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Prototype of a Safety Management Support Tool Using the Results of a Safety Activity Awareness Survey

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ABSTRACT

In recent years, safety management has been increasingly strengthened, and employees are now expected to voluntarily assess safety awareness and organizational culture. However, the evaluation of motivation for safety activities is primarily conducted through surveys and interpreting the results and identifying issues often rely on expert assessments. This approach is costly, making detailed analysis at the departmental level difficult. This study aims to develop a system that automatically analyzes the results of safety awareness surveys from multiple perspectives and suggests challenges and solutions for safety management. Using data collected from over 70 businesses, totaling approximately 200,000 individuals since 2007, we modeled the relationships using variance-covariance structure analysis and formulated correlations with expert assessments through machine learning (deep learning). As a result, we developed an application that automatically identifies current challenges in safety activities and provides potential solutions. In summer 2024, the system was implemented in a business with approximately 15,000 employees to evaluate the validity of management advice for on-site operations. Moving forward, we plan to expand the system to industries such as railways, manufacturing, IT services, and healthcare to enhance its practical application.

Keywords: Human factors, Safety management, Safety activity awareness survey

INTRODUCTION

If there is insufficient understanding of safety activities, including countermeasures, at the site where safety and human error countermeasures are implemented, the countermeasures are more likely to become formalities. Human errors are more likely to occur if employees are not motivated to participate in safety activities. It is challenging to maintain high motivation among all frontline workers to engage in safety activities. Human error often seems less significant unless it directly affects the individual.

In safety management activities, on-site 'safety awareness' is one of the most important aspects. However, it is not the overall 'safety awareness' that the site supervisor should evaluate, but the depth of understanding and confidence in individual activities. The depth of understanding and confidence in various safety activities and approaches can provide valuable insights to improve the 'safety awareness' of the department. If the issue

is employee participation in safety management activities, education can be perceived as a mentality of 'doing your best' and 'being positive'. This mindset can lead to the misidentification of problems such as 'lack of feeling' or 'weak awareness', which may contribute to human errors. Such analyses can demotivate workers, discourage them, and put them in situations where they are more prone to errors. This negative cycle can lead to departments being labelled as 'error-prone' or 'error-prone teams'. In the construction industry, safety climate has been shown to strongly correlate with leadership and safety behaviours (Chen et al., 2021). Workplace safety can be perceived by employees as a time-based utility or value (Hantula et al., 2001). Safety culture factors and risk perception vary significantly depending on industry and organizational context (Kao et al., 2007). After major disasters, safety culture is increasingly seen not only as a managerial issue but also as an ethical concern (Kastenberg, 2015). Establishing a flow that allows for the accurate assessment of employees' basic understanding of safety activities and human error, as well as their understanding of various safety management activities, is essential. Reviewing safety management activities based on these assessments can help revitalize overall safety management efforts. Research on safety culture and climate has shown a growing trend, with shifting thematic focus over time (Li and Hale, 2016). Improving process safety culture often benefits from using root cause analysis (Sutton, 2008). Additionally, a safe workplace can contribute to higher customer satisfaction (Willis et al., 2012). By understanding employees' perceptions of human error and safety activities, safety management issues can be more effectively identified and addressed. This study aims to utilize data from the "Employee Understanding of Safety Activities Survey", which has been conducted across various industries (e.g., railways, airlines, steel, heavy industry, medical, IT services, general contractors, etc.) since 2010, and to develop tools based on these findings.

MATERIALS

This study utilized a survey consisting of 55 items, organized into seven categories: (1) Basic Knowledge on Human Error, (2) On-site Atmosphere, (3) Check/Confirmation System, (4) Accident/Incident Reporting, (5) Recurrence Prevention Countermeasures, (6) Investigation of Latent Factors on Human Error, and (7) Strategic Safety Management (Tables 1 and 2). The 55 survey items used in this study are part of a validated and widely applied evaluation framework that has been developed and refined through a series of practical implementations (Yokomizo et al., 2009; Mori et al., 2006; Nakayama and Okada, 2006). The questionnaire has been continuously applied since 2010 in various industries such as railway, aviation, steel, heavy industry, healthcare, IT services, and construction. It was originally developed by the authors and has been refined through repeated implementation in practical settings, ensuring its validity and reliability. The dataset used in this study comprises responses from approximately 200,000 individuals across over 70 organizations, collected between 2007 and 2022.

Table 1: Survey items (basic knowledge on human error).

Evaluation Category		Survey Items
Basic Knowledge on Human Error	Fundamental Ideas on Human Factors	1 I think I don't make human errors. 2 I think human errors occur because of low skills (ability). 3 When I make a human error, I would prefer to hide it if possible. 4 I think the cause of human errors is the fault of the person who made the error. 5 I think carelessness and absent-mindedness are the individual's responsibility. 6 I think human errors can be eliminated through individual effort. 7 I think human error prevention measures should focus on developing people who do not make mistakes. 8 When I make a human error, I think it was just bad luck. 9 Writing human error or trouble reports is troublesome, so I only write the bare minimum necessary. 10 I don't understand why I have to write reports for incidents that haven't caused any trouble. 11 I don't know that there is an academic field dedicated to studying human errors. 12 I have never attended a lecture or training on safety or human errors. 13 I think investigating human errors is a waste of time, and I would prefer not to do it. 14 I don't understand the purpose of analyzing human errors. 15 I do not conduct cause analysis of human errors. 16 As long as recurrence prevention is in place, that is sufficient. 17 The current human error prevention activities are sufficient. 18 I am not interested in other companies' human error prevention activities. 19 I think human error prevention activities should be considered and addressed individually. 20 There is no need to manage human errors at the organizational level.

Table 2: Survey items (6 categories).

Evaluation Category		Survey Items
On-site Atmosphere	An environment where individuals feel comfortable reporting incidents when trouble occurs	21 In your department, people who make human errors are sometimes scolded. 22 In your department, punishments are sometimes given for making errors. 23 In your department, there is a tendency to look down on people who make errors. 24 In your department, there is an atmosphere that makes it difficult to report human errors. 25 In your department, investigations into the causes of human errors and troubles tend to focus on assigning blame.
Check/ Confirmation System	Procedures and mechanisms for error prevention through systematic checks	26 I do not know that "Ensuring Transport Safety" includes not only transport safety but also customer safety. 27 In your department, the awareness of prioritizing safety has not taken root. 28 In your department, employees are unable to think and take action on their own in daily operations. 29 In your department, the concept of "Bad News First" is not well understood, implemented, or practiced. 30 In your department, psychological safety is low, and employees cannot freely express their opinions and thoughts.

Continued

Table 2: Continued

Evaluation Category		Survey Items
		31 In your department, it is not easy to make suggestions to the department head, supervisors, or senior colleagues. 32 You are not familiar with the regulations that outline the "Basic Safety Policies." 33 In your department, regular training on the "Basic Safety Policies" is not conducted. 34 In your department, the "Basic Safety Policies" and the "Code of Conduct for Officers and Employees Regarding Transport Safety" are not being practiced. 35 In your department, regulations, manuals, and checklists are not reviewed regularly, and continuous improvements are not being made.
Accident/Incident Reporting	Investigation and analysis of accident causes	36 In your department, trouble case analyses are sometimes conducted based only on the reports from those directly involved in the incident. 37 In your department, managers do not visit the site of the trouble to conduct investigations. 38 In your department, investigations focus only on the moment when the trouble occurred, without examining the workflow leading up to the incident. 39 In your department, the factors and background of human errors are not analyzed. 40 In your department, investigations focus only on direct causes, without examining indirect or latent causes.
Recurrence Prevention Countermeasures	Measures to prevent the recurrence of incidents	41 In your department, human error countermeasures sometimes consist only of the reflection of those involved in the trouble. 42 In your department, countermeasures focus on raising awareness, including that of the individuals involved and the entire department. 43 In your department, countermeasures are not planned according to the background of human errors. 44 In your department, statistical analysis of trends and characteristics of trouble occurrences is not conducted. 45 In your department, countermeasures from other companies are not used as a reference.
Investigation of Latent Factors on Human Error	Proactive measures, including near-miss incident reporting and minor event prevention	46 I do not know that there is a department responsible for providing guidance on trouble countermeasures in my department. 47 In your department, near-miss incidents are not being accurately collected. 48 In your department, training sessions, including those on human errors, are not conducted regularly. 49 In your department, human error education is not provided to both managers and frontline workers. 50 In your department, information on incidents, near-misses, and their countermeasures is not being shared.
Strategic Safety Management	Organizational-level framework for preventing human errors	51 Not all managers in your department have adequate knowledge of human error management. 52 In your department, information on human error prevention activities from other companies in the same industry or different industries is not being collected. 53 I do not know that there are external connections where advice on human error management can be obtained. 54 In your department, risks related to human errors are not being accurately assessed. 55 In your department, the concept of human error management has not been widely adopted.

METHOD

This study employed a multi-step analysis approach to develop a system that automatically classifies organizational safety awareness levels and generates appropriate feedback.

First, among the 55 items, five core categories excluding "Basic Knowledge" and "Check/Confirmation" were selected for analysis. For each category, a cluster analysis was performed on the normalized distribution of five response options (ranging from 1 to 5). The clustering process was adjusted to maintain even representation across departments and to capture distinct response patterns. The results were stratified into six levels representing varying degrees of safety awareness and reporting culture.

Second, a classification model was developed using LightGBM, a Gradient Boosting Decision Tree algorithm. The model was trained to predict the six-level evaluation hierarchy based on the response distribution ratios as input features. Compared to traditional decision tree algorithms, LightGBM adopts a leaf-wise growth strategy, which enables higher prediction accuracy and reduced computational cost. It also uses Gradient-based One-Side Sampling (GOSS) and Exclusive Feature Bundling (EFB), making it suitable for large-scale organizational data.

Finally, a comment generation mechanism was integrated into the system. For each predicted evaluation level, the system automatically selects and outputs a feedback comment tailored to the organization's response tendencies. These comments are based on expert assessments and practical safety management insights, enabling the system to offer actionable advice.

As illustrated in Figure 1, the proposed system consists of two main steps following the input of survey responses. In Step 1, the response distributions are analyzed using LightGBM, which automatically determines the evaluation levels for each of the five categories. In Step 2, based on these levels, the system generates feedback comments referencing expert evaluation data. These outputs provide safety managers with insights into employees' understanding of safety activities, supporting smooth and effective safety operations. Ultimately, this process contributes to raising employees' safety awareness through tailored guidance derived from organizational data. (Figure 1).

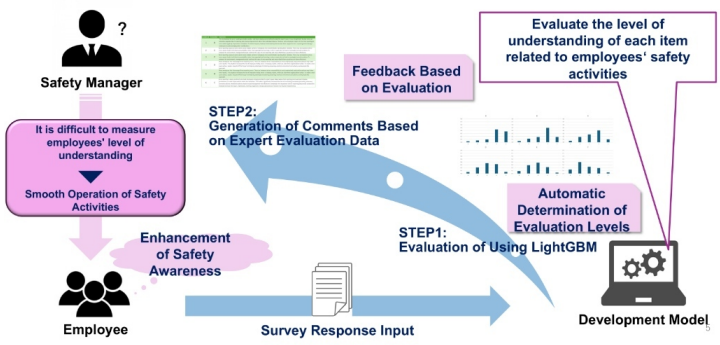

Figure 1: Outline of the supporting system developed in this study.

Classification and Stratification of Evaluation Scales Using Response Patterns

In this study, we first conducted cluster analysis on response patterns for five items, excluding the basic concepts and checklist among the 55 survey items. These clusters were then stratified into six levels. The cluster analysis was adjusted to ensure that response patterns across different departments were evenly distributed, and responses with distinct tendencies were appropriately identified. Groups were formed at unit size ranging from several dozen to around one hundred individuals. As a concrete example, this paper presents the stratification results for "Atmosphere" (Figure 2).

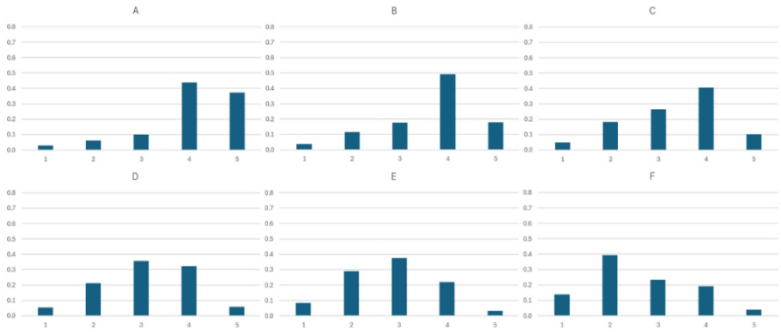

Figure 2: Six-level response patterns ("On-site Atmosphere").

Upon analyzing the histogram distributions of each cluster, clear trends were observed regarding the status of error reporting and the degree of psychological safety within the organization.

Cluster A: Predominantly responses of 4 and 5, with minimal selections of 1 to 3. This indicates a highly favorable error reporting culture, where employees feel secure in reporting errors, reflecting a high level of psychological safety. In such organizations, errors are appropriately shared, enabling prompt implementation of corrective measures and effective risk management.

Cluster B: While 4 is the most frequent response and 5 is also present, there are slight occurrences of responses from 1 to 3. This suggests that, although the error reporting environment is generally well-established, some employees may still harbor concerns. Particularly, there may be apprehension among employees that reporting could negatively impact their evaluations. Therefore, it is necessary to further encourage error reporting and for management to actively provide feedback to ensure a higher degree of psychological safety.

Cluster C: Responses of 3 and 4 are predominant, with 1 and 2 being less frequent but still present. This implies that, while the organization's safety culture is somewhat established, there is variability in the frequency and quality of error reporting. Some employees understand the significance of error reporting and engage proactively, but there may not be a unified approach across the organization. Differences in managerial responses and

feedback quality could lead to varying levels of comfort in reporting errors across departments. Moving forward, it is essential to reform management's mindset and enhance transparency in error reporting.

Cluster D: The majority of responses are 3, with 2 and 4 also comprising a significant portion. This suggests that error reporting is not sufficiently promoted within the organization. If there is a tendency to emphasize individual responsibility post-reporting, employees may hesitate to report errors. Continuing in this manner could lead to concealment of issues, increasing the risk to organizational safety. Therefore, fostering a culture that focuses on utilizing errors for improvement rather than assigning blame, and ensuring management actively secures psychological safety, is necessary.

Cluster E: Responses of 2 and 3 are prevalent, with 4 and 5 being very rare. This distribution indicates that the error reporting culture is not well-established, and many employees feel significant resistance to reporting. Particularly, if employees believe that reporting could lead to blame or lower evaluations, error concealment may become routine, severely hindering organizational improvement. To address this, management must consistently communicate the importance of error reporting and provide appropriate feedback to reporting employees. Additionally, it is urgent to reassess perceptions of human error and advance education and awareness reforms.

Cluster F: Responses of 1 and 2 are predominant, with very few responses of 3 or higher. This distribution suggests that error reporting is scarcely conducted, and psychological safety is extremely low. If reporting leads to severe reprimands or punitive actions, employees will avoid reporting errors altogether. Past experiences where reporting employees faced isolation, or disadvantages may further exacerbate this trend. In such situations, identifying the root causes of human errors and implementing preventive measures becomes exceedingly difficult. To fundamentally transform the organization's safety culture, it is imperative to reform management's mindset and initiate top-down policy changes. In the short term, introducing incentive systems for error reporting and establishing mechanisms to ensure reporting does not negatively impact evaluations are necessary steps.

Automatic Evaluation Hierarchy Determination and Feedback Generation Using LightGBM

In this study, we utilized response data collected between 2007 and 2022 to create feedback comments corresponding to evaluation results for five items, excluding basic concepts and checklists from the 55-question survey. Using these data, we trained a model with six-level hierarchical evaluations as training data, employing LightGBM, a type of Gradient Boosting Decision Tree (GBDT).

Traditional decision tree algorithms adopt level-wise growth, where all branches are expanded evenly, often leading to higher computational costs. In contrast, LightGBM employs leaf-wise growth, prioritizing the expansion of branches with more information, thereby achieving high-accuracy predictions with reduced computation. Additionally, LightGBM

utilizes Gradient-based One-Side Sampling (GOSS) to focus on learning from significant data and Exclusive Feature Bundling (EFB) to group low-correlation features, enabling efficient learning even with high-dimensional data.

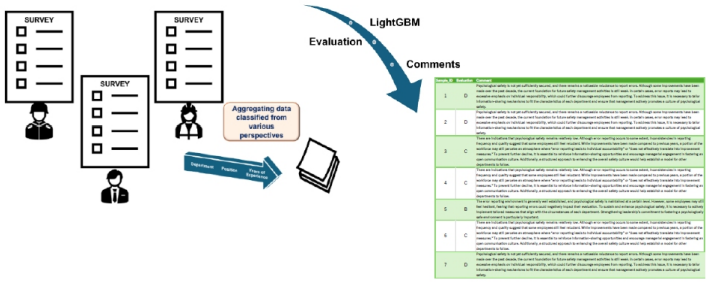

Figure 3: Examples from response results to evaluation and comment output.

As a result, compared to traditional decision tree algorithms, LightGBM achieves faster and more accurate classification while minimizing computational costs.

Leveraging these characteristics, we constructed a classification model that takes the feature quantities of each response pattern as input and outputs the corresponding evaluation hierarchy. The input data consists of normalized proportions of responses ranging from 1 to 5 for specific evaluation items within the departments under assessment. By applying this method, when new response data are input, the system automatically determines the hierarchy for each evaluation item and instantly generates corresponding feedback comments.

In this paper, we present an example of evaluation results obtained by inputting response data collected in 2024 (Figure 3).

Table 3: Presents the similarity between the generated comments and the actual comments.

Sample_ID	Evaluation	Generated Comment	Actual Expert Comment	Similarity Score
1	D	Psychological safety is not yet sufficiently secured, and there remains a noticeable reluctance to report errors. Although some improvements have been made over the past decade, the current foundation for future safety management activities is still weak. In certain cases, error reports may lead to excessive emphasis on individual responsibility, which could further discourage employees from reporting. To address this issue, it is necessary to tailor information-sharing mechanisms to fit the characteristics of each department and ensure that management actively promotes a culture of psychological safety.	There is a tendency for psychological safety to be low. Although it has significantly improved compared to ten years ago, it is still weak as a foundation for future activities. However, it is important to foster an environment for information sharing (management) to ensure that supervisors do not hesitate to provide guidance.	0.7713

Continued

Table 3: Continued

Sample_ID	Evaluation	Generated Comment	Actual Expert Comment	Similarity Score
2	D	Psychological safety is not yet sufficiently secured, and there remains a noticeable reluctance to report errors. Although some improvements have been made over the past decade, the current foundation for future safety management activities is still weak. In certain cases, error reports may lead to excessive emphasis on individual responsibility, which could further discourage employees from reporting. To address this issue, it is necessary to tailor information-sharing mechanisms to fit the characteristics of each department and ensure that management actively promotes a culture of psychological safety.	There is a tendency for psychological safety to be low. Although it has improved compared to ten years ago, it remains quite weak as a foundation for future activities. However, it is important to foster an environment for information sharing, tailored to the characteristics of each district, to ensure that supervisors do not hesitate to provide guidance (on-site management).	0.806
3	C	There are indications that psychological safety remains relatively low. Although error reporting occurs to some extent, inconsistencies in reporting frequency and quality suggest that some employees still feel reluctant. While improvements have been made compared to previous years, a portion of the workforce may still perceive an atmosphere where "error reporting leads to individual accountability" or "does not effectively translate into improvement measures." To prevent further decline, it is essential to reinforce information-sharing opportunities and encourage managerial engagement in fostering an open.	There is a tendency for psychological safety to be low. To prevent further deterioration, we hope that the appropriate implementation of psychological safety will be actively promoted in accordance with the situation of each department.	0.5801
4	C	There are indications that psychological safety remains relatively low. Although error reporting occurs to some extent, inconsistencies in reporting frequency and quality suggest that some employees still feel reluctant. While improvements have been made compared to previous years, a portion of the workforce may still perceive an atmosphere where "error reporting leads to individual accountability" or "does not effectively translate into improvement measures." To prevent further decline, it is essential to reinforce information-sharing opportunities and encourage managerial engagement in fostering an open.	Psychological safety is low. It is important to foster an environment for information sharing (management) to ensure that supervisors do not hesitate to provide guidance.	0.758
5	B	The error reporting environment is generally well established, and psychological safety is maintained at a certain level. However, some employees may still feel hesitant, fearing that reporting errors could negatively impact their evaluation. To sustain and enhance psychological safety, it is necessary to actively implement tailored measures that align with the circumstances of each department. Strengthening leadership's commitment to fostering a psychologically safe environment is particularly important.	There is a tendency for psychological safety to be low. To prevent further deterioration, we hope that the appropriate implementation of psychological safety will be actively promoted in accordance with the situation of each department.	0.6629

Continued

Table 3: Continued

Sample_ID	Evaluation	Generated Comment	Actual Expert Comment	Similarity Score
6	C	There are indications that psychological safety remains relatively low. Although error reporting occurs to some extent, inconsistencies in reporting frequency and quality suggest that some employees still feel reluctant. While improvements have been made compared to previous years, a portion of the workforce may still perceive an atmosphere where "error reporting leads to individual accountability" or "does not effectively translate into improvement measures." To prevent further decline, it is essential to reinforce information-sharing opportunities and encourage managerial engagement in fostering an open communication culture. Additionally, a structured approach to enhancing the overall safety culture would.	There is a tendency for psychological safety to be low. Although it has significantly improved compared to ten years ago, it remains quite weak considering its role as a central command center. We hope that the appropriate implementation of psychological safety will be actively promoted to serve as a leading example for other departments.	0.5663
7	D	Psychological safety is not yet sufficiently secured, and there remains a noticeable reluctance to report errors. Although some improvements have been made over the past decade, the current foundation for future safety management activities is still weak. In certain cases, error reports may lead to excessive emphasis on individual responsibility, which could further discourage employees from reporting. To address this issue, it is necessary to tailor information-sharing mechanisms to fit the characteristics of each department and ensure that management actively promotes a culture of psychological safety.	There is a tendency for psychological safety to be low. Although it has significantly improved compared to ten years ago, it is still weak as a foundation for future activities. However, it is important to foster an environment for information sharing (management) to ensure that supervisors do not hesitate to provide guidance.	0.7713

The comments for each evaluation were organized and constructed based on existing human factories and expert opinions. In this study, we measured the semantic similarity between the generated comments and the assessment results provided by experts and safety managers from various organizations. To measure this similarity, we utilized the pre-trained Sentence-BERT (SBERT) model "sentence-transformers/paraphrase-multilingual-MiniLM-L12-v2". This model maps sentences and paragraphs to a 384-dimensional dense vector space, facilitating tasks such as clustering and semantic search. We converted each text into embedding vectors and then calculated the cosine similarity between them. The resulting similarity scores ranged from 0.5663 to 0.7713, with all scores exceeding 0.5 (Table 3).

The measurement results indicate that the generated comments exhibit a certain degree of similarity to the actual comments, suggesting they are generally appropriate. Specifically, comments with scores above 0.75 imply expressions and content nearly identical to the actual comments. Conversely, comments with scores around 0.6 may reflect differences in expression or information content; however, no significant discrepancies were observed. To achieve higher similarity in the future, adjusting expressions to better reflect the characteristics of actual comments is considered effective.

CONCLUSON

Much of the safety-related information, especially human error-related information, is obtained through reports from the workplace. In addition to the knowledge and experience of the field, the quality and quantity of the information collected can be enhanced by increasing the willingness to collect information.

Detailed analysis of the results of comprehension surveys can help to identify ways to motivate employees to participate in safety and human error response activities. If employees are motivated to participate, it is expected that this will lead to a revitalization of safety activities as a whole. Furthermore, if a mechanism can be introduced to accurately collect a variety of information while devising ways to increase the level of understanding of safety activities in the workplace, this will also promote DX in all aspects of work, including safety activities. We plan to enhance the predictive accuracy of LightGBM by optimizing feature selection and tuning hyperparameters. We also intend to compare this model with other approaches, such as deep learning, to construct a more precise evaluation model. Currently, evaluations are conducted on individual items like "atmosphere"; however, analyzing relationships with other evaluation items and developing an integrated evaluation model will improve the system's versatility. Additionally, by collecting and training data from a broader range of organizations, we aim to strengthen the model's adaptability, ensuring effective functionality across various industries and organizations. To verify the system's effectiveness and practicality in real-world settings, we will collaborate with companies and organizations for system evaluation. Gathering feedback from actual users and continuously refining the system will help evolve it into a more user-friendly and practical tool. The automated evaluation system developed in this study has the potential to enhance the quality of human error prevention activities within organizations. Through ongoing improvements in practical applications, we strive to build an even more effective system.

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