

Article

Identifying the Risk Factors in the Context-of-Use of Electric Kick Scooters Based on a Latent Dirichlet Allocation

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Abstract: Accidents related to electric kick scooters, which are widespread globally, are increasing rapidly. However, most of the research on them concentrates on reporting accident status and injury patterns. Therefore, while it is necessary to analyze safety issues from the user's perspective, interviewing or conducting a survey with those involved in an accident may not return enough data due to respondents' memory loss. Therefore, this study aims to identify the risk factors in the context-of-use for electric kick scooters based on a topic modeling method. We collected data on risk episodes involving electric kick scooters experienced by users in their daily lives and applied text mining to analyze text responses describing the risk episodes systematically. A total of 423 risk episodes are collected from 21 electric kick scooter users in South Korea over two months from an online survey. The text responses describing risk episodes were classified into nine topics based on a latent Dirichlet allocation. From the result, four risk factors can be identified by analyzing the derived topics and the cause of the risk according to the context. Moreover, we suggested design improvement directions. This study can be helpful for designing safer electric kick scooters considering safety.

Keywords: electric kick scooter; safety; context-of-use; ergonomic design; topic modeling

1. Introduction

Electrification has replaced the internal combustion engine, given power to non-powered products, introduced personal means of transportation, and is bringing about a variety of changes in our lives. In various forms, personal mobility devices (PMDs) are being developed for conventional vehicles (e.g., cars, bikes, or kick scooters) or novel vehicles (e.g., self-balancing boards, one-wheels, or hoverboards) [1–3]. Among these, products such as electric kick scooters enmeshed in the Internet of things (IoT) are rapidly distributed as shared services [4].

Although PMDs have been increasingly distributed due to their advantages of reducing transportation costs and providing convenient means to use information and communication technology (ICT), PMD-related traffic accidents and those caused by product failures are also rapidly on the rise [3,5–7]. In the emergency departments of two downtown hospitals in Indiana, 92 patients reported injuries from electric kick scooters in 61 days in 2018, while no injuries from electric kickboards were reported in the same period in 2017 [4]. At a hospital in South Korea, which had more than 100,000 patients annually, the number of PMD-related accidents tripled from 14 in 2016 to 51 in 2017 [6].

Due to the increasing number of accidents, efforts are needed to ensure the safety of PMDs in terms of research, industry, and society. However, existing studies on PMD mainly focus on functional areas

or only report the status of PMD-related accidents. Noguchi and Jeong [8] studied the center-of-gravity shifting ability and the patterns of stand-lining-type self-balancing PMD users, and Yokota et al. [9] studied how to design PMDs to rotate naturally by analyzing patterns of rotation like how a person walks. Dozza et al. [10] studied electric bicycle use in Europe and analyzed risk events to identify the differences between conventional bicycles and electric bicycles, and Bai et al. [11] investigated the risk cases related to PMDs such as electric bicycles and electric scooters, but both studies could be seen as reporting on the phenomenon rather than revealing the cause of the risk and suggesting improvements. However, although many recent studies have been conducted on electric kickboards, most only report accident sites or give medical descriptions of accident situations [1,4,6,7]. Moreover, PMD-related accidents occur even when a product is being charged or carried [12], but most studies address accidents in driving situations.

While the proportion of electric kick scooters among PMD products worldwide is considerable, and accidents related to electric kick scooters are increasing, insufficient studies analyzed the users' actual cases of electric kick scooter-related risks. To understand the safety issues and find solutions accordingly, research from a user-centered perspective is needed to explore the factors that hinder safety. Although studies that analyzed actual user behavior in the studies mentioned above, there are lacking studies that comprehensively reflect the environmental factors of PMD use and the product factors of PMDs. Further, to understand users' risk episodes, it is practical to analyze the participants' textual responses describing the risk episodes. However, because electric kickboard users experience various categories of risk episodes, the manual work of reading and analyzing many responses directly had limited success [13–17].

Therefore, this study collected the actual cases experienced by users to conduct research from the user's perspective, to understand and analyze the context related to the safety of electric kick scooters. We provided an online form for participants to respond to comfortably and then applied text mining to systematically analyze a large number of responses. Moreover, among various text mining analysis methods in popular use (e.g., word cloud, bag of words, or association rule analysis), we applied latent Dirichlet allocation (LDA) topic modeling to understand the context of risk episodes and to extract risk factors [18,19]. Finally, in this study, episodes of actual electric kick scooter use—as the most frequently used PMD and the most frequently involved in accidents—were collected using a diary method. By analyzing the users' responses, composed in their own words, using topic modeling, risk factors were explored in real-world risk episodes. Then discussing the derived risk factors and suggesting further research and solutions to alleviate the risk, we intend to contribute to enhancing the electric kickboard's safety.

2. Related Work

To improve the safety of the electric kickboards, this study explored the context-of-use surrounding the use of electric kickboards based on user-centered design methodology. The diary survey methodology was applied to investigate the risk cases experienced by electric kickboard users among the various user inquiry methodologies. LDA topic modeling was used to analyze the collected text responses. In this regard, the introduction of each methodology and related studies are as follows:

2.1. User-Centered Design for Safety

Product safety is frequently studied in user-centered design research as a factor of usability and user experience (UX); it is also treated as a usability factor in relevant standards [20,21]. Systematic exploration of various use context factors related to a product can be an effective way to analyze safety inhibitors and find improvement measures. Seol [22] confirmed that safety affects hand tools' perceived usability in a study on injuries experienced by users, and Wegge and Zimmermann [23] revealed the importance of usability and safety in product design. In this study, safety issues related to electric kick scooters were understood and analyzed using the framework of the context of use to find the risk factors and suggest ways to improve the products. Figure 1 below shows the composition of

the context-of-use covered in ISO 9241-210 and ISO 20282-1 [24,25]. To confirm the safety of electric kick scooters, we focused on the effects of contextual factors in Figure 1, identifying the risks experienced by various users in terms of product factors and environmental factors.

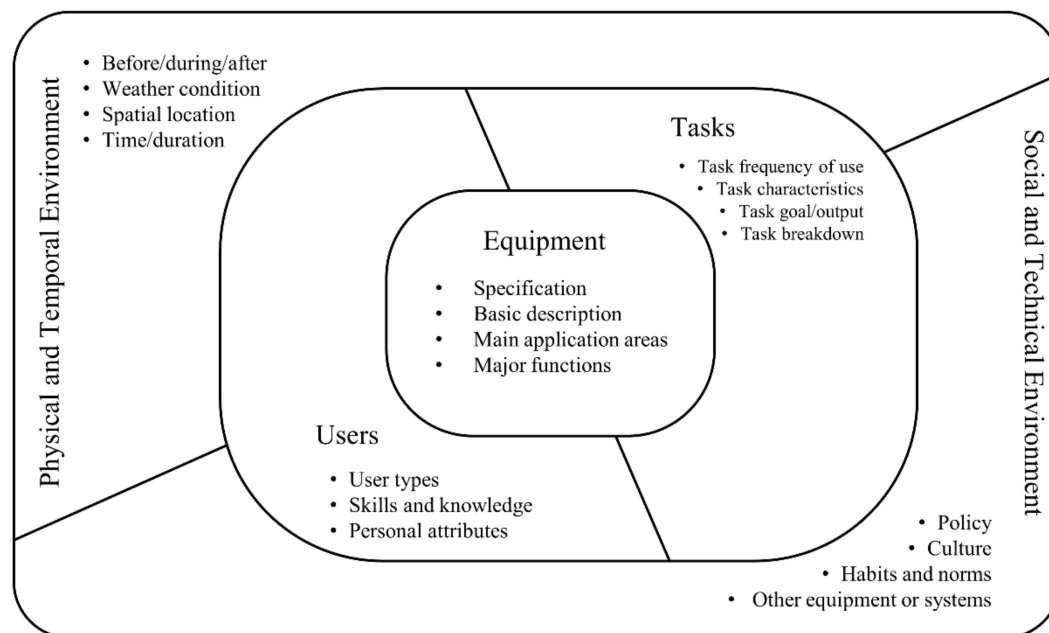


Figure 1. Context of use based on ISO 9241-210 and ISO 20282-1.

2.2. Diary-Based Approach

In this study, risk factors were extracted by collecting data on the risk episodes experienced by electric kick scooter users. Out of methods such as interviews, questionnaires, and observations, this study utilized a diary recording method in which episodes that occurred in a certain period were immediately recorded. This methodology takes longer to conduct than other survey methods but has the advantage of minimizing the memory loss of respondents and of being able to capture the frequency or rate of events of interest in a specific period, allowing various analyses [26–28].

Researchers have established the usefulness of the diary recording method, applying it to conduct user surveys. Karapanos et al. [29] investigated how users' UX with iPhones changed over five weeks, and Ayuso-Mateos et al. [30], using the day reconstruction method and targeting respondents from different countries, studied how well-being differs in countries. Most such studies using the diary recording method are common in that the survey items were selected according to the purpose of the study to immediately collect data on any episodes that occurred. Though these studies dealt with small samples of people, they had overcome the data scale issues by collecting records for several weeks [29–32].

This study aims to clarify the context factors such as the product and environmental factors that caused danger when using an electric kick scooter. Therefore, it is necessary to collect various responses necessary for understanding the context of risk episodes. The electric kick scooter characteristically involves changes in the environment or product status during the boarding process that make it difficult for the user to retain the memory of such context information. Thus, in this study, the context related to daily risk episodes was captured by minimizing the respondents' memory loss through the diary recording method.

2.3. Topic Modeling Using Latent Dirichlet Allocation

LDA topic modeling was used to analyze the electric kick scooter users' descriptions of the risk episodes. LDA is a methodology for deriving a probability model of the topics of specific documents

under the assumption that the frequency of words in a document is determined by predefined probabilities [33]. Through LDA, the topic sentences or keywords that permeate the documents can be extracted by grouping documents with similar meanings.

Tsolmon and Lee [34] used LDA to analyze South Koreans' reactions to major social events that appeared on Twitter. They suggested more reliable tools through timeline-based analysis, including issue extraction using topical modeling, rather than traditional frequency-based analysis because tweets are usually short and noisy. Wang et al. [19] used LDA as a tool for reviewing and studying research on adolescent substance use and adolescent stress. They also applied LDA to 17,723 abstracts published in PubMed and revealed the association links between adolescent substance use and adolescent depression, such as sexual experience and violence, and the risk factors of adolescent substance use, such as family factors and peer networks.

As such, LDA is an established, useful analysis tool for qualitative, unstructured, uncategorized data and unsupervised learning analysis. Although this study only supplies a small amount of data, the LDA application is still appropriate for analyzing the collected risk episodes and extracting relevant issues. This study also classified the types of risk episodes experienced by electric kick scooter users by analyzing their responses describing the episodes. We analyzed the product context, environmental context, and situational reasons why the users experienced risk through this classification.

3. Method

This study collected and analyzed the risk episodes experienced by electric kick scooter users in daily life in three steps, as shown in Figure 2. First, the questionnaire structure was designed to collect the context in which the risk episode occurred. Second, 21 participants recorded their risk episodes online. Finally, the collected responses were analyzed for descriptive statistics, and LDA was applied to each risk episode description item's response text to extract the types of episodes and key issues.

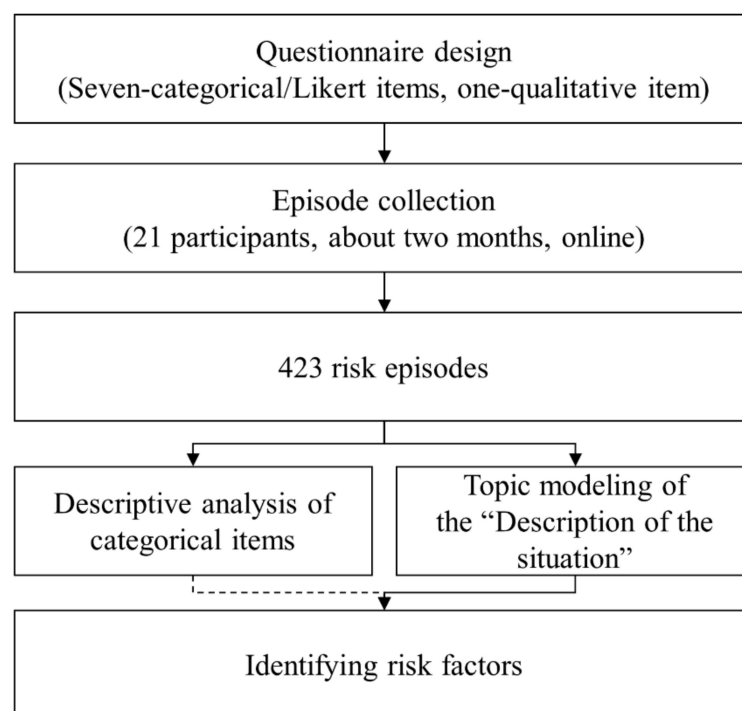


Figure 2. Overall flow of this study.

3.1. Inquiry Method for Collecting Risk Episodes Involving Electric Kick Scooters

The questionnaire items were designed to collect the context of the risk episodes that occurred when using an electric kick scooter. The unit of episodes to be responded was decided based on the features of the interactions between the user and the product as well as the goal of the user. The types of episodes were “driving”, “inspection”, “maintenance”, and “other”. For these four episode types, we defined the context factors that could lead to the risk. With manifold factors in the context of using electric kick scooters, this study mainly focuses on the product and environmental factors illustrated in Table 1.

Table 1. List of product factors.

Product Factors	Environmental Factors
wheels, display, deck, handle, brake, controller (throttle), battery, charger, accelerator, portable handle, saddle, main body and accessories, none	obstacles, weather condition, road type, road surface, slope, brightness, transport environment, parking environment, noise, none

Regarding the product factor, the “normal” and “defect” states are distinguished as follows: if some part of the product is in the “normal” state, it may cause danger under normal operation, and if it is in the “defect” state, its failure may cause danger. Based on the above design, the questionnaire was constructed, as shown in Table 2.

Table 2. Questionnaire structure.

Questions	Description
Type of episode	Type of the episode that occurred while driving, inspecting, during maintenance, or “other”
Date/time/driving distance	Basic information
The accident occurred or not	Whether an accident actually occurred or the danger was only perceived
Perceived dangerous level (PDL)	Perceived danger level on the 7-point Likert scale
Level of the accident	The level of the accident that occurred or might have occurred (some descriptions are given attached to the 7-point Likert scale)
Product factor	The product factor designated as the cause of the risk
Product status	Whether the selected product factor is defective
Environmental factor	The environmental factor designated as the cause of the risk
Description of the situation	Description of the initial situation focused on risk factors

3.2. Data Collection and Data Preprocessing

We recruited a total of 21 electric kick scooter users (average age: 27.86 years; standard deviation: 6.57 years) through electric kick scooter communities in South Korea. The participants reported cases where they experienced risks or accidents while riding or managing electric kick scooters in everyday life for about two months (1 July–28 August 2019). The participants responded to the risk or accident episodes they experienced while using an electric kick scooter using the questionnaire implemented using “Google Spreadsheet”. Our researchers regularly monitored the responses and checked their quality.

Before performing the LDA on the “description of the situation” items, they underwent preprocessing, as shown in Figure 3. For Korean responses, nouns, verbs, adjectives, and adverbs were extracted using the “KoNLPy v0.5.2” package. Subsequently, a dictionary consisting of 1142 words was obtained by removing the words corresponding to stop words, recombining compound words separated by tokenizing, and converting derived words into representative words. After removing words that appeared less than five times, topic modeling was performed using “Gensim LDA”, based on the dictionary’s remaining 201 words.

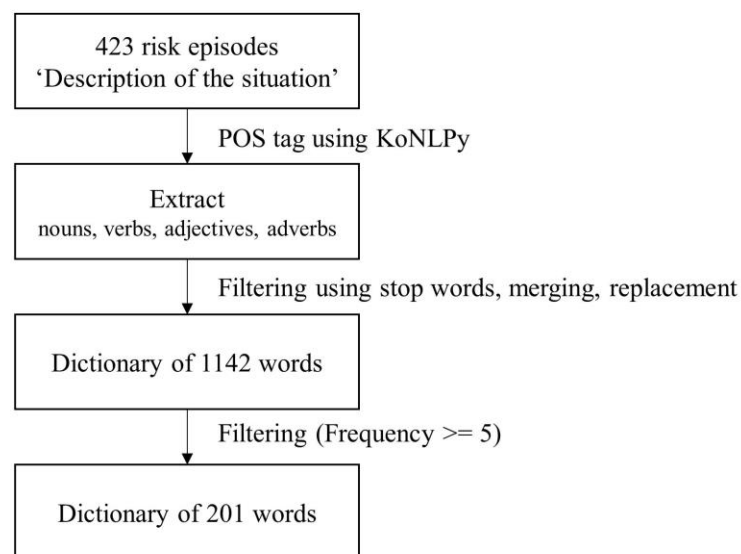


Figure 3. Preprocessing flow for the “description of the situation” item.

3.3. Risk Episode Classification Using Latent Dirichlet Allocation Topic Models

To comprehend electric kick scooter risk episodes, we executed topic modeling on the “description of the situation” item using “Gensim latent Dirichlet allocation (LDA)”, “pyLDAvis 2.1.2”, and “Python 3.8.5”. To search for the optimal LDA model, hyperparameters such as the number of topics passes and alpha were changed, and an appropriate hyperparameter set was selected using the coherence index. Coherence is an indicator of the consistency of the contents of the classified topics. Coherence is a representative intrinsic metric used when topic modeling is performed on data for which the answer to the classification result is not determined.

We obtained two topic-model candidates through the above process and then conducted a qualitative evaluation to determine the final LDA model. The qualitative evaluation reviewed the keywords of the derived topics and assigned actual responses, comparing each model’s topics to assess whether they represent the risk episodes of electric kick scooters. This process finally resulted in the selection of a topic model consisting of nine topics.

4. Results

The collected responses were analyzed and reported, as shown below. These are the descriptive statistical results, which synthesized the inherent characteristics of risk cases experienced by users, and the results of conducting topic modeling on text responses.

4.1. Descriptive Results of Questionnaires

A total of 423 risk episodes were collected from the 21 users over a period of about two months. Average perceived dangerous level, average level of accident, and frequency of each task type are shown in Table 3.

Table 3. Episode distributions relying on the “type of episode”.

Type of Episode	Average PDL	Average Level of the Accident	Frequency	Ratio [%]
Driving	3.12	1.66	310	73.29
Maintenance	2.30	1.43	56	13.24
Inspection	3.37	1.81	43	10.17
Others	1.86	1.36	14	3.31

As seen in Table 4, 36 accidents occurred during the response collection period. Even though no accident actually occurred in the other instances, in these episodes, the participants perceived danger while riding, doing maintenance, or inspecting their scooters.

Table 4. Episode distributions relying on “the accident occurred or not”.

The Accident Occurred or Not	Average PDL	Average Level of the Accident	Frequency	Ratio [%]
Just feel dangerous	2.93	1.62	387	91.49
Accident	3.78	1.81	36	8.51

Figure 4 presents the results of the respondents selecting product factors as the cause of their risk episode. Except for “none” (occurring when the participants did not select a product factor as the cause of the risk), “wheels” was the most selected item, followed by “brake” and “main body”.

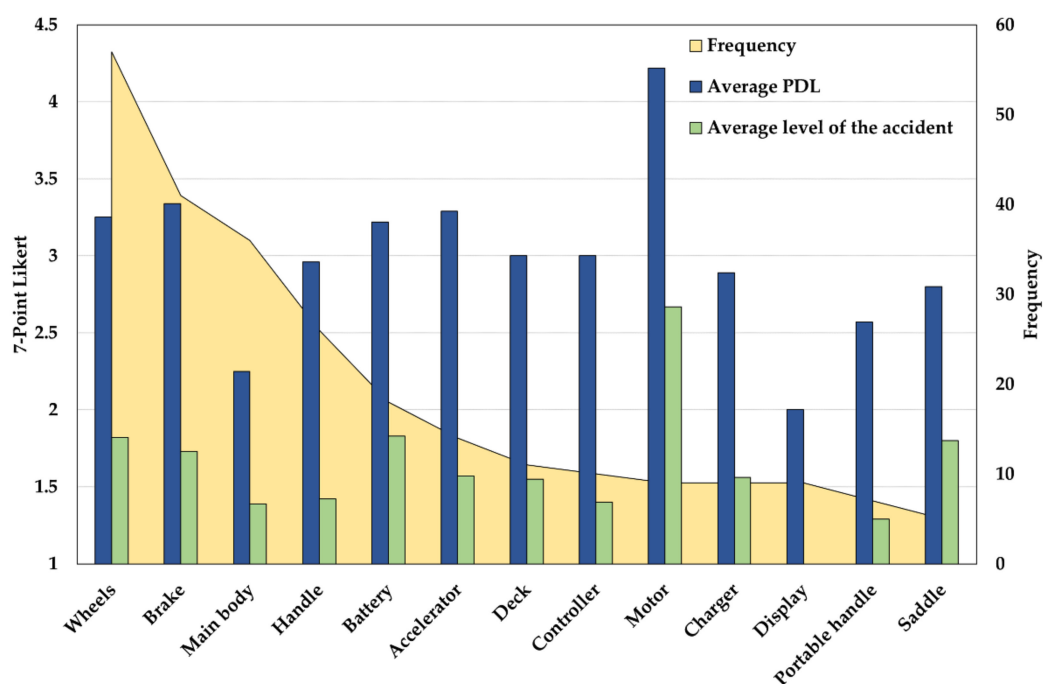


Figure 4. Episode distributions and average scores relying on the “product factor”.

Table 5 reflects the product factor status for the episodes where the respondents chose a product factor as the cause of risk. Based on the selected subfactor, the episodes were classified according to whether the product was in a normal state or was malfunctioning.

Table 5. Episode distributions relying on the “product status”.

Product Factors	Average PDL	Average Level of the Accident	Frequency	Ratio [%]
Normal	3.09	1.64	161	64.66
Defect	2.80	1.52	88	35.34

Figure 5 shows the results of the respondents’ choices of environmental factors as the cause of risk episodes. “none” (occurring when participants did not select an environmental factor as the cause of the risk), “road type” was the most selected item followed by “obstacles”, and “road surface”. Among these, “road type” was chosen when participants felt danger due to the nature of the road environment depending on the type of road, such as along curves, on sidewalks, or in alleys.

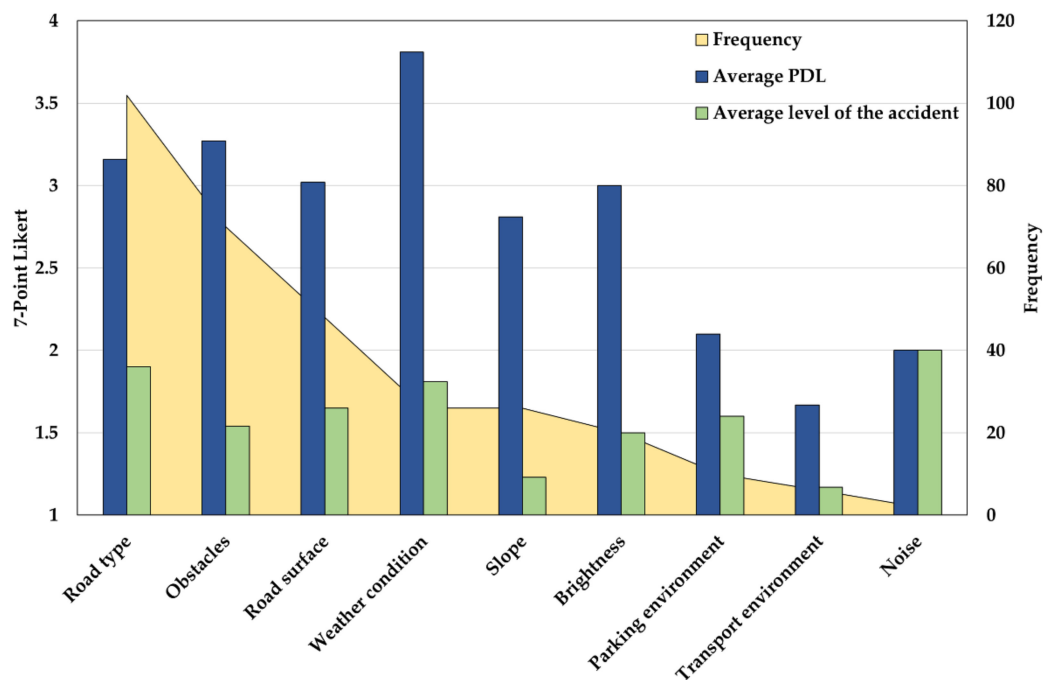


Figure 5. Episode distributions and average scores relying on the “environmental factor”.

4.2. Classification of Risk Episodes Using LDA

For the 423 “description of the situation” items that were collected, topic modeling was conducted as described in Section 3.3. Through the search for the best hyperparameter set, model candidates with high coherence values were determined, and an LDA model composed of nine topics was determined through qualitative evaluation. The coherence value represents the degree of semantic similarity within each topic of the model. During searching for the best hyperparameter set, several parts of speech combinations, the number of topics, and several learning parameters were explored. A value of 0.44 was obtained as the highest coherence value among the various hyperparameter sets. Although it is difficult to say that coherence value is an absolute measure, it is the result of similar processes in standard LDA utilization studies, and there is a precedent that includes similar amounts of data [35,36].

Table 6 shows the nine topics and keywords that construct the selected LDA model. The keywords in each topic were organized into two types, and the top five words were sorted through “pyLDAvis” for 1.0 and 0.2 of lambda (λ). Lambda is a relevance metric; if its value is high, the ranking of keywords is determined by the absolute frequency. Conversely, if the value is low, the keywords that appear relatively more frequently in that topic compared to other topics are ranked higher [37,38]. Table A1 in the Appendix A lists the representative episodes of each topic.

Table 6. Nine topics and keywords of risk episodes classified using latent Dirichlet allocation (LDA).

Topic A (13.7%)	Felt danger from cars or pedestrians that suddenly appeared
Keywords	$\lambda = 1.0$; car, speed, check, road surface, road $\lambda = 0.2$; alley, night, opposite side, invisible, road surface
Topic B (11.8%)	Difficulty driving due to road surface or product condition; Detected problems with parts.
Keywords	$\lambda = 1.0$; wheel, check, battery, air pressure, charge $\lambda = 0.2$; air pressure, fall, rough, entrance, deck
Topic C (11.7%)	Experienced impact from bumps, downhill, pushed brakes, or loosen handlebars
Keywords	$\lambda = 1.0$; wheel, brake, impact, handle, prevent $\lambda = 0.2$; brake, loose, maintenance, pushed, connection
Topic D (11.6%)	Experienced risk of collision on slopes. Threatened by a car.
Keywords	$\lambda = 1.0$; speed, car, lane, detection, stop $\lambda = 0.2$; shoulder, underground, stopped, slope, car way
Topic E (11.5%)	Impact from uneven sidewalk or bumpy road surfaces. Experienced sparks while charging.
Keywords	$\lambda = 1.0$; speed, handle, road, impact, accelerator $\lambda = 0.2$; hand, accelerator, unstable, stem, complex
Topic F (11.1%)	Problems with parts of the electric kick scooter.
Keywords	$\lambda = 1.0$; light, accident, signal, start, speed $\lambda = 0.2$; light, sensitivity, power, start, sudden
Topic G (10.6%)	Sudden decrease in battery voltage. Product malfunction. Risk caused by bumpy or slippery surfaces.
Keywords	$\lambda = 1.0$; voltage, wheel, battery, mode, dual $\lambda = 0.2$; voltage, noise, villa, current, gear
Topic H (9.6%)	Lost balance or perceived danger due to other moving objects.
Keywords	$\lambda = 1.0$; pedestrian road, people, accident, bicycle, road $\lambda = 0.2$; pedestrian, jaywalking, person, saddle, side
Topic I (8.4%)	Felt danger when being overtaken by cars. Felt danger from rainy roads.
Keywords	$\lambda = 1.0$; road, car, lane, rain, fall $\lambda = 0.2$; rain, overtake, fall, lane, report

5. Discussion

The meaning of the analysis results and the methods to improve the electric kickboard safety were discussed as follows: Descriptive statistical analysis provided a basic understanding of the risk situations experienced by electric kickboard users, and specific improvement or research suggestions were discussed based on risk factors extracted using topic modeling results.

5.1. Description of the Collected Risk Episodes

Most participants ride their electric kick scooters every day or more than twice a week and, thus, have ample electric kick-scooter experience in their daily lives. “driving” was the most frequently reported type of risk episode. Most of the episodes were cases of “Just feel dangerous,” which occurred while inspecting the scooter, during maintenance, or while otherwise trying to prevent safety-related problems.

As shown in Figure 4, “wheels”, “brake”, and “main body” were selected as the most dangerous product factors after “none”. Wheels and brakes are essential parts as a means of transportation, and the main body is the central element that constitutes the entire product, so it is natural that these are chosen the most often. Among the risk product factors, “none” was the most commonly chosen one, indicating that environmental factors are at fault. Meanwhile, Table 5 shows that the number of times participants selected a product factor as the risk factor when the product failed is lower than when the product was in its normal, functional state; it can be said that the conventional design form or specifications may not prevent a hazardous situation. Among the hazardous environmental factors in Figure 5, “road type”, “obstacles”, and “road surface” were selected the most after “none”. This is the

same selection of environmental factors that frequently interact when driving an electric kick scooter, and the results are self-evident.

The results shown above have been reported as natural results that can be predicted, to some extent, because the electric kick scooter is a means of transportation. Although the results are meaningful because they are drawn from actual experiences of users of electric kick scooters, it is difficult to determine what caused the respondents to select items as a risk factor. However, these results supported the LDA results for the item describing risk episodes in Section 5.2. They were used as clues for interpretation, contributing to the proposal to enhance electric kick scooters' safety.

5.2. Key Issues Described in the Collected Risk Episodes

Topic modeling was applied to the responses describing the risk episodes, and Table 6 shows the resulting classification. Through a total of nine topics, we were able to identify product elements and environmental factors that caused the risks experienced by the electric kick scooter users. The nine topics of the risk episodes can be further grouped into four categories through qualitative analysis. The aspects of the risks that appeared in each topic could be classified based on the interaction between the product factors, environmental factors, and users that construct the context of using the electric kickboard. Environmental factors could be divided into physical environmental factors and social environmental factors that can be called "other moving entities" such as other vehicle drivers and pedestrians.

The first category involves interaction with other mobile entities, such as cars, pedestrians, bicycles, and motorbikes, and encompasses risk episodes related to collisions while moving on existing roads. As electric kick scooters are a means of transportation, collisions with other moving subjects are an inevitable risk type. Topic A identifies the risk of collision in a dark environment, and Topic H identifies the risk of collision with other mobile entities that suddenly appear. Topics D, H, and I include episodes in which the respondents were threatened by cars or motorcycles. From these episodes, it can be derived that (1) the front and rear lights need to be improved so that the electric kick scooter is highly visible, (2) rear-view mirrors need to be fitted, (3) the road environment needs to be improved in consideration of the electric kick scooter, and (4) other drivers' perceptions of these scooters need to be improved.

The second category involves product failure or malfunction and episodes caused by problems with chargers, accelerators, and brakes. These risks can be found in Topics E and F. As can be seen in Topic E, episodes related to chargers involve sparks occurring during charging, causing danger. Topic F addresses the malfunctions of accelerators and brakes and mainly depicts malfunctions of unknown cause or episodes caused by malfunctions in dangerous situations. The solution to these problems is not only to increase the durability of the product element but also to provide feedback to confirm the content or degree of the problem or to provide an auxiliary means to cope with the problem. In particular, useful feedback on the condition of the product would help users avoid risk in advance.

The third category involves a type of safety problem in which the occupants are shocked or lose balance due to environmental factors. Topic C includes episodes in which respondents have been shocked by brakes or suspension while going over a bump or riding downhill. Besides this, Topic E includes episodes of erratic driving, such as respondents losing balance or brake pushing on bumpy or slippery road surfaces. Applying a more suitable suspension or larger wheels may be one solution to such problems caused by environmental factors after verifying the idea by experiments or further research. However, in addition to enhancing the parts' specifications, helping users to check for appropriate conditions for safe use according to the product specifications and to plan their route would significantly improve safety.

The fourth category includes safety issues caused by the interaction of specific environmental and product factors. Topic B covers episodes of problems with wheels, brakes, and nuts and bolts on uneven road surfaces. Moreover, Topic G addresses risk episodes in which the battery voltage suddenly

decreased when the accelerator was engaged more for uphill driving or speed and episodes in which accelerator malfunctions caused danger. These problems can be improved by further research on the bumpy, sloping, and slippery surfaces that users usually experience and wheel size, suspension strength, brake performance, and the combined stability of nuts and bolts. Actively operated electric kick scooter sharing services also benefit from durability and other specifications required, depending on the driving environment. Especially in South Korea, where topographical features are local and diverse, the specifications of suitable electric kickboards differ depending on the characteristics of the slope, road environment, and traffic volume in the area where the service is provided. By providing products with appropriate specifications and establishing a fee system according to such geographical characteristics, it is possible to ensure service competitiveness while ensuring convenience and safety for users.

Table 7 shows the organization of the four categories. Each of the four safety issues can be defined as a risk factor, based on the structure of user, product, and environmental factors that constitute the context of use. As discussed so far in this section, risk factors can be explored from a user-centered design perspective, and the direction of improvement can be explored by clarifying the causes of the risks experienced by the users. Figure 6 describes the risk factors and the interactions between the contextual factors and their context-of-use.

Table 7. Summary of the risk factors experienced by electric kick scooter users.

Type of Risk Factor	Description
Other moving entities—user topics A, D, H, I	Risks arising from interaction with other moving entities, such as cars, pedestrians, bicycles, and motorcycles.
Product—user topics E, F	Hazard from charger, accelerator, brake malfunction and short circuit
Environment—user topics C, E	Erratic driving on bumpy or slippery roads.
	Shock from bumps, braking while going downhill, suspension
Environment—product topics B, G	When climbing or accelerating uphill, the battery suddenly decreases or malfunctions
	Shock and damage to users and products, including wheels, brakes, handles, and nuts and bolts, due to impacts from bumpy roads.

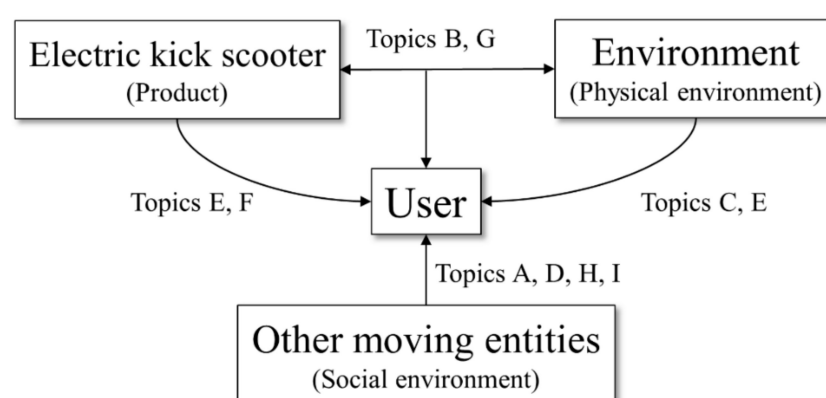


Figure 6. Interactions of each contextual factor and the risk topics in risk factors.

The safety-related issues of electric kick scooters derived from this study are in line with the findings of previous studies. Kim et al. [6] reported the types of PMD-related accidents observed in hospitals in South Korea, including their location, PMD type, and whether the participant was driving under the influence while focusing on the severity of the injuries, areas of injury, and treatment methods. The results showed that PMD-related accidents were more common on sidewalks (24.6%), in alleys (23.1%), and on streets (23.1%), and that there were more cases (86.2%) of injuries caused by

falling from PMDs than by collision with other moving entities (13.8%). Liew et al. [3] investigated the status of electric kick scooter-related injuries in Singapore and reported the site of the injury, the cause of the injury, and the relationship between the driver and other moving entities. According to the study, accidents mainly occurred in cases where a user lost balance or control and fell (38.9%), crashed with another vehicle (27.8%), and crashed with objects such as a lamppost or curbs (16.7%). This study also reported several types of incidents in which electric kick scooter users felt the danger of losing their balance on the road (topics C, E, and G), and others felt threatened by or experienced a collision risk from other moving agents (topics A, D, H, I). Existing studies, such as Kim et al. [6] and Liew et al. [3], have thus reported on accidents related to electric kick scooters or PMDs. This study analyzed the cases experienced by users based on their own descriptions. This analysis is meaningful because organizing electric kick scooter risk episodes more systematically and specifically from the users' perspectives can provide direction for solving the problem rather than merely reporting on the phenomenon.

6. Conclusions

The safety of electric kick scooters has been called into question due to numerous accidents, which grow along with PMD use. We designed a questionnaire to collect the context of electric kick scooter use and capture the factors that cause risk.

Over two months, data on risk episodes were collected from 21 participants using electric kick scooters through "Google Spreadsheets" online. This returned a total of 423 responses. Based on the context of the use framework, the product and environmental factors and task types that made users feel a risk were analyzed and reported as descriptive statistics. Additionally, LDA was applied to the "Description of the situation" items in the text to derive the topics that constitute the risk episodes for electric kick scooter and report the representative keywords and episodes for each topic.

Through the analyzed results, this work identified the types of safety issues experienced by electric kick scooter users and proposed various improvement measures depending on the risk episode types. In addition to the measures proposed in the discussion above, this study contributes to the improvement of the design direction and promotes a system for improving the safety of the electric kick scooter by encouraging follow-up studies and experiments based on the significant risk factors and representative episodes derived.

In this study, four risk factors were summarized in terms of the interaction between each factor constituting the context-of-use. Based on these results, it is expected that more specific design criteria or new ideas for enhancing safety can be developed through in-depth experiments or user surveys. From these results and suggestions, we can reflect the environmental and task impacts on electric kick scooters when designing each product element to enhance safety further.

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Appendix A

Table A1. Representative episodes of nine topics consisting of electric kick scooter risk episodes.

Topic A	Felt danger from car and pedestrians appeared in sudden.
Episode No. 399	<i>"While driving straight at the intersection near Samjeon-dong, the electric kickboard was approaching fast on the left side. Since I drive mainly with the car or pedestrian in mind, I was embarrassed. Can see approaching car easily with a little attention at the intersection since a car is big and noisy. Because pedestrians are slow, can pass with a high speed even if they were not in the vision when access to the intersection."</i>
Episode No. 311	<i>"A vehicle came out from blind spots in the residential area. Went through this often, but I am always exposed to danger. Since the electric kickboard doesn't make any sound, I don't think the vehicle driver can see me."</i>
Topic B	Erratic driving by road surface or product condition. Detected problems with some parts.
Episode No. 252	<i>"While passing a sunken spot due to poor road conditions, I collapse posture from sudden impact by the jammed wheel, causing my legs to fall off from the deck and lose balance."</i>
Episode No. 013	<i>"There is no major problem driving cobbled or bumpy roads, but the suspension on the front wheels is so stiff that delivers impact from the roads almost as they are."</i>
Topic C	Experienced impact from bumps, downhill, pushed brakes, or loosen handlebar.
Episode No. 091	<i>"When I pass the raised spot, rear mudguard collide with main body as the rear rubber suspension fluctuates. I found it when I was inspecting kickboard at home, and if the impact accumulates, the risk of damage due to worn-out is high."</i>
Episode No. 126	<i>"On unpaved roads, by unexpected raised spot, the suspension fails to absorb the impact, causing miss the handle."</i>
Topic D	Experienced the risk of collision or accident on slopes. Threatened by a car.
Episode No. 186	<i>"Unable to drive in the third lane due to taxis and parked vehicles. Need to turn right to the alley on the right while driving in the second lane. At the moment I tried to slow down and make a right turn, a car that was driving on the first lane quickly crossed the third lane and entered the right side of the alley without turning on the indicator."</i>
Episode No. 174	<i>"Although there is a rear light, it is too weak for the vehicle behind me to detect me. The car soon found me and passing with raging and honking hard."</i>
Topic E	Impact from sidewalk blocks or bumpy road surfaces. Experienced spark while charging.
Episode No. 105	<i>"As the kickboard passes the small pothole, it doesn't absorb much of the impact, and the impact goes up to the handle."</i>
Episode No. 235	<i>"The moment the charger is connected to the kickboard main body, it has a spark."</i>
Topic F	Problems with some parts of the electric kick scooter.
Episode No. 354	<i>"By the excessive performance and sensitivity of brake, slight braking makes a sudden stop."</i>
Episode No. 180	<i>"Illumination part malfunction. Left and right lights operate mixed with different order of flashing, light, and intensity. The malfunction causes inconvenience to the driver and lighting problem. Mounted additional key box."</i>
Topic G	Sudden decrease in battery voltage. Product malfunction. Risk from bumpy or slippery surfaces.
Episode No. 191	<i>"Screen showing a single bar of battery. The voltage was 46.3 V voltage eco mode. A truck suddenly follows at high speed from behind while driving in the second lane on the first gear of dual mode. Turn off eco mode and switch to dual mode third gear. After I throttle up to speed, instrument panel and key box powered off as soon as the voltage on the key box is below 43 volts."</i>
Episode No. 047	<i>"When operating a very steep uphill in dual mode, the power slowly decreases and climbs tightly, and get nervous that I might be pushed back, when the accelerator is released."</i>
Topic H	Lost balance or felt danger due to other moving objects.
Episode No. 068	<i>"Vehicle is stopped ahead of the road, and as soon as I tried to get up to the sidewalk to avoid it, it almost collides a motorcycle driving in the opposite direction on the sidewalk."</i>
Episode No. 194	<i>"On a road with frequent jaywalking and bicycle, when a pedestrian or bicycle suddenly pops out of the way without realizing that the kickboard is running at low speed, the first thing to do is honking. If the horn malfunction, it may lead to a collision or major accident."</i>
Topic I	Felt danger from overtaking cars. Felt danger from rainy roads.
Episode No. 192	<i>"Because elementary school and middle school are adjacent to each other, while driving on a road with a lot of speed bumps, at the moment passing a bump, lose balance by rainy road, and fell on the asphalt road with a product."</i>
Episode No. 151	<i>"While driving in the fourth lane as possible, some clueless vehicles pushed into the lane and almost led to an accident. When driving the kickboard, cars often take over my lane without turning the indicator lights."</i>

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