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REAL-TIME CONSTRUCTION SAFETY MONITORING WITH OBJECT DETECTION ALGORITHMS: FEATURES' IDENTIFICATION AND IMPLEMENTATION CHALLENGES

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ABSTRACT:

This research bridges this gap by identifying the essential features and functionalities construction professionals prioritize for effective object detection in real-time safety monitoring. By understanding these needs, this study guides the development of more practical and impactful object detection models, ultimately leading to enhanced safety monitoring and management. Through a questionnaire survey targeting 240 construction professionals, this study gathered insights into current safety management practices, practical considerations for technology implementation, and most importantly, the preferred features for object detection systems. The survey revealed an industry trend towards proactive safety management approaches, with a particular emphasis on features that enable real-time worker tracking and work environment monitoring. While acknowledging the potential benefits of object detection technology, professionals also highlighted concerns regarding data privacy, integration with existing systems, and implementation costs. This study addresses these concerns by emphasizing the need for user-focused, affordable, and seamlessly integrated object detection applications.

1. INTRODUCTION

Safety in construction is a critical issue that affects not only the workers on site, but also the overall success of a project (Li et al., 2015). The construction sector exhibits a notably elevated occurrence of injuries and accidents compared to other industries, resulting in substantial expenses, project setbacks, and potential loss of life (Alkaissy et al., 2022). Falls, object strikes, and electrocutions were the primary causes of fatalities among private sector workers in the construction industry (Singh and Maiti, 2020). Based on data provided by the Bureau of Labor Statistics (BLS, 2021), the construction industry experienced a rate of nonfatal occupational injuries and illnesses of 2.9 cases per 100 full-time workers in 2021. The effective management of risk is a crucial element in ensuring construction safety. This process entails the identification of potential hazards, the evaluation of the corresponding risk level for each hazard, and the implementation of appropriate measures to mitigate or eliminate the identified risks (Newaz et al., 2022). Effective safety management can help to prevent injuries and accidents, improve productivity, and reduce costs (Dobrucali et al., 2022). However, despite ongoing efforts to improve safety in construction, accidents and injuries continue to occur at a high rate. This highlights the need for new and innovative approaches to construction safety management, such as the use of real-time monitoring algorithms and deep learning technologies (object detection algorithms), which have the potential to significantly improve safety on construction sites.

The emergence of advanced technologies, such as deep learning, offers a transformative approach to construction safety. The term 'real-time' refers to the system's ability to process and analyze data, using object detection algorithms, nearly instantaneously as it is captured. This enables the immediate identification and analysis of objects within the monitored environment, facilitating prompt generation of insights and actionable responses (Alateeq et al., 2023; Lee and Lee, 2023; Mei et al., 2023), detect and track individuals and equipment (Song et al., 2023; Wu et al., 2022; Zuraimi and Zaman, 2021), and automatically detect and prevent collisions (Chern et al., 2023; Elelu et al., 2023; Kim et al., 2017; Son et al., 2019). The application of object detection algorithms in construction safety management presents a unique opportunity to shift the paradigm from reactive to proactive safety measures. By automatically identifying and tracking workers, equipment, and potential hazards in real-time, these algorithms can provide insights for preventing accidents and improving overall safety performance. However, the successful implementation of such technology relies heavily on understanding the specific needs and challenges faced by construction professionals. While deep learning has been increasingly explored for construction safety applications, particularly in object detection, there remains a critical gap in research that integrates expert opinions and

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industry needs in the development and implementation of these models (Hou et al., 2021; Pham et al., 2021). This study addresses this gap by focusing on the practical application of deep learning-powered real-time safety monitoring algorithms in construction, specifically through identifying the object detection features that are needed in the upcoming models. This is achieved by conducting a questionnaire survey to gather insights from industry professionals on the use of object detection algorithms for construction site safety management. The survey aims to: (1) assess current safety management practices, (2) identify preferred system features, and (3) outline challenges to integrating object detection algorithms into safety management practices. By analyzing the collected data, this study seeks to provide recommendations and pave the way for the successful adoption of object detection algorithms as a transformative tool for improving construction safety.

2. EXPERIMENTAL INVESTIGATION

2.1 Construction Safety Management

The construction industry around the globe frequently faces numerous safety issues, presenting a major challenge to occupational health and safety measures [19]. Construction sites are typically characterized by their dynamic, complex, and often high-risk environment [1]. Therefore, understanding the nature of hazards in the construction industry is the first step towards addressing the associated safety issues. Statistically, the construction industry has one of the highest accident rates among all industries, contributing significantly to the global occupational fatality rate. According to [20], construction-related accidents account for nearly 30% of occupational fatalities worldwide. Moreover, the nonfatal injury rate is also disconcertingly high, often resulting in temporary or permanent disabilities, causing a ripple effect of socio-economic implications. Factors contributing to the high accident rates in construction are manifold, encompassing technical, managerial, and human elements. Inadequate hazard identification, insufficient safety training, poor communication, equipment malfunction, and human error are often cited as primary causes of construction accidents [21]. However, the effectiveness of these traditional safety measures is often compromised by factors such as non-compliance, inadequate training, poor communication, and the dynamic and unpredictable nature of construction environments [22]. The inherent limitations of these conventional safety measures underscore the need for innovative approaches, particularly technological interventions, to enhance safety performance in the construction industry.

2.2 Deep learning in construction

Technological advancements have indelibly marked almost every industry, and the construction sector is no exception. The deployment of innovative technologies within construction practices has not only facilitated efficiency and productivity but has also served as a crucial driver for enhancing safety measures (Hou et al., 2021). The relationship between technology and safety in construction is an emerging field of study that has identified many effective strategies for reducing the common risks in construction work (Baduge et al., 2022). Early technological interventions in construction safety focused on conventional methods such as safety training through educational videos, use of standard safety equipment, and manual site inspections (Arif et al., 2021; Yao et al., 2022). While these contributed to risk reduction, they lacked the capacity for proactive hazard prediction and prevention (Baduge et al., 2022). In contrast, recent advancements like Building Information Modelling (BIM) (Yi et al., 2015), Virtual Reality (VR), and Augmented Reality (AR) have significantly improved safety planning, training, and hazard identification (Li et al., 2018). Drones or unmanned aerial vehicles (UAVs) further augment this capability by providing aerial site inspections, minimizing human exposure to dangerous environments (Nwaogu et al., 2023). However, the limitations of these technologies, including high operational costs and extensive data analysis requirements, have paved the way for more advanced solutions (Khalid et al., 2021). Here, the role of deep learning, a subset of machine learning (ML) as showing in Figure 1, becomes critical (Singh and Maiti, 2020).

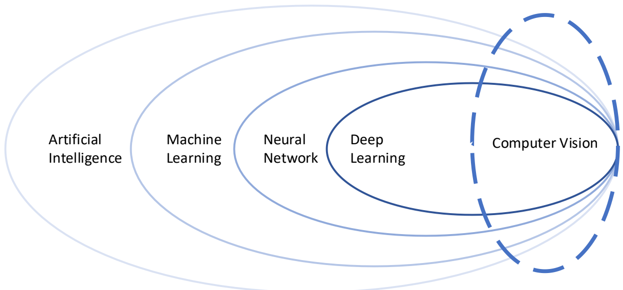

Figure 1. Artificial intelligence, machine learning, and deep learning intersections with computer vision

Deep learning enables the analysis of vast datasets, identification of patterns, and generation of actionable insights (Emaminejad and Akhavian, 2022). Computer vision, , as depicted in Figure 1, a key application of deep learning, leverages algorithms like Convolutional Neural Networks (CNNs) to process and analyze visual data from the real world (Alateeq et al., 2023). Within computer vision, object detection algorithms stand out for their ability to identify and locate objects within images, making them particularly valuable for monitoring construction sites (Song et al., 2023). These algorithms can perform real-time monitoring and hazard detection, facilitating immediate corrective actions and reducing accidents (Liu et al., 2022; Nath et al., 2020; Wang and El-Gohary, 2023). They can identify safety violations such as inadequate PPE usage and unsafe machinery operation (Anushkannan et al., 2022; Nath et al., 2020). Furthermore, object detection algorithms can predict potential hazards and failures in construction processes (Ayhan and Tokdemir, 2019), shifting the safety management paradigm from reactive to proactive. The integration of traditional safety practices with the predictive capabilities of object detection algorithms creates a framework for proactive safety management, leading to a safer work environment for construction professionals.

However, despite the potential of object detection algorithms to improve safety management in construction, there is a notable gap in research regarding the perspectives of industry professionals. While previous studies have focused on developing object detection algorithms models and theoretical frameworks, the practical implications and real-world challenges faced by construction professionals remain underexplored. Additionally, research on integrating object detection algorithms with existing safety algorithms and examining their successful implementation and adoption by industry professionals is lacking. This study aims to address these gaps by employing a questionnaire survey to gather insights from industry professionals on the use of object detection algorithms for construction site safety management

3. METHODOLOGY

3.1 Research Philosophy and Design

This study employed a pragmatic approach to identify key features and functionalities required for effective object detection models in construction safety. A comprehensive online survey, targeting construction professionals with experience in safety management practices, was conducted to gather a diverse range of perspectives. The survey design focused on identifying desired system features, understanding the challenges of implementing these technologies, and exploring considerations for successful adoption within the industry.

To effectively capture the preferred features of object detection models for construction safety, this study employed a comprehensive online survey targeting a diverse group of construction professionals. The online survey methodology facilitated the efficient collection of data from a substantial sample size, ensuring representation across various cultural and economic backgrounds. While recognizing the inherent limitations of survey methods in obtaining in-depth perspectives, this method effectively gathered quantitative data on preferred functionalities and challenges encountered by construction professionals. This data provides a valuable foundation for feature identification and model development. Future research could complement these findings with qualitative studies to delve deeper into individual experiences and needs.

The research design focused on identifying and analyzing industry needs and preferences for object detection models in construction safety. The study employed a mixed-methods approach, utilizing a questionnaire survey to gather quantitative data on desired features and functionalities, while also incorporating qualitative insights from open-ended survey responses to gain a deeper understanding of the challenges and opportunities associated with object detection technology implementation (Fellows and Liu, 2015). This design was conceived to not only investigate theoretical safety measures but also their practical deployment across the globe, as evidenced by a thorough literature review. This foundational work paved the way for a deeper investigation into the latest advancements in real-time monitoring technologies, particularly those powered by object detection algorithms, and their pivotal role in enhancing safety at construction sites. The study developed targeted questions aimed at understanding construction professionals' preferences for features and functionalities within object detection systems. A pilot study was conducted with a select group of international construction professionals to ensure the clarity and relevance of the questionnaire. Feedback from the pilot study was used to refine the questions and enhance the validity of the data collected.

Following data collection, an analysis was conducted using descriptive statistics and inferential methods. This analysis served three primary purposes: (1) Identify key features: Determine the specific functionalities and capabilities that construction professionals prioritized for object detection models in safety management. (2) Understanding Challenges and Barriers: Analyze challenges: Understand the barriers and concerns associated with the adoption of object detection technology, informing the development of solutions that address these challenges. (3) Explore correlations: Investigate potential relationships between the responses and the preferences for specific features, providing deeper insights into industry needs. The research process, as illustrated in Figure 2, demonstrates a rigorous approach to data collection and analysis, ensuring the identification of relevant and practical features for enhancing construction safety.

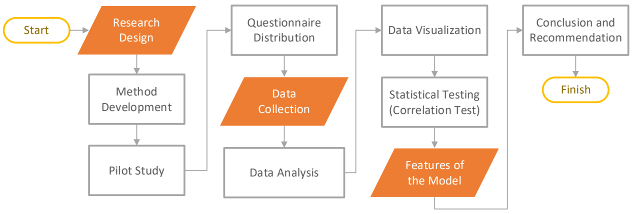

Figure 2. Research flowchart

3.2 Questionnaire Design and Administration

In the process of data collection for scientific research, the design of a questionnaire is considered pivotal for ensuring the efficacy and efficiency of the study. For this investigation, aimed at exploring the use and potential benefits of real-time monitoring algorithms for enhancing construction site safety management, the development of the questionnaire was subjected to a meticulous process. Initially, a review of pertinent literature was undertaken, leading to the identification of key variables and constructs. This alignment of the survey questions—with both open-ended and closed formats—to established theories and knowledge was crucial for ensuring the research's theoretical grounding and its contribution to the existing body of knowledge. The questionnaire employed a diverse range of question types, including Likert-scale items to assess the importance of various features, multiple-choice questions to identify preferred functionalities, and open-ended questions to capture feedback and suggestions. Moreover, the questionnaire was only designed in English. However, to mitigate potential language barriers, terms were simplified as much as possible. This simplification of terms was aimed at ensuring that participants could understand and respond to the questions without significant misunderstanding, thus aiming to maintain the accuracy and validity of the data collected, despite the limitations posed by language differences.

The survey was structured into six sections, each designed to gather specific data relevant to the development of object detection models for construction safety: (1) Demographics and Work Experience, providing context for participants' perspectives; (2) Current Safety Measures, assessing existing practices and identifying areas for improvement; (3) Understanding of Deep Learning and Object Detection, gauging familiarity with these technologies; (4) Potential Impact of Object Detection Algorithms, exploring perceived benefits and challenges; (5) Desired Features and Implementation Considerations, identifying key functionalities and practical requirements; and (6) Feedback and Suggestions, allowing for further refinement of the research approach.

The survey was designed to be completed within 15–20 minutes, and participants were asked to provide their consent to participate in the study before starting the survey. The survey was conducted in English, and participants were asked to indicate their level of proficiency in the English language to ensure that the survey was accessible to all participants. The online nature of this survey inherently encompassed a diverse and global participant pool. To ensure a wide representation, an online distribution method was employed, facilitating the inclusion of participants from diverse cultural and economic backgrounds, resulting in a wider-reaching and potentially more generalizable sample. This inclusivity enriches the study by incorporating a spectrum of perspectives and experiences, particularly relevant in investigating a globally applicable technology like object detection algorithms in safety management.

The sample size was determined using Andrew Fisher's calculation Equation 1 (Dattalo, 2011; Verma and Verma, 2020). To determine the necessary sample size, the study considered the desired level of confidence, margin of error, and the estimated proportion of the population exhibiting the attribute of interest. The formula for calculating the sample size accounts for these factors. Given the absence of prior data, an estimated proportion (p) of 0.5 was used, which is standard practice when the attribute's prevalence is unknown, as it provides the maximum sample size. This assumption provides the maximum sample size for the given margin of error. Using a 90% confidence level and a 5% margin of error in the formula, sample size was calculated approximately 240. Following data collection, a rigorous cleaning and validation process was conducted to ensure data integrity. The analysis employed descriptive statistics and inferential methods to identify statistically significant relationships between variables, with a particular focus on understanding the preferred features for object detection models and the challenges associated with their implementation. This approach allowed for an understanding of industry needs and preferences, directly informing the development of future models.

$$n = (E^2 * p * (1-p)) / E^2) \quad (1)$$

Where:
n = the sample size needed
Z = the z-score associated with the desired level of confidence.
p = the estimated proportion of the population with the attribute being measured
E = the desired margin of error (expressed as a proportion)

3.3 Pilot Study

The execution of a pilot study constitutes an essential part of any scientific research, serving as the cornerstone for validating the relevance and adequacy of the tools used for data collection (Verma and Verma, 2020). To this end, prior to the full-scale survey, a preliminary investigation involving a pilot sample of five construction professionals was conducted to refine the questionnaire and prepare for the main study. These professionals were carefully selected based on their expertise, experience, and willingness to provide feedback. The cohort included two Project Managers, one Quality Engineer, one Civil Engineer, and one Safety Inspector. Their collective knowledge of everyday operations, objectives, and limitations within the construction sector offered a perspective in the initial stages of the study, illuminating potential pitfalls and challenges associated with the questionnaire. The summary of the feedback from the pilot study participants is shown in
.

The pilot study feedback led to several refinements in the questionnaire. Analysis of responses and feedback from the initial participants led to the refinement of several questions to more closely reflect the specific terminology and context of the construction industry. For example, certain questions were identified as being potentially unclear due to their vague language. To address this issue, these questions were reworded for greater precision, ensuring the language was direct and easily comprehensible to all participants. For questions that could be interpreted in multiple ways, additional clarifying notes were provided to assist participants, thereby reducing the likelihood of bias from misunderstandings. These adjustments made certain that each response would be relevant to the study. Furthermore, the pilot study played a role in assessing the online survey's technical setup. It highlighted minor usability issues, such as challenges in selecting multiple options and navigating between sections. Based on this feedback, enhancements were made to the survey platform (e.g., Google Form), including clearer instructions, more visible selection boxes, and streamlined navigation. These improvements aimed to offer a smooth, intuitive, and hassle-free experience for participants when filling out the survey.

Participant	Job Title	Feedback	Action Taken
P1	Project Manager	Suggested adding a question regarding the frequency of safety inspections.	Revised language and simplified technical terms.
P2	Quality Engineer	Found some technical jargon confusing. Recommended simplifying the20ulfil20ee.	Revised language and simplified technical terms.
P3	Civil Engineer	Recommended a question about the use of deep learning in current safety practices.	Revised language and simplified technical terms.
P4	Safety Inspector	Felt the survey was too long. Suggested combining similar questions.	Combined and streamlined several questions to reduce the length.
P5	Project Manager	Wanted more options for "other" selections.	Added free-text "other" options to applicable questions.

Table 1. Summary of the feedback from the pilot study participants

4. DATA COLLECTION AND DESCRIPTIVE ANALYSIS

4.1 Participant Demographics

Over a period of six weeks, data was collected from 240 construction professionals through online platforms and professional networks, reaching a broad range of individuals with diverse experiences in safety management from various countries. This ensured a comprehensive understanding of current practices, challenges, and desired functionalities for object detection algorithms in the industry. The most significant groups were Site Engineers (75 respondents), Safety Engineers (35 respondents), Quality Control Engineers (31 respondents), Planning Engineers (21 respondents), and Project Managers (34 respondents). Other participants included Assistant Lecturers, Construction Managers, Technical Office Engineers, Company Owners, and individuals from various other technical roles. These diverse perspectives provided valuable insights into safety management practices, challenges, and preferences for real-time monitoring algorithms.

Job positions differed in safety management participation. The neutrality of 36.67% of participants may indicate ambiguous role definitions or changeable involvement based on project demands. In contrast, 19.17% participated in safety decision-making, perhaps as Project Managers or Safety Engineers. 22.92% were not directly involved, showing their positions were peripheral to safety management. Figure 3 shows that hard hats, high-visibility apparel, safety glasses, gloves, steel-toed boots, and ear protection were the most often used PPE across locations. This shows the industry's dedication to worker safety and protocol. However, 74.4% of respondents reported daily safety inspections, demonstrating proactive risk mitigation. Weekly and monthly inspections were rare, demonstrating the industry's focus on extensive safety assessments. Participants' safety practices satisfaction varied. Despite 17.9% great satisfaction, 31.3% and 27.1% were dissatisfied. This mixed feedback shows that construction safety practices must be improved and adapted.

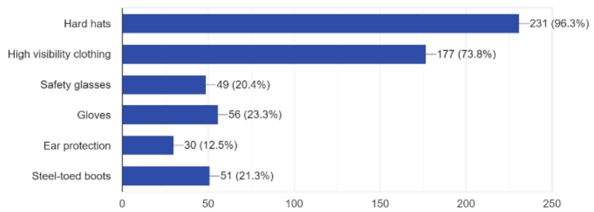

Figure 3. Types of PPE Used on Construction Sites, according to the participants

4.2 Knowledge of Real-Time Monitoring Algorithms

While the survey identified a level of hesitation among some participants regarding the adoption of object detection technologies, the findings also revealed a growing recognition of the potential benefits these models offer for construction safety. The results indicated a preference for features that enhance real-time safety monitoring and management efficiency. Specifically, worker tracking and work environment monitoring were highlighted as top priorities by a significant portion of respondents (212 and 165 respondents, respectively). This suggests a growing industry trend towards proactive safety management approaches, where potential hazards are identified and addressed before they escalate into incidents. Despite this prevalent hesitance, there is a noticeable segment within the industry that is open to adopting real-time monitoring algorithms. About 25 respondents were "extremely likely," and eight were "very likely" to implement these algorithms, reflecting a growing interest and recognition of their safety benefits. Additionally, a moderate group, comprising 21 "moderately likely" and 13 "somewhat likely" respondents, indicates a potential shift towards a more positive stance, given sufficient resources and evidence of the system's effectiveness.

The survey results indicate that a significant portion of participants (30%) expressed confidence in the ability of object detection algorithms to enhance safety on construction sites. This is complemented by 21% expressing very high confidence, suggesting an overall positive outlook towards the potential of these technologies. However, 17% were only "somewhat confident," indicating existing reservations and uncertainties, possibly due to implementation challenges or lack of proven efficacy. Addressing concerns related to data privacy, integration challenges, and implementation costs could be crucial in increasing confidence and encouraging wider adoption of object detection technologies. By providing adequate support, success stories, and addressing concerns, the industry can move towards wider acceptance and implementation of real-time monitoring algorithms, leveraging their capabilities to Improve safety on construction sites.

4.3 Impact of Using Deep Learning Real-Time Monitoring Algorithms

Survey respondents recognized the potential of object detection algorithms to enhance incident response and emergency management as sowing in Figure 4. The immediate notifications and accurate worker location data provided by these algorithms can significantly reduce response times, facilitating more effective emergency protocols and ultimately contributing to a safer work environment (Son et al., 2019; Chern et al., 2023; Elelu et al., 2023). Participants also highlighted the benefits of these algorithms in improving worker safety, increasing compliance with safety regulations, and ultimately leading to a significant reduction in the costs associated with safety incidents.

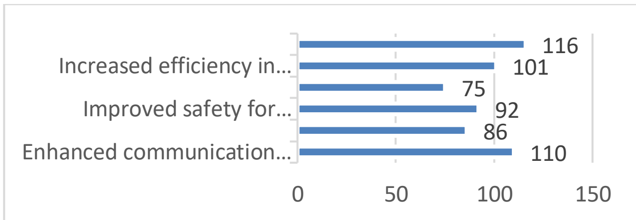

Figure 4. Perceived Benefits of Real-Time monitoring Algorithms

4.4 Desired Deep Learning System Features and Challenges to Adoption

This study investigated the construction industry's preferences and concerns regarding the adoption of object detection algorithms. Specifically, the research differentiated between the system's functionalities, user interface features, and broader objectives like improving site safety and efficiency. Respondents prioritized functionalities such as real-time worker tracking and work environment monitoring, indicating a strong demand for systems that enhance on site safety and operational efficiency. Table 1 categorizes these features into operational functionalities, user interface characteristics, and strategic goals to offer a clearer understanding of industry needs. The "operational functionalities" category emerged as a focal point, with respondents emphasizing real-time worker tracking and work environment monitoring (212 and 165 respondents, respectively). This preference signifies a strong industry interest in leveraging cutting-edge technology to significantly enhance on site safety and operational efficiency. Feedback suggests an acute recognition of the paramount importance of these functionalities in not only ensuring heightened construction site surveillance but also in mitigating prevalent risks like worker collisions, ultimately facilitating a greater understanding and management of site conditions.

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Category	Feature	Number of Responses	Percentage (%) Selecting Feature
Operational Functionalities	Track and Monitor workers in real-time	212	25.39%
	Monitor the work environment	165	19.76%
	Provide real-time alerts and notifications	97	11.62%
	Improve the accuracy and efficiency of inspections	90	10.78%
User Interface Characteristics	Easy and intuitive user interface	59	7.07%
Strategic Goals	Scalability to different construction sites	70	8.38%
	Integration with existing safety algorithms	64	7.66%
	Remote access and control	46	5.51%
	Reporting and analytics capabilities	32	3.83%

Table 1. Preferred Features in Real-Time monitoring Algorithms, according to the participants

Furthermore, the survey responses concerning user interface characteristics shed light on the criticality of user-friendly design. Notably, 59 participants explicitly advocated for an interface that embodies ease and intuitiveness. This aspect highlights the industry's understanding that the utility and effectiveness of real-time monitoring algorithms are intrinsically linked to their user-friendliness. Such an interface is recognized as crucial for ensuring the seamless adoption and integration of these technologies into existing operational workflows, enabling users to effortlessly navigate and leverage the system's capabilities to their full potential. Reflecting broader ambitions, responses within the "strategic goals" segment highlighted the industry's pursuit of operational flexibility and oversight through features like remote access and control (46 participants). Additionally, the expressed need for scalability to diverse construction sites and seamless integration with existing safety algorithms (70 and 64 responses, respectively) illuminates the vision for adaptable and safety solutions. These strategic goals not only envision a technological ecosystem that can effortlessly adjust to varying project demands but also emphasize the imperative for algorithms that enhance safety protocols through advanced integration and customization capabilities.

Through an in-depth examination of these categorizations, the study endeavors to underscore the critical distinctions between the immediate functionalities offered by real-time monitoring algorithms, the interface features that facilitate optimal user engagement, and the far-reaching goals these technologies are aimed to 22ulfil within the construction industry. This analysis underlines the necessity for a multifaceted approach towards evaluating and implementing such algorithms, emphasizing a balance between operational demands, user experience, and strategic considerations.

4.5 Challenges to Adoption

The survey identified several key factors influencing the adoption of real-time monitoring algorithms in the construction industry. Concerns regarding financial constraints (76 respondents), integration with existing systems (111 respondents), and data privacy (62 respondents) were highlighted as primary challenges. However, a significant portion of participants expressed a strong interest in specific functionalities offered by these systems. Notably, real-time worker tracking (212 respondents) and work environment monitoring (165 respondents) were identified as highly desirable features. This suggests a growing recognition of the potential benefits of object detection algorithms in enhancing safety and efficiency on construction sites as showing in Figure 5.

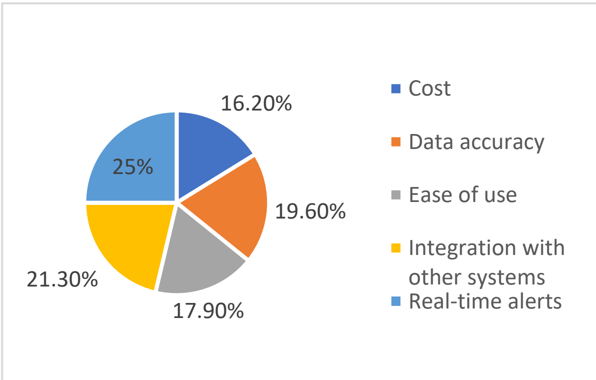

Figure 5. Factors Influencing Efficiency of Safety Monitoring Algorithms

The complexity of data acquisition and labelling, essential for the development of deep learning (DL) algorithms such as object detection algorithms, was highlighted by 37 respondents as a significant challenge, indicating the specialized and often intensive nature of data preparation required for DL models. While 73 respondents pointed to a gap in DL knowledge, it is essential to recognize that the end-users of AI-enabled algorithms need not be experts in DL; instead, they require tools that are effective and user-friendly. Therefore, the emphasis should not be on extensive DL education but on understanding how AI can be applied to improve safety and efficiency in construction. The demand for AI-enabled solutions is further complicated by the absence of industry standards, as indicated by 92 respondents, which hinders the integration and trust in such technologies. As illustrated in Figure 6, the industry's recognition of these challenges underscores the need for streamlined, user-focused AI applications that align with practical needs and existing workflows, while industry-wide standards would provide a framework for consistent and effective implementation of AI technologies in construction safety monitoring.

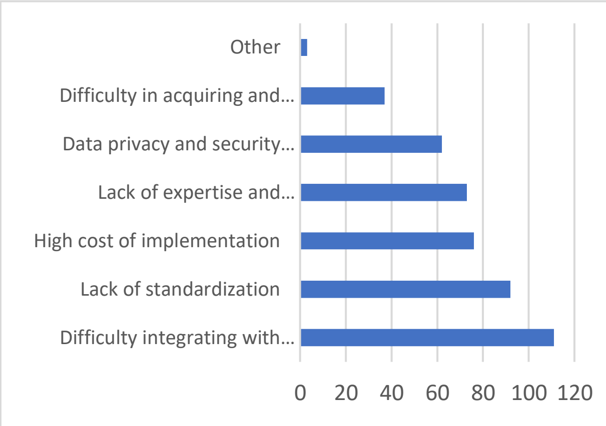

Figure 6. Preferred Technologies for Monitoring Safety on Construction Sites

4.6 Evaluating the Interconnection of Variables Through chi-square Test

The chi-square test matrix presents a overview of the interdependencies among various operational and safety-related factors within the construction industry. The statistical significance of these relationships is pivotal for understanding the dynamics of safety management and the potential impact of real-time monitoring algorithms as showing in
Figure 7. Significant correlations were observed between 'experience' and factors like 'company size', 'PPE', and 'safety inspection'. This suggests that more experienced individuals may play pivotal roles in larger organizations and tend to prioritize the use of PPE and regular safety inspections. Their experience might also contribute to shaping and enforcing safety protocols, reflecting a deeper understanding of safety management. Education level exhibited a notable relationship with 'decision-making', implying that higher educational achievements might correlate with greater authority or involvement in safety-related decisions. This could be attributed to a more understanding of safety protocols and the ability to critically evaluate and implement these practices.
The association between 'safety inspection' and both 'PPE' and 'satisfaction' highlights the link between the frequency of safety checks and adherence to safety equipment usage, as well as job satisfaction. This indicates that regular safety inspections not only ensure compliance with safety norms but also contribute to overall job satisfaction. Additionally, the correlation of 'satisfaction' with 'benefits' suggests that satisfaction in the workplace might be influenced by perceived benefits like reduced accidents and increased operational efficiency. In terms of cost and operational performance, 'cost effectiveness' is significantly linked to 'benefits' and 'efficiency', highlighting the understanding that cost-effective solutions are crucial not only for financial savings but also for enhancing operational performance. The close association between ' monitoring system implementation' and 'confidence' underscores the importance of trust in the system's efficacy for its adoption. Moreover, the relationship between 'benefits' and the likelihood of adopting such algorithms suggests that perceived advantages play a significant role in driving adoption rates. Lastly, the interconnectedness of 'technologies', 'features', and 'integration importance' points to a significant industry trend towards advanced algorithms that offer features and seamless integration.
The significant correlations of 'challenges' with almost all factors, from 'experience' to 'integration importance', underscore the multifaceted nature of challenges in safety management, affecting various aspects of construction practices, including the adoption and implementation of new technologies.

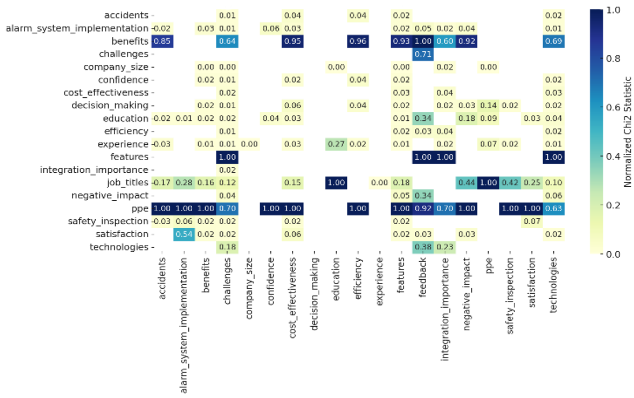

Figure 7. Chi-square Test Results for Association Between Variables in Survey Data

4.7 Predicting Adoption of Monitoring Systems in Construction

The factors influencing the likelihood of implementing monitoring algorithms in the construction industry, a crucial component for enhancing safety and operational efficiency, were investigated using a Random Forest Classifier in this study. The target variable for the model was 'monitoring_system_implementation', which represented different likelihood levels of adopting monitoring algorithms. The selection of key predictor variables was based on their relevance to the context of construction management. These variables encompassed demographic information, opinions, and behavioral factors. The variables considered were 'experience', 'education', 'company_size', 'decision_making', 'safety_inspection', 'confidence', 'accidents', 'cost_effectiveness', 'efficiency', and 'integration_importance'. Label encoding was used to encode the categorical variables in order to facilitate their utilization in the model. For the evaluation of the model's predictive performance, the dataset was judiciously divided into a training set (70%) and a test set (30%). This split ratio was chosen after considering several factors. First, it provides a balanced approach that ensures enough data for training the model while retaining a substantial portion for testing, thus allowing for an evaluation of the model's performance. Furthermore, literature reviews and preliminary testing suggested that this ratio offers a good compromise between overfitting and underfitting, making it a common practice in similar studies where maintaining the generalizability of the model is crucial.
An overall accuracy of 80.56% was demonstrated by the Random Forest model on the test dataset, indicating a strong capacity to predict the likelihood of monitoring system implementation based on the selected factors. Varying degrees of precision and recall were observed in the classification report for different response categories, indicating differences in predictive accuracy based on response frequency in each category. High precision and recall were demonstrated by the model as showing in Figure 8, especially in predicting the most common response category, labelled as '2', which likely represents a moderate likelihood of implementation. The multifaceted nature of decision-making regarding the adoption of safety technologies in construction is illuminated by the results of the predictive model. The willingness to implement new safety algorithms is significantly

influenced by specific combinations of factors, such as experience level, organizational size, and safety perceptions, as indicated by the high accuracy in certain classes.

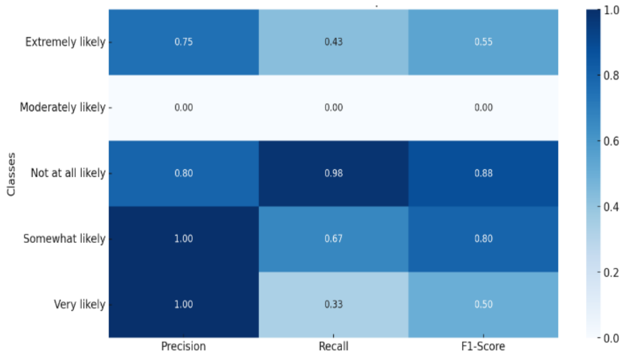

Figure 8. Classification Report of the predictive model

5. DISCUSSION

This study underscores the critical need for enhanced safety protocols within construction sites, a concern shared by industry professionals. The research emphasizes the potential of object detection algorithms to significantly improve construction safety by offering advanced features such as real-time alerts, user-friendly interfaces, and seamless integration with existing systems. These advancements hold the promise of reducing the frequency and severity of accidents, contributing to a proactive safety culture within the industry. The strong preference for real-time alerts signals a shift towards a proactive risk mitigation paradigm. This necessitates the development of object detection models equipped with features that provide immediate warnings for potential safety hazards, enabling prompt corrective actions and accident prevention. These systems could leverage real-time data processing and analysis to identify unsafe situations, such as workers entering restricted zones or equipment malfunctions, triggering instant notifications to relevant personnel.

An overview of the specific features and functionalities deemed important by construction professionals for object detection algorithms-based safety monitoring systems is presented in Table 2. The emphasis placed on real-time alerts suggests a desire within the industry for immediate warnings of potential hazards, enabling prompt corrective actions and accident prevention. This aligns with the growing recognition of the importance of proactive risk management in construction safety. The demand for intuitive and user-friendly interfaces that facilitate seamless adoption and integration into existing workflows is highlighted by the emphasis on ease of use. Resistance from users is likely to be encountered with complex and cumbersome systems, hindering their effectiveness in improving safety practices. This is particularly relevant in the construction industry, where varying levels of technological proficiency may exist among workers. A user-friendly system ensures that the technology can be easily understood and interacted with by all workers, maximizing its impact on safety.

The importance of integration with existing safety systems reflects the understanding within the industry that object detection algorithms should not be viewed as standalone solutions, but rather as complementary tools that enhance existing safety protocols. A safety coverage and facilitated data exchange between different systems can be achieved through this integration, leading to more informed decision-making. For example, a more comprehensive view of safety risks on site could be provided by integrating object detection algorithms with existing CCTV systems, allowing for better risk assessment and allocation of resources. The emphasis on work environment monitoring capabilities demonstrates a significant shift within the construction industry toward a proactive approach to safety. This proactive approach involves identifying and addressing potential hazards before they escalate into incidents. Continuous monitoring facilitated by object detection algorithms enables early intervention, significantly reducing the likelihood of accidents. Recognizing the limitations of traditional manual monitoring methods, the industry advocates for automated identification and tracking of individuals. This automated process, made possible by object detection algorithms, provides real-time data on worker location and movement, aiding in preventing collisions and ensuring worker safety in hazardous areas.

Feature	Brief Description
Real-time Alerts	Immediate warnings for safety hazards to prevent accidents
Ease of Use	Intuitive, user-friendly interface for efficient operation
Integration with Existing Safety Algorithms	Compatibility with existing safety algorithms for coverage
Work Environment Monitoring	Continuous monitoring for potential safety issues
Automatic Identification and Tracking of Individuals	Autonomously tracks workers for safety
Improved Safety Inspection Accuracy and Efficiency	Enhances accuracy and efficiency in inspections
Scalability and Adaptability	Suitable for various sites and projects
Data Accuracy	High-quality data production for effective monitoring
Rich and Diverse Dataset	Utilizes varied scenarios for training and validation
Data Labeling and Annotation	Efficient and accurate data processing
Data Privacy and Security	Maintains high standards for sensitive data

Table 2. Summary of the features needed in the model, according to the survey

The limitations of manual monitoring are recognized by the industry, as reflected in the need for automatic identification and tracking of individuals (implied by the high importance of worker tracking). This process can be automated by object detection algorithms, providing real-time data on worker location and movement, which can be in preventing collisions and ensuring worker safety in hazardous areas. For example, workers and equipment operators could be alerted to potential collisions by an automated tracking system in a busy construction site with heavy machinery operating, significantly reducing the risk of accidents. The features identified in this study will directly inform the architecture and functionality of any object detection model developed for construction safety. The development of algorithms that excel in real-time worker tracking and comprehensive work environment monitoring will be prioritized. This includes utilizing advanced object recognition techniques to identify workers, equipment, and potential hazards within the construction site. To ensure adaptability and effectiveness across diverse projects and environments, the model will be trained on a large, diverse dataset encompassing a range of construction scenarios. Challenges such as financial constraints, data privacy concerns, and the need for user-friendly interfaces will be addressed through the development of cost-effective solutions and the implementation of robust data security measures. Educational resources and training programs will be provided to address knowledge gaps and facilitate seamless integration of these technologies.

6. CONCLUSIONS

This study offers insights into the features and functionalities desired for object detection models in construction safety, as perceived by industry professionals. The findings suggest that the development and implementation of such models could potentially contribute to improved safety practices on construction sites. The primary objective of this research was to identify the essential features and functionalities required for developing object detection algorithms in construction safety applications by gathering data from industry experts. The survey results revealed a strong interest in and belief in the potential effectiveness of real-time monitoring systems for improving construction site safety. Data analysis methods, including chi-square tests and cluster analysis, supported the conclusion that the industry has a significant potential for adopting these technologies.

The integration of object detection algorithms into safety management could potentially lead to improvements in hazard communication, hazard identification, incident response, and a reduction in costs associated with safety incidents. The study's findings offer a potential roadmap for future object detection model development. The prioritization of features such as real-time worker tracking and work environment monitoring underscores the industry's need for solutions that extend beyond basic object detection. Future models could incorporate these functionalities to enable more comprehensive safety monitoring, proactive hazard mitigation, and a safer work environment for construction personnel. It is important to acknowledge the limitations of this study. The participant pool may not be fully representative of the entire construction industry, and the findings may reflect a perspective skewed towards individuals with more experience or familiarity with safety systems. Future research could focus on developing a tailored dataset specifically focused on construction safety hazards. This data, combined with the qualitative research findings, could inform the creation of an object detection algorithm specifically designed for construction sites. This approach could further advance the role of information technology in enhancing construction safety.

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