

Article

Evaluation of Mobile Risk Perception Training System for Improving the Safety Awareness of Construction Workers

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Abstract: Toolbox Meeting (TBM) activities conducted before work at construction sites are representative activities with characteristics such as work sharing and improving safety awareness. However, there is a limitation to the conventional TBM approach as it proceeds only formally and is not systematic because it proceeds without the manager's prior preparation. Therefore, in this study, TBM was conducted using a mobile app by supplementing the limitation of conventional TBMs, and we examined whether mobile TBM is more effective in improving the safety awareness of construction site workers. A survey of 400 people was conducted at two sites implementing existing TBM or mobile TBM. This study included survey development, survey target selection, and statistical analysis. The analysis revealed three main results. First, mobile TBM was more efficient. Second, workers at mobile TBM application sites ($M = 4.24$) were more positive and satisfied with daily safety activities than those using existing TBMs ($M = 3.95$). Finally, the impact of TBM education and worker safety awareness was higher in sites using mobile TBM ($M = 4.14$) than those using existing TBM ($M = 3.94$). This study provides valuable evidence for construction site safety management decision-makers considering the adoption of smart safety management tools such as mobile TBMs.

Keywords: toolbox meeting; perception training system; daily safety activities; safety awareness



Citation: Kim, M.; Jo, D.; Jeong, J. Evaluation of Mobile Risk Perception Training System for Improving the Safety Awareness of Construction Workers. *Buildings* **2023**, *13*, 3024. <https://doi.org/10.3390/buildings13123024>

Academic Editor: Paulo Santos

Received: 26 October 2023

Revised: 1 December 2023

Accepted: 2 December 2023

Published: 5 December 2023



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1. Introduction

The construction industry, given its inherent characteristics, is often associated with higher risk than other industries [1]. Notably, based on the findings of previous research, many accidents on construction sites (more than 70%) are directly related to workers' unsafe behaviors [2]. Furthermore, Tixier et al. [3] pointed out that many workers do not engage in safety violations intentionally but rather display such behaviors because of a lack of adequate awareness of the risks.

To mitigate industrial accidents, the foremost and optimal approach is the complete elimination of hazards [4]. However, given the inherent characteristics of construction sites, achieving total risk elimination or control often proves impractical [5]. Therefore, in pursuit of reducing accidents, it is imperative to accurately perceive risks before any operation and implement effective safety measures to prevent potential accidents [6]. Enhancing individual safety awareness and fostering collaborative work-sharing among workers via risk perception training is essential in recognizing these risks [7]. A prime example of a risk perception training method is a toolbox meeting (TBM).

The TBM is a bottom-up safety management activity, convened before work starts, where workers gather around a team leader to mutually confirm and discuss job details and safety procedures [8]. Essentially, a TBM facilitates communication among workers, enhancing and keeping their safety knowledge and information up to date. However, a prevailing issue is that the TBMs conducted at various sites lack uniformity across different team leaders, often proceeding merely as a formality without genuine communication and

consensus-building among workers [9]. Additionally, a limitation of TBMs is that when they are conducted without prior preparation, the progression lacks consistency and is not systematically structured [9]. With the advent of technological advancements, smart safety management technology has gained widespread adoption [10]. Simultaneously, the prevalence of smartphones has reached such a level that the majority of the populace now operates within a smartphone-centric environment [11]. Considering this, our study aimed to confirm the effect of improving the safety awareness of construction workers by applying mobile TBM applications, which supplement the limitations of conventional TBM that proceed formally without prior preparation.

2. Literature Review

In this study, the difference between workers' safety awareness and the effectiveness of TBM education was analyzed when using conventional TBM and mobile TBM. In this regard, we analyzed the limitations and implications of relevant previous studies and presented their main differences. The analysis included previous studies related to (i) safety management and TBMs at existing construction sites and (ii) studies on the use of smart safety management technology for safety management at construction sites. Table 1 summarizes the relevant previous studies.

Table 1. Purpose of reference papers by subject.

Subject	No.	Reference	Purpose
Studies on Safety Management and TBMs at Existing Construction Sites	1	Eggerth et al., 2018 [12]	This study evaluated whether talking and asking questions during toolbox safety training could increase its effectiveness.
	2	Jeschke et al., 2017 [13]	This study aimed to improve the knowledge and communication of risks related to safety and health at construction sites via TBMs.
	3	Alkaissy et al., 2020 [14]	The purpose of this study was to review safety risk management in the construction industry and emphasize the development of simulation and optimization technologies.
	4	Olson et al., 2016 [5]	This study showed that supervisors prefer toolbox talks with scripts and prompts and that new methods for toolbox talks save time and improve worker understanding.
	5	Zhou et al., 2015 [15]	This study aimed to analyze the Construction Safety Research Group to provide insights and research trends for future research.
Studies on the Use of Smart Safety Management Technology for Safety Management at Construction Sites	6	Choudhry et al., 2008 [16]	The purpose of this study was to evaluate the importance of safety in the construction industry and provide practical insights for improving the safety of construction sites.
	7	Nnaji and Karakhan, 2020 [17]	This study examined strategies to overcome barriers to the continued use of technology to improve safety in the construction industry and to strengthen technology implementation.
	8	Zhang et al., 2017 [18]	This paper describes the introduction of a mobile computing-based safety check approach to improve data collection and safety management at construction sites.
	9	Rice et al., 2022 [19]	This study showed that delivering toolbox talks via mobile messages increased safety conference standards by 19.39%.

First, previous research focused on the analysis of conventional TBMs and safety management at construction sites. The predominant challenges identified in this foundational research centered on communication and information-sharing issues between team leaders and workers, as well as among the workers themselves during TBM [5,12–15]. However, research showed a lack of exploring specific solutions or conducting post-solution evalua-

tions. In addition, there was a broad consensus in the studies about the need for technology in construction site safety management, yet no instances of its use in TBMs were found.

Second, previous research focused on the use of smart safety management technology to ensure safety at construction sites. Analyses related to this subject suggested that the deployment of smart safety management technology could contribute to enhancing safety measures at construction sites [16–19]. However, there was a noticeable lack of detailed exploration of the tangible effects of this technology when applied. Although there has been previous research on mobile TBMs, the methodology used for the mobile TBMs adopted in these studies was notably unsystematic.

Consequently, regarding the part that presented the problem of communication as a limitation of TBM in previous studies, this study further attempts to solve the communication problem between workers and managers by presenting mobile TBM as a solution. In addition, there are currently few prior studies on mobile TBM, and no studies have conducted post-evaluation after conducting TBM via the application, so this study intends to analyze the effectiveness of TBM by applying mobile TBM and conducting post-evaluation.

3. Materials and Methods

3.1. Mobile TBM Application

At construction sites, risk perception training is employed before daily tasks commence to prevent accidents and ensure safety management. A prime example of this anticipatory risk awareness and sharing mechanism is the TBM [8].

The Korea Occupational Safety and Health Agency (KOSHA) provides guidelines for a successful TBM. As per their guidelines, an effective TBM session should be conducted near the work site, led by a team leader, and consist of a small team ranging from 4 to 10 participants. The session is most effective when limited to approximately 10 min [8].

However, there are two prominent issues with the current implementation of TBMs.

First, TBMs often lack structure because of inadequate preparation by supervisors. Second, there is a recurring problem of inadequate information sharing among TBM participants [20]. Considering these limitations, this study attempted to merge a TBM with mobile technology, leading to the application of mobile TBMs at construction sites. This study investigated the effects of TBMs and the safety awareness of workers at sites where both conventional and mobile TBMs were held.

As shown in Figure 1, the mobile TBM used in this study consisted of four steps: a worker attendance check, safety training, pre-task safety training, and task execution. In contrast to a conventional TBM, the team leader was required to pre-input the safety rules related to the tasks to be performed that day before commencing the TBM. Furthermore, the safety team had to register any notices or announcements for the day in advance before the TBM. The mobile TBM was also integrated with computational systems like risk assessment and permit-to-safety work (PTW) systems, which allowed managers to utilize safety management data without the need for additional paperwork.



Figure 1. Example of Mobile TBM application.

Figure 2 summarizes the research flow, which includes (i) survey development, (ii) survey target selection, and (iii) statistical analysis. For this analysis, we utilized four distinct statistical methods to evaluate the improvement in the safety awareness of workers and the efficacy of mobile TBMs compared to conventional TBMs.

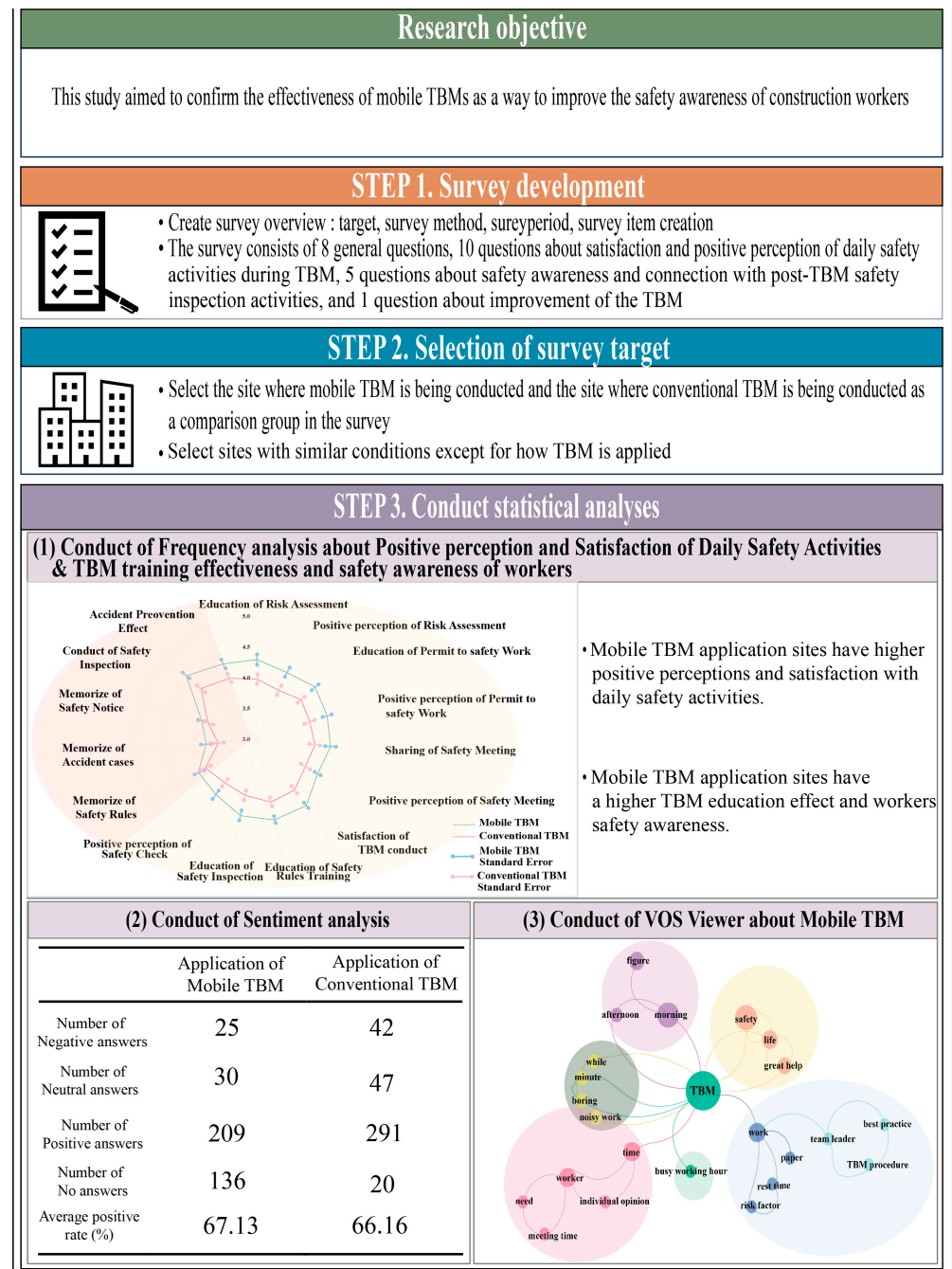


Figure 2. Summary of research flow.

3.2. Collection of Data

The respondents targeted in this survey consisted of supplier construction managers, team leaders, and workers. Surveys were distributed to 400 participants at each of the two sites, which implemented either mobile or conventional TBMs, for a total of 800 respondents. Of these, 74% of the respondents were workers, 12% were team leaders, and 14% were supplier construction managers. The survey, comprising 24 questions, was

disseminated via a URL link. The survey was conducted during regular safety training sessions and took place during June and July of 2022.

The purpose of this survey was to compare the implementation methodologies for TBMs, the safety awareness of the workers, and the effectiveness of the safety training between sites that applied mobile and conventional TBMs. The questionnaire comprised 24 items across six sections: 3 items on general information, 4 on the appropriateness of TBM operations, 1 on the usability of smart devices, 10 on their satisfaction with daily safety activities and positive perception of TBMs, 5 on post-TBM safety inspection activities and safety awareness levels, and 1 on suggestions for potential improvements for TBMs. The items related to satisfaction, positive perception, safety inspection activities, and safety awareness were rated on a 5-point Likert scale [21,22]. The last item, regarding areas for TBM improvement, allowed respondents to provide subjective responses using keywords. In the analysis, a total of 21 items, specifically items 4–24, were considered, with general information items 1–3 excluded.

3.3. Selection of Survey Target

The two sites where the survey was conducted were both under the management of Company S, and they were industrial plant sites chosen as sites with similar conditions, except for the TBM progression method, as shown in Table 2. These two sites were managed using the same safety management system, were primarily involved in machinery and equipment construction, and followed identical TBM procedures. At the site where conventional TBMs were implemented, a regular monthly training session was conducted for team leaders to educate them about the TBM procedures. Every morning at 7 a.m., all team members gathered for a safety briefing, followed by team-specific TBM meetings led by the team leaders. Therefore, the level of TBM execution at the site using conventional TBMs could vary depending on the team leader's competence. At the site where mobile TBMs were implemented, a regular monthly training session was also conducted for team leaders, and morning briefings were held at 7 a.m., with teams gathering to conduct TBMs following the procedures provided by the mobile TBMs.

Table 2. Selection of survey targets.

	Application Site of Mobile TBMs	Application Site of Conventional TBMs
Construction Period	24 months	24 months
The Main Process	Facility piping, mechanical equipment, electrical control	Facility piping, mechanical equipment, electrical control, construction finish
Safety Management System	KOSHA MS, ISO45001 [23]	KOSHA MS, ISO45001 [23]
TBM Progression Method	Application of mobile TBM	Application of conventional TBM
TBM Details	Daily morning check at 7:00 a.m. Regular monthly training of the task team leaders	Daily morning check at 7:00 a.m. Regular monthly training of the task team leaders

3.4. Statistical Analysis of Survey Results

In this study, a statistical analysis was conducted using SPSS 18. To ensure the accuracy of the survey responses, a reliability analysis was initially performed for each response. Subsequently, frequency analyses and *t*-tests were conducted to analyze the differences in worker safety awareness and the effectiveness of the TBMs between the two survey groups. Finally, sentiment analyses and VOSViewer were employed to visualize the responses to the open-ended questions in the survey and identify improvement suggestions for TBMs. Table 3 summarizes the results of the statistical analyses conducted for each survey item.

Table 3. Statistical analysis results by survey item.

Survey Item	Statistical Analysis
Q4–Q8	Frequency analysis
Q9–Q23	Frequency analysis, reliability analysis, <i>t</i> -test
Q24	Sentiment analysis, VOSViewer

3.4.1. Reliability Analysis

A reliability analysis examines the consistency of a measurement tool or survey items in measuring [24]. In this study, Cronbach’s Alpha was utilized as one of the methods for reliability analysis. Cronbach’s Alpha is a widely recognized approach for estimating internal consistency reliability, which allowed us to validate the reliability by estimating the internal consistency among individual items [25]. Cronbach’s Alpha ranges between 0 and 1, with values closer to 1 indicating higher reliability. An Alpha coefficient of 0.6 or higher is generally considered acceptable. Cronbach’s Alpha can be calculated using the following formula:

$$\alpha = \frac{K}{K-1} \left(1 - \frac{\sum_{i=1}^K \sigma_{Y_i}^2}{\sigma_X^2} \right) \quad (1)$$

Here, K represents the number of items, $\sigma_{Y_i}^2$ denotes the variance of the scores for the i th item, and σ_X^2 signifies the variance of all the scores.

In this study, reliability analyses were conducted for survey items related to positive perception and satisfaction regarding daily safety activities, as well as items related to the effectiveness of TBM training and the safety awareness of workers. These analyses aimed to verify the consistency of the respondents’ responses.

3.4.2. Frequency Analysis

Frequency analysis is a method used to understand the distribution characteristics of each survey response [26]. In this study, a frequency analysis was conducted to analyze the effectiveness of the TBMs by examining the proportions of responses from workers in the survey. Additionally, for the items using a 5-point Likert scale, a frequency analysis was used to calculate the means (M) for each of the two groups. Frequency analyses were performed for all the items to gain insights into the overall characteristics of the survey responses.

3.4.3. *t*-Test

A *t*-test is one of the statistical hypothesis tests and is used to compare the means of two groups [27]. In this study, an independent-sample *t*-test was conducted to compare and analyze the differences in worker safety awareness and the effectiveness of TBMs between the sites with mobile and conventional TBMs to determine if there were significant differences between the two groups [28].

3.4.4. Sentiment Analysis

Sentiment analysis is an analysis method that automatically classifies emotions in sentiment reviews using natural language processing or text analysis [29]. Sentiment analysis involves identifying keywords during the preprocessing stage to emphasize the core message of the text. These keywords are then analyzed using natural language processing techniques to provide sentiment scores. A score close to 1 indicates a higher proportion of positive sentiment, while a score close to 0 suggests a closer association with negative sentiment [30]. Sentiment analysis was applied to the short-answer question responses in the survey to assess the sentiment associated with the feedback from the participants.

3.4.5. VOSViewer

VOSViewer (version 1.6.19) is a software tool for constructing and visualizing networks, making it an excellent method for analyzing and visualizing desired data. And results showed the frequencies of keywords can be determined by their sizes. Additionally, clusters, which are categorized groups of keywords, can be identified by the colors of the keywords in the results, and the relationships between keywords are indicated by connecting lines [31,32]. In this study, VOSViewer was employed to perform text mining with a focus on keywords extracted from the short-answer question responses in the survey.

4. Results

This study aimed to investigate the effectiveness of mobile TBMs via a survey analysis, which was categorized into four major sections for statistical analyses. First, we conducted a statistical analysis on four survey items (q4–q7) from the perspective of the appropriateness of the TBM implementation. Second, we analyzed a total of 15 survey items (q9–q23) related to positive perceptions and satisfaction regarding daily safety activities, the effectiveness of TBM training, and the safety awareness of workers. Third, we examined workers' perceptions of the use of mobile devices with one item (q8). Lastly, we analyzed and visualized the responses to an open-ended question (q24) to assess the positivity and areas of improvement for each type of TBM.

4.1. Results of Relating to the Appropriateness of TBM Operation

To assess the appropriateness of the TBM operations at the mobile and conventional TBM sites, this study conducted a survey and performed a frequency analysis. The frequency analysis was conducted for four general items, excluding q1–q3.

Figure 3 presents the results of the frequency analysis for these four general items. Each item is represented from (a) to (d), with the red bars indicating responses from the mobile TBM site and the blue bars representing responses from the conventional TBM site. The y-axis of each item indicates the number of respondents, while the x-axis represents the choices for each survey item.

In Figure 3, the (a) panel presents that at both sites, the team leaders were the primary individuals responsible for TBMs, accounting for 73.3% of the responses. Notably, at the mobile TBM site, team leaders accounted for 83.5%, while at the conventional TBM site, the percentage of team leader-led TBMs was 63%, indicating a 20.5% higher prevalence at the mobile TBM site.

In Figure 3, the (b) panel presents the number of individuals involved in TBM activities at both the mobile and conventional TBM sites; 5–10 people accounted for the highest percentage at 52.5%. Among these, the mobile TBM site had 74.25%, while the conventional TBM site had 30.75%, with the mobile TBM site showing a 43.5% higher rate. Additionally, at the conventional TBM site, the response of more than 20 people was more than 20%.

Figure 3, (c) panel presents the worker participation rates during TBMs. At both types of sites, the responses indicating that safety rules were always discussed during TBMs accounted for 60.3%. Notably, at the mobile TBM site, this response was 73.75%, whereas it was 46.75% at the conventional TBM site, indicating a 27.0% higher rate at the mobile TBM site.

Lastly, as shown in Figure 3d, the frequency analysis results regarding the time taken for TBMs showed that at the mobile TBM site, 10–15 min was the most common duration at 49.75%. Conversely, at the conventional TBM site, 5–10 min was the most common duration at 50.5%.

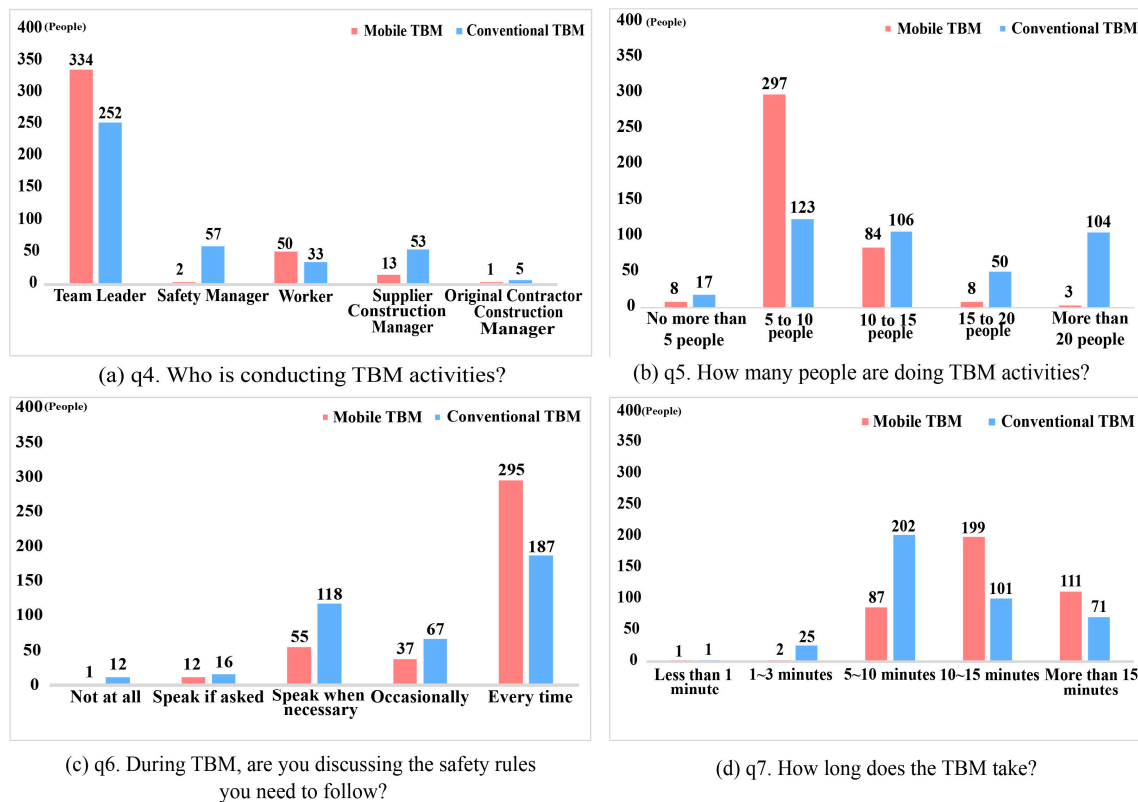


Figure 3. (a) Survey results of who is conducting TBM activities; (b) survey results of how many people are doing TBM activities; (c) survey results of the number of individuals speaking on safety rules during TBM; (d) survey results of how long does the TBM take.

4.2. Results of Positive Perception and Satisfaction with Daily Safety Activities and TBM Training Effectiveness and Safety Awareness of Workers

This survey assessed the positive perception and satisfaction with daily safety activities, as well as the effectiveness of the TBM training and safety awareness of workers at each site. Subsequently, we performed reliability analyses, frequency analyses, and *t*-tests.

Table 4 showed results of the reliability analysis results for the survey items related to positive perception and satisfaction with daily safety activities. The results yielded a Cronbach's Alpha coefficient of 0.964, while the items related to the effectiveness of the TBM training and safety awareness of workers produced a coefficient of 0.752. Both coefficients exceeded the threshold of 0.6, confirming the consistency of the respondents' answers.

Table 4. Results of the reliability analysis for survey responses.

	Number of Survey Items	Cronbach's Alpha
Positive perception and satisfaction with daily safety activities	10	0.964
TBM training effectiveness and safety awareness of workers	5	0.752

As shown in Figure 4, first, the yellow area on the right represents the questions on the positive perception and satisfaction with daily safety activities, while the red area on the left represents the questions on the effectiveness of the TBM training and safety awareness of workers. Secondly, the red radial graph signifies the average responses for each respective survey item for conventional TBMs, while the green radial graph represents the average responses for each respective survey item for mobile TBMs. Finally, light blue and pink bars on the graph represent the standard error for each item.

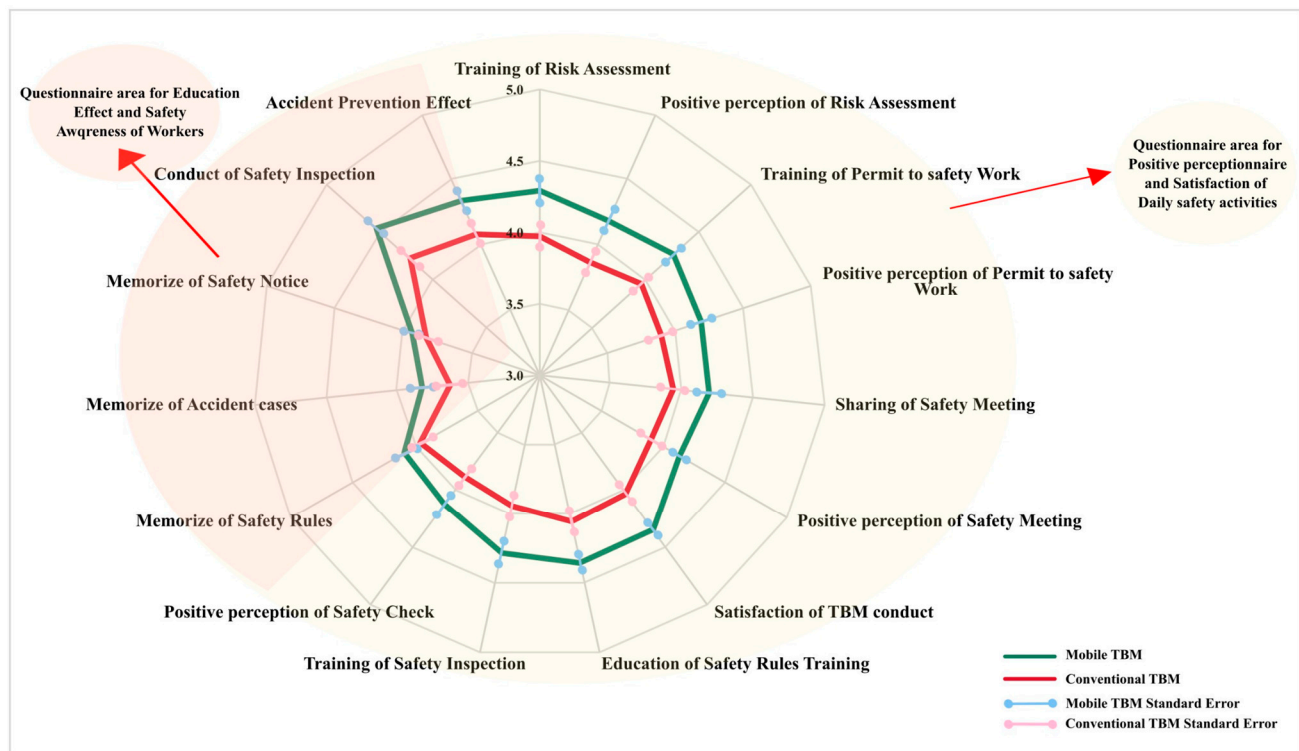


Figure 4. Response results from the questionnaire related to positive perception and satisfaction with daily safety activities and TBM training effectiveness and safety awareness of workers.

Table 5 presents the values corresponding to the graph in Figure 4, indicating the average responses for each survey item across the application sites for both TBM types.

Table 5. Average responses from the questionnaire for positive perception and satisfaction with daily safety activities and TBM training effectiveness and safety awareness of workers.

	Application Site of Mobile TBMs			Application Site of Conventional TBMs		
	Average	The Upper Limit	The Lower Limit	Average	The Upper Limit	The Lower Limit
Risk assessment training	4.29	4.33	4.24	3.97	4.01	3.93
Positive perception of risk assessment	4.19	4.24	4.14	3.87	3.91	3.82
Training on the permit to safety work	4.26	4.30	4.22	3.96	4.00	3.92
Positive perception of permit to safety work	4.19	4.23	4.15	3.89	3.94	3.85
Sharing of safety meeting	4.20	4.24	4.15	3.95	3.99	3.91
Positive perception of safety meeting	4.14	4.18	4.09	3.91	3.95	3.86
Satisfaction with how TBM was conducted	4.35	4.39	4.31	4.03	4.07	3.99
Education on safety rule training	4.36	4.31	4.10	4.06	4.10	4.02
Safety inspection training	4.28	4.32	4.24	3.95	3.99	3.91
Positive perception of safety check	4.13	4.17	4.08	3.89	3.93	3.85
Memorizing safety rules	4.09	4.14	4.04	3.95	4.00	3.90
Memorizing accident cases	3.83	3.88	3.77	3.63	3.69	3.57
Memorizing safety notice	3.93	3.96	3.90	3.83	3.86	3.79
Conducting safety inspections	4.54	4.57	4.51	4.21	4.25	4.17
Accident prevention effectiveness	4.33	4.37	4.26	4.08	4.12	4.04

Overall, the analysis of the responses to the ten survey items related to positive perceptions and satisfaction with daily safety activities revealed that the site where mobile TBMs were implemented showed the result mean score was 4.24 compared to the site where conventional TBMs were applied showed the result mean score was 3.95. The results of the *t*-test analysis confirmed a significant difference between the two groups in their responses to the questions related to daily safety activities, with a *p*-value shown to be under 0.001.

Furthermore, in the responses to the five survey items regarding the TBM training effectiveness and safety awareness of workers, the result of the site that implemented mobile TBMs was 4.14, and the result of the site with conventional TBMs was 3.94. The *t*-test results indicated a significant difference between the two groups in their responses to these questions, with a *p*-value shown to be under 0.1.

Detailed *t*-test values for individual survey items are provided in the Supplementary Material (Tables S1 and S2).

4.3. Results of Frequency of Use of Mobile Devices When Providing Safety Information

Figure 5 presents the results of the frequency analysis based on respondents' feedback regarding their level of engagement when receiving safety information via smartphones. The results indicated a positive response, with 36.38% selecting "Often" and 47.63% choosing "Frequently". In total, 84.01% of the respondents expressed a favorable inclination toward utilizing smartphones for safety information.

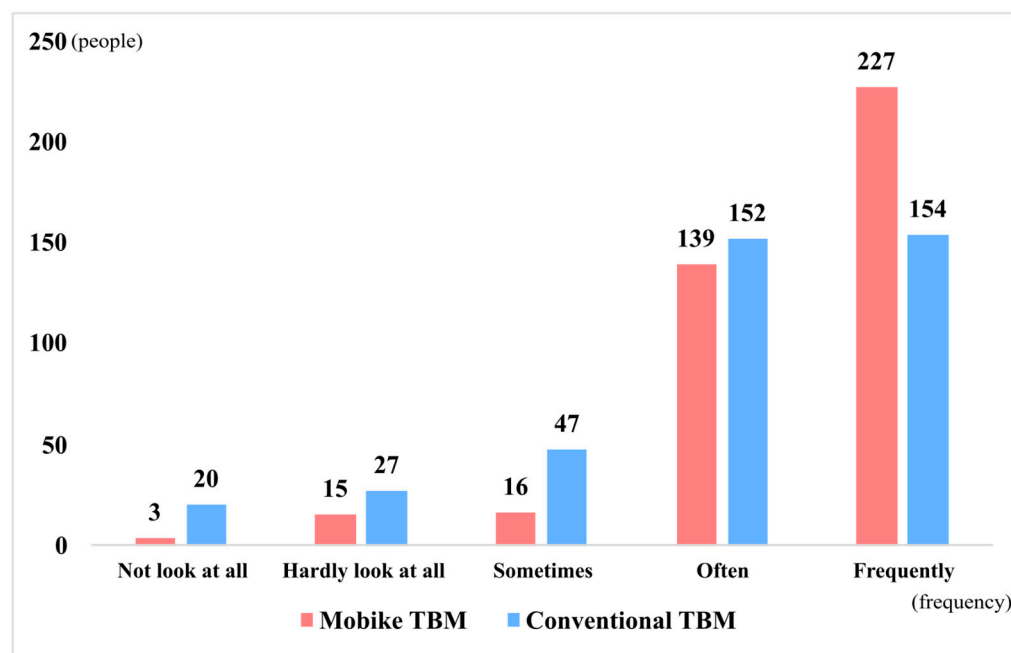


Figure 5. Survey results of how often would you watch if you were provided safety information through your smartphone.

4.4. Results of Positive Rates and Improvements for TBMs

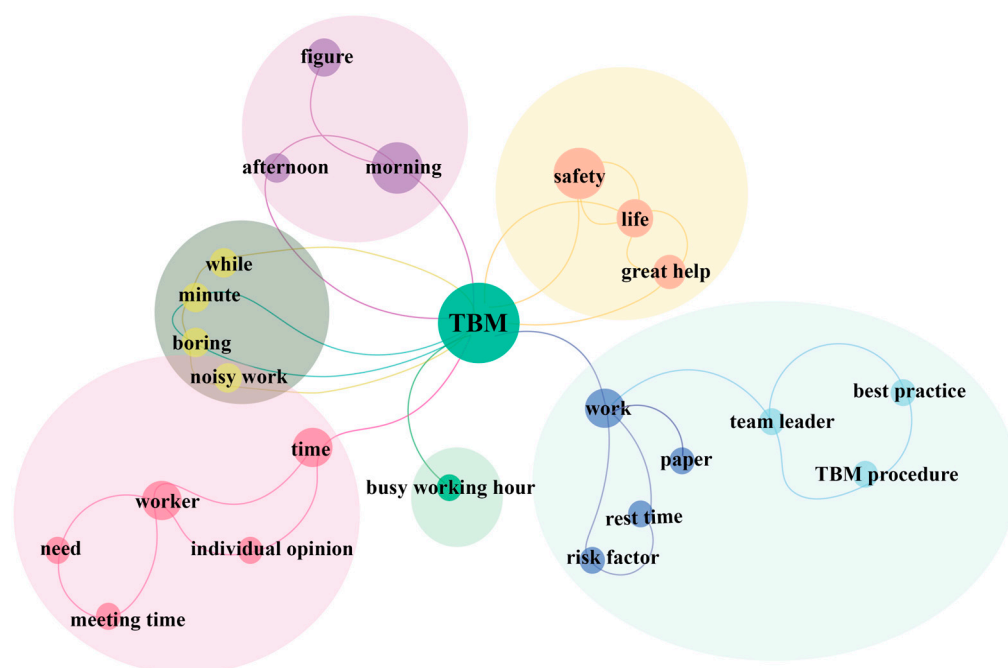
We performed a sentiment analysis and employed VOSViewer to assess and visually represent the open-ended question on improvement suggestions for both mobile and conventional TBMs.

As shown in Table 6, the sentiment analysis revealed that 67.13% of the responses were positive for mobile TBMs, while 66.16% were positive for conventional TBMs.

Table 6. Results of sentiment analysis.

	Application Site of Mobile TBM	Application Site of Conventional TBM
Number of Negative answers	25	42
Number of Neutral answers	30	47
Number of Positive answers	209	291
Number of No answers	136	20
Average positive rate (%)	67.13	66.16

In Figure 6, the results revealed the requests into six clusters based on color, indicating different categories of improvement suggestions. In Figure 6, the red cluster highlights improvement requests related to time. The results of the VOSViewer analysis for improvement requests with conventional TBMs are presented in the Supplementary Material (Figure S1).

**Figure 6.** The results of VOSViewer about Mobile TBM improvement requests.

5. Discussion

The following explanations are based on the analysis results related to the various aspects of the application of conventional and mobile TBMs. The analysis of survey responses revealed three key aspects related to the effectiveness of mobile TBMs.

First, according to the TBM guidelines provided by KOSHA, it is recommended that the TBM should be organized with a team leader at the center, and the ideal team size is 4–10 members. Moreover, Demirkesen and Arditi [33] suggested that active worker participation in communication can reduce incidents and enhance safety awareness. Therefore, based on the analysis results presented in Section 4.1, it can be inferred that the mobile TBMs followed the TBM guidelines set by KOSHA more than the conventional TBMs. Consequently, it can be concluded that operations at the mobile TBM site were better than those at the conventional TBM site.

Second, the analysis of the responses regarding positive perception and satisfaction related to daily safety activities conducted during TBMs revealed that the site where mobile TBMs were implemented showed a higher degree of positivity compared to the site where conventional TBMs were conducted. Consequently, coordinating mobile TBMs with daily safety activities should boost workers' positive perceptions. Furthermore, this integration is expected to have a positive impact on the safety awareness and safety culture of workers.

Finally, the analysis revealed that the mobile TBM site had higher levels of TBM training effectiveness and individual safety awareness compared to the conventional TBM site. This suggests that mobile TBMs can contribute to the establishment of a safety culture where workers autonomously adhere to safety rules.

Additionally, an analysis of the open-ended responses revealed specific improvement suggestions for both types of TBMs. At the conventional TBM site, there were frequent requests to conduct TBMs by teams because of excessive participant numbers and suggestions to create manuals for TBM procedures. On the other hand, participants at the mobile TBM site expressed the need to address communication issues related to mobile device signal quality and the extended duration of TBMs. Both sites shared concerns about the limited space for TBM implementation. Consequently, addressing the improvement needs of mobile TBMs should involve enhancing the communication infrastructure and streamlining safety training topics to address communication issues and reduce time consumption. Notably, one of the reasons a mobile TBM takes longer than a conventional TBM is that, in a conventional TBM, the procedure can be streamlined or omitted based on the team leader's preferences. However, given the inherent characteristics of a mobile TBM, such an omission or simplification is not possible. As it necessitates adherence to predetermined procedures, conducting a mobile TBM is considered to require more time.

6. Conclusions

Because of the inherent risks associated with the construction industry, it is crucial to reduce accidents via worker collaboration and improving individual safety awareness. TBMs are held before work at construction sites to encompass activities such as sharing tasks and enhancing safety awareness among workers. However, there are limitations to conventional TBMs because they are often conducted informally and lack systematic preparation, making them less structured. To address these limitations, this study aimed to examine the effectiveness of mobile-based TBMs in enhancing safety awareness among construction workers as a means of improving safety on construction sites. The study collected and analyzed data related to TBMs in the construction industry, developed survey questions, conducted surveys among relevant participants, and analyzed the responses. The study's findings can be summarized in three main points.

First, the survey analysis indicated that mobile TBMs are more properly conducted than conventional TBMs in terms of key facilitators, the number of participants in TBM activities, and individual opinions voiced.

Second, the site employing mobile TBMs had higher levels of positive perception and satisfaction regarding daily safety activities ($M = 4.24$) compared to the site using conventional TBMs ($M = 3.95$).

Third, the site utilizing mobile TBMs reported higher scores in TBM training effectiveness and the safety awareness of workers ($M = 4.14$) compared to the site implementing conventional TBMs ($M = 3.94$).

The contribution of this study lies in its alignment with the growing trend of emphasizing smart safety management. This study suggested that improving TBM activities initiated by workers can help establish autonomous safety management systems and cultures, ultimately enhancing safety management standards. Moreover, the study confirmed that mobile TBMs are more effective in terms of the safety awareness of workers and TBM effectiveness compared to conventional TBMs.

To implicate this study, safety managers and decision-makers at construction sites can use this study as a reference when considering the adoption of smart safety management tools such as mobile TBMs. Notably, this study was distinct from previous research because it surveyed both workers and managers, providing evidence of the practicality of mobile TBMs.

However, this study had several limitations. Despite selecting sites with the most similar conditions possible for comparison, various complex factors, such as site conditions,

TBM facilitators and managers, individual worker competencies, and the level of the site's safety management system, were not fully considered.

Further research will solve the communication errors of mobile TBM by improving the limitations of mobile communication networks at construction sites. Secondly, further research will suggest ways to improve workers' safety awareness by finding ways to communicate more actively between workers in the mobile TBM process.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/buildings13123024/s1>. Figure S1: Graph showing conventional TBM improvement requests; Table S1: *t*-test results of the positive perception and satisfaction of daily safety activities; Table S2: *t*-test results of TBM training effect and safety awareness of workers; Table S3: Full text of the survey.

Author Contributions: Conceptualization, M.K. and J.J.; methodology, M.K. and J.J.; resources, D.J.; writing—original draft preparation, M.K.; writing—review and editing, J.J.; supervision, J.J.; funding acquisition, J.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was financially supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (No. RS-2023-00213165).

Data Availability Statement: The data generated and analyzed during this research are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy.

Conflicts of Interest: Author Dongmyung Jo was employed by the company Samsung Engineering. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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