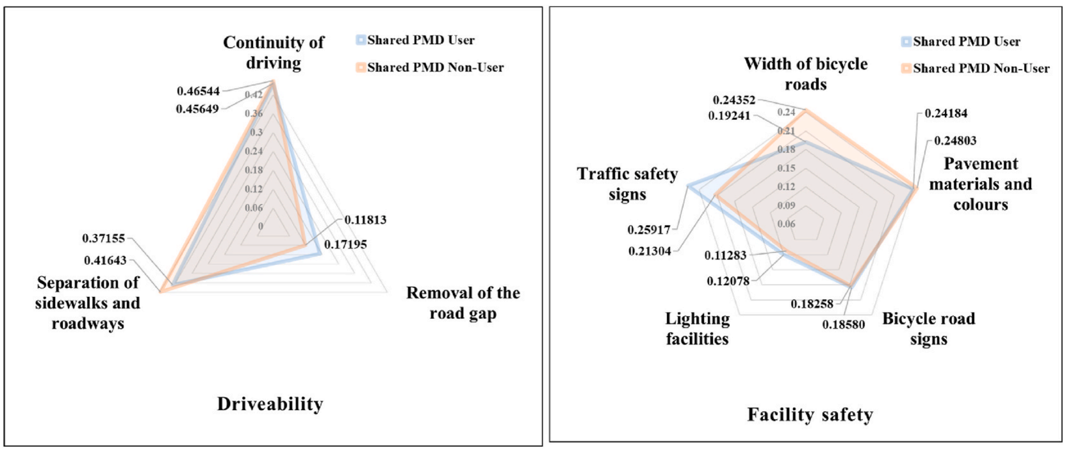

Fig. 7. Comparison weights of elements (driveability and facility safety).

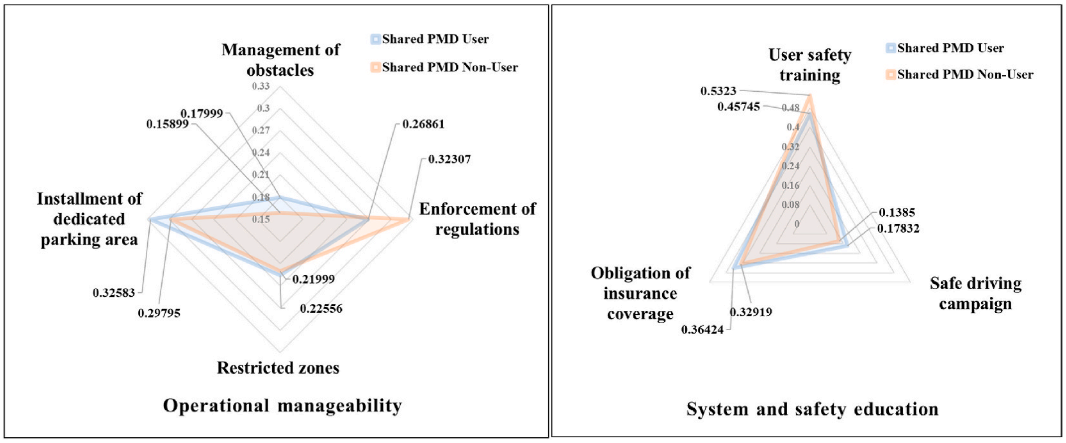

Fig. 8. Comparison weights of elements (operational manageability and system and safety education).

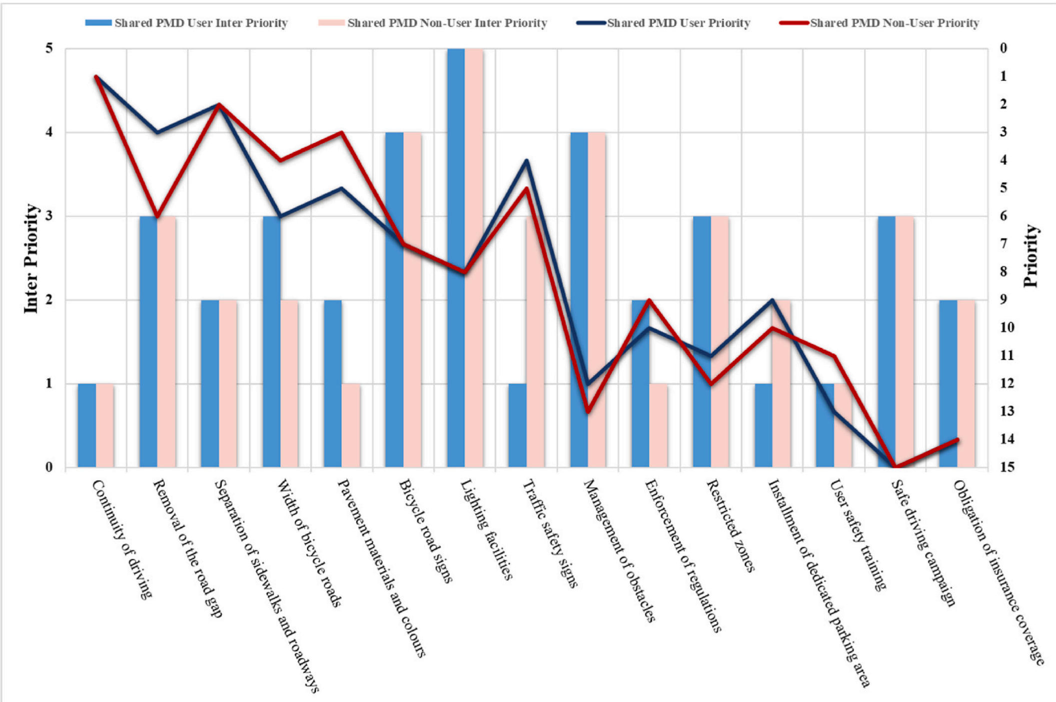

Fig. 9. Priority of assessment.

of insurance coverage and a safe driving campaign. However, when these importance values were compared with the all importance values, which were derived by multiplication with a weight of top factors, the overall order of priority varied (Fig. 9.).

5. Discussion

This study found that the importance of the top factors did not differ significantly by experience in using shared PMDs because of the significant influence of internal and external dependence. Both shared PMD users and non-users placed a great importance on driveability and facility safety, both of which are associated with the physical environment. They also gave low importance values to operational manageability, and system and safety education, both of which are associated with non-physical elements. Specifically, shared PMD users applied a greater weight to driveability and facility safety than non-users, although the difference was slight.

This study compared all the evaluation factors based on users' experiences of using shared PMDs. The results showed that the importance of each evaluation factor varied according to whether the participants were shared PMD users or non-users. For instance, non-users selected bike lane width as the second most important evaluation factor and resolving the road gap as the sixth most important evaluation factor, while shared PMD users selected resolving the road gap as the third most important evaluation factor, and thus placed greater importance on this evaluation factor than non-users did. This result indicates that the width of bike lanes did not significantly affect the driving of PMDs as long as a certain standard for the width of bike lanes was satisfied. Shared PMD users placed less importance on bike lane width than non-users and considered resolving the road gap more important than bike lane width. As PMDs have small wheels and do not have a frame that can protect PMD users, PMD users tend to be affected by the road gap more critically while driving and find it difficult to maintain a certain driving speed. Thus, it can be inferred that shared PMD users place greater importance on resolving the road gap to ensure a safe PMD driving environment.

Furthermore, non-users assigned a higher rank to the enforcement of regulations (9th) than shared PMD users (10th). Non-users placing higher priority on this evaluation factor indicates that they were more likely to recognise PMDs as a threat. Although the South Korean government enacted laws on fines and safety obligations related to the operation of PMDs, practical enforcement rarely occurs. In practice, failure to implement these laws has led to the careless driving of PMDs on every type of road and an increase in the general public's negative perceptions of PMDs. From the perspective of shared PMD users, regulations can be regarded as both measures for increasing safety and elements that hinder the use of PMDs. This perception of shared PMD users explains why non-users place greater importance on the enforcement of regulations than shared PMD users. In addition, shared PMD users gave the highest importance value to dedicated parking areas among the elements that reflected operational manageability. This result indicates that shared PMD users expressed a higher demand for dedicated parking areas for the safe use of PMDs [18,53]. Last, the management of obstacles was ranked higher by shared PMD users (12th) than by shared non-users (13th) because obstacles exerted a direct effect on the driving safety of shared PMD users.

A number of previous studies have also mentioned the need to develop effective strategies and management for travel behaviour and driving environment in shared PMD [31,51]. In this study, the difference in importance for user experience was further identified through ANP analysis. The dependencies between evaluation factors were considered, and it was found that the importance between clusters did not show any significant difference according to the user experience. From a user's point of view, strengthening regulations and crackdowns is also a factor to be reflected, but it was an expected result that was less important than infrastructure. In the case of non-users, strengthening regulations and education was evaluated as important compared to users. Previous studies have also shown that non-users are more anxious about safety when interacting on the road, which is similar to the expected results of raising their voices about stricter regulations [47]. In order to create a safe driving environment, user and non-user could be coordinated together and flexibly responded to each target environment. It means that even in urban planning, it should be discussed together at an early stage to accommodate shared PMDs.

6. Conclusion

This study analysed the importance of evaluation factors in the PMD driving environment. To this end, the study investigated fitness and correlations between the evaluation factors by applying the ANP methodology and using the Super Decisions programme to model the networks of evaluation factors. The results showed that driveability and facility safety were the most important factors. In addition, operational manageability and system and safety education were ranked comparatively low. The results are in line with, who found that safety education was the least advantageous solution and that enhanced infrastructure was the most advantageous solution [10]. Moreover, this study found that the relative importance of evaluation factors differed between PMD users and non-users.

This study examined priorities in evaluation factors based on the interests of PMD users and non-users within the limited environment, which includes public roads for motorised vehicles and sidewalks [18]. Shared PMD users and non-users ranked several evaluation factors for PMD driving safety differently according to whether they regarded PMDs as a dangerous means of transport or as a threat that could cause a collision. Thus, the perspectives of both shared PMD users and non-users should be considered concurrently to establish a safe shared PMD driving environment. This study proposes an order of priority on evaluation factors, which could be applied to enhance the shared PMD driving environment and policies. The South Korean government should gradually expand shared PMD infrastructure based on the priorities identified and ranked by this study and develop laws and systems to improve existing infrastructure.

Deveci et al. stated that governments should promote the implementation of Shared PMDs based on appropriate restrictions on the authority for use of shared PMDs and discussions with shared PMD providers in accordance with present circumstances instead of recklessly adopting these devices [10]. Reck and Axhausen reported that an excessive number of PMDs increased short-term CO_2 emissions and hindered safety in the limited urban environment [6]. In this regard, the central and local governments should pay attention when approving shared PMD operators and 'users' licences [17].

Finally, this study answers the two questions and suggests the following.

Q1) Is shared PMD a dangerous existence considering that it shares the driving environment with other means? Rather, are you in danger?

A1) As shared PMDs expanded rapidly, existing roads saturated with other means were shared. In the process, it was left without any action or restrictions so that it could be used not only on car roads, but also on all types of roads such as bicycle tracks and sidewalks. Even after the regulation is established, it is difficult for users to implement laws due to regulations that are not properly recognised and far from the actual driving environment. Shared PMDs are exposed to collision problems between various means due to high speed and unauthorised storage, which has become a danger to pedestrians, cyclists, and motorists at the same time. As a result, is safety for the driving environment of shared PMD secured? The question is the fundamental reason why the study was conducted.

Q2) Does the improvement of the driving environment of shared PMD differ in priority according to the user experience?

A2) Since the introduction of shared PMDs, related traffic accidents have increased, and it is recognised as a threat if limited roads are shared without improving the driving environments. In fact, regulations and status of each country are applied differently, and there is a lack of awareness of other regulations and education, which further causes important traffic problems in the city. However, it cannot be denied that it is a convenient means by facilitating transfer to other means by appropriate means for the first mile/last mile. In order to promote convenient transfer between other transport, but to reduce the possibility of collision and improved individual safety, sustainable environmental improvement should be supported. In fact, it is expected that there will be many conflicts in decision-making as well as considerable time for infrastructure expansion and legislation, so it is necessary to understand the difference in perception depending on the user experience of shared PMD. Environmental improvement includes both physical and non-physical improvements, so this study compares similarities and differences according to importance differences, and suggests that problems can be recognised and anticipated in actual decision-making, and applied differently depending on the environment.

This study has a limitation that it did not quantitatively analyse the effects of factors in the practical PMD driving environment that contribute to traffic accidents. Further research should be conducted to overcome this limitation. Further research applying a quantitative analysis method will provide effective data for decision-making and policy implementation [35,54]. In practical terms, the expansion of infrastructure will require a considerable budget, time allocation, and a decision-making process that includes citizens and interested parties with sufficient discussions based on users' and non-users' priorities [37]. It was found that the difference in perception divided according to the use experience of shared PMD. The results showed that shared PMD driving safety should be prioritised in the process of establishing plans and policies on shared PMDs. In the case of users, it is more important to expand infrastructure such as installing signatures and installing parking areas for safety, while for non-users, it is more important to limit and regulation, indicating that perception based on their experience is an important basis for judgment. Therefore, it is anticipated that the findings of this study will serve as the foundation for policy implementation and decision-making related to shared PMDs. In order to introduce policies for safe shared PMD in the future, it is necessary to listen to and establish the opinions of these citizens, and it is judged that related research is necessary.

In this study, the responses of both users and non-users were collected for the difference in driving environment perception according to the use experience, and it was determined by considering the demographic characteristics of previous studies in the sampling process. The sampling method was based on the assumption that even a small number of samples can represent the characteristics of the population as the characteristics of the respondents aligned with those of previous studies. However, in this process, the discussion on statistical significance was insufficient, and it was replaced by limiting the effective number through consistency analysis in ANP. In the future, it is considered necessary to conduct additional verification including various classes when making actual policies.

Author contribution statement

Min Kyoung Cho: Conceived and designed the experiments; Performed the experiments; Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Min Gu Kang: Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Youngsang Kwon: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

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Appendix D. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.heliyon.2023.e13615.

Appendix

Appendix A. Assessment suitability t-test

Evaluation elements	Average	Standard deviation	t-value	p-value
Continuity of driving	4.161	0.898	7.2	2.58E-08
removal of the road gap	3.645	1.198	2.997	0.002715
Separation of sidewalks and roadways	3.967	0.982	5.483	2.97E-06
Mounting composition	3.322	0.944	1.901	*0.03346
Ensuring safety from vehicles	4.483	0.769	10.743	4.19E-12
Ensuring safety from pedestrians	4.612	0.615	14.596	1.80E-15
Type of bike lanes	3.677	1.107	3.406	0.000945
Width of bicycle roads	4.129	0.805	7.800	5.26E-09
Packaging materials and colours	3.548	1.027	2.971	0.002895
Backward driving prevention guide	3.580	1.336	2.419	*0.01089
Bicycle road signs	3.580	1.204	2.683	0.005873
Entry prevention facilities	3.806	1.166	3.848	0.000289
Lighting facilities	3.774	1.023	4.212	0.000106
Visual guidance facilities	3.290	1.039	1.555	*0.06512
Traffic safety signs and road surface markings	4.387	0.803	9.615	5.66E-11
PM driving information sign	4.064	1.030	5.750	1.40E-06
Active maintenance	4.451	0.888	9.097	1.97E-10
Management of obstacles	4.064	0.813	7.282	2.07E-08
Maintenance of parking facilities	3.870	1.024	4.733	2.46E-05
Enforcement of regulations	4.161	1.067	6.056	5.95E-07
Restricted zone	4.064	1.181	5.016	1.11E-05
Installment of dedicated parking area	4.129	1.087	5.780	1.29E-06
User safety training	4.129	1.117	5.623	2.00E-06
Safe driving campaign	4.064	1.152	5.141	7.81E-06
Obligation of insurance	3.838	1.213	3.847	0.000289
Expansion of insurance coverage	3.870	1.231	3.938	0.000226

Appendix B. Correlation analysis (Shaded area correlated)

Assessment factor	Cluster				Node														
	Driveability	Facility safety	Operational manageability	System and safety education	Continuity of driving	Removal of the road gap	Separation of sidewalks and roadways	Width of bicycle roads	Pavement materials and colours	Bicycle road signs	Lighting facilities	Traffic safety signs	Management of obstacles	Enforcement of regulations	Restricted zones	Installment of dedicated parking area	User safety training	Safe driving campaign	Obligation of insurance coverage
Driveability		33.3	22.2	0.0	66.7	44.4	44.4	33.3	33.3	44.4	22.2	33.3	33.3	22.2	11.1	0.0	11.1	0.0	11.1
Facility safety	88.9		22.2	44.4	88.9	11.1	33.3	22.2	33.3	55.6	66.7	66.7	22.2	33.3	44.4	22.2	44.4	44.4	33.3
Operational manageability	88.9	66.7		22.2	77.8	0.0	22.2	11.1	55.6	55.6	33.3	44.4	66.7	77.8	44.4	44.4	22.2	33.3	33.3
System and safety education	44.4	22.2	66.7		33.3	0.0	0.0	11.1	11.1	11.1	11.1	11.1	22.2	44.4	22.2	11.1	66.7	66.7	33.3
Continuity of driving	100.0	33.3	22.2	22.2		22.2	22.2	33.3	44.4	22.2	22.2	44.4	44.4	22.2	33.3	0.0	22.2	22.2	22.2
Removal of the road gap	100.0	66.7	11.1	11.1	88.9		44.4	44.4	77.8	22.2	11.1	55.6	44.4	0.0	11.1	0.0	33.3	22.2	22.2
Separation of sidewalks and roadways	88.9	55.6	22.2	22.2	88.9	22.2		66.7	77.8	77.8	0.0	88.9	33.3	33.3	11.1	0.0	22.2	22.2	0.0
Width of bicycle roads	88.9	100.0	44.4	22.2	100.0	11.1	33.3		33.3	33.3	22.2	22.2	22.2	11.1	33.3	11.1	22.2	22.2	22.2
Pavement materials and colours	100.0	88.9	44.4	22.2	100.0	55.6	77.8	11.1		11.1	11.1	44.4	22.2	0.0	11.1	11.1	33.3	22.2	0.0
Bicycle road signs	77.8	100.0	55.6	44.4	55.6	11.1	55.6	22.2	0.0		22.2	33.3	22.2	44.4	22.2	11.1	33.3	22.2	0.0
Lighting facilities	77.8	100.0	33.3	22.2	66.7	0.0	0.0	0.0	0.0	44.4		55.6	22.2	33.3	11.1	22.2	22.2	33.3	0.0
Traffic safety signs	88.9	88.9	44.4	22.2	66.7	0.0	33.3	0.0	22.2	22.2	22.2		33.3	44.4	11.1	0.0	33.3	22.2	11.1
Management of obstacles	88.9	44.4	100.0	11.1	100.0	11.1	0.0	11.1	22.2	11.1	11.1	22.2		22.2	22.2	11.1	22.2	22.2	11.1
Enforcement of regulations	77.8	22.2	88.9	66.7	88.9	0.0	0.0	0.0	0.0	22.2	11.1	22.2	33.3		44.4	33.3	66.7	55.6	44.4
Restricted zones	44.4	33.3	88.9	22.2	88.9	0.0	22.2	33.3	44.4	11.1	11.1	22.2	55.6	66.7		44.4	22.2	22.2	11.1
Installment of dedicated parking area	55.6	11.1	100.0	22.2	88.9	0.0	0.0	22.2	66.7	0.0	22.2	22.2	33.3	55.6	44.4		22.2	33.3	22.2
User safety training	44.4	22.2	44.4	88.9	55.6	0.0	0.0	0.0	22.2	33.3	0.0	33.3	44.4	44.4	22.2	22.2		55.6	44.4
Safe driving campaign	66.7	22.2	33.3	88.9	66.7	0.0	0.0	11.1	11.1	11.1	11.1	22.2	55.6	33.3	0.0	22.2	66.7		55.6
Obligation of insurance coverage	33.3	22.2	33.3	88.9	22.2	0.0	0.0	11.1	11.1	22.2	22.2	22.2	22.2	44.4	33.3	33.3	33.3	22.2	

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