Web-Based Job Hazard Assessment for Improved Safety-Knowledge Management in Construction

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Abstract –

An essential component of effective safety management systems is the identification and proactive mitigation of hazards through the completion of job hazard assessment (JHA). Aimed at identifying potential hazards and subsequently implementing controls that reduce the likelihood or severity of incidents, JHA is a manual process influenced by the experiences, specific expertise, and biases of safety practitioners, rendering the development of standard mitigation strategies difficult in practice. Due to factors including ineffective information storage and dissemination systems, knowledge management of JHA data remains a challenge in the industry. To overcome these limitations, this paper proposes and describes the development and application of a web-based JHA system designed to enhance JHA management efficiency by facilitating accessibility, interfacing, connectivity, and information-sharing between users during the completion of JHAs. By increasing and facilitating access to information, the proposed system can enhance the consistency of JHAs generated throughout the organization, while also ensuring that potential safety risks are not overlooked by less experienced or otherwise biased personnel. Project and safety managers validated the functionality of the proposed system; they indicated that the proposed system could enhance the efficiency and consistency with which JHAs were generated, resulting in the improvement of real practice. The proposed system's importance is described, and its approach is detailed.

Keywords –

Safety; Job Hazard Assessment; Web-Based; Knowledge Management

1 Introduction

The construction phase of many projects has multiple potential hazards associated with various activities and tasks [1]. Many researchers have aimed to understand, identify, and analyze the root cause of construction-site incidents with the goal of reducing or preventing occupational hazards. These research efforts can be divided into two categories, namely: pre-hazard (proactive) analysis, and post-hazard (reactive) analysis [2]. Whereas reactive analysis research focuses on mitigating future reoccurrence by analyzing incidents that have occurred , proactive analysis research focuses on preventing incidents through advanced construction planning by analyzing factors that may result in potential hazards (e.g., equipment, height, or space requirements) [2]. Planning for safety typically involves the identification of all potential hazards and the selection of corresponding safety measures through a pre-hazard analysis process [3]. Effective safety planning can prevent incidents and the injury of construction personnel, in turn reducing associated project costs and delays [3].

Job hazard analysis (JHA) is one of the most widespread safety management practices for proactive safety planning in construction [2]. The Occupational Safety and Health Administration (OSHA) recommends conducting JHAs to address hazards in the workplace, and to reduce injuries and illnesses [4]. By identifying all potential task-related hazards and suggesting the means to reduce or avoid them, JHAs can be an effective tool for examining workplace operations, establishing proper job procedures, and ensuring that all employees are properly trained [4]. If effectively performed, JHAs can result in fewer worker injuries and illnesses, safer and more effective work methods, reduced workers' compensation costs, and increased productivity [4].

As with many construction practices, efficient management of JHA data is critical for preventing errors from reoccurring,[5] particularly when construction personnel lack sufficient experience, or are biased by the occurrence of prior incidents. A lack of safety knowledge has been reported as one of the main reasons for high incident rates in the construction industry [6]. In many circumstances, worksite fatalities are associated with the insufficient sharing and communication of required information [7]. The role of knowledge management in improving the performance of occupational health and safety systems has been analyzed in the academic literature [8][9], where sharing safety knowledge and experience has been found to improve safety performance. The traditional JHA process requires construction personnel to perform several tasks, including reviewing historical documentation and applying findings to activities on new construction projects [10][11]. While several research studies aimed at enhancing JHA practices have been conducted, none has addressed the inherent problem of knowledge-management in traditional construction JHA practice.

Due to varying site conditions, job constraints, and work environments, no construction project is truly identical to any other. JHAs must be continuously recompiled or re-performed [2][12][10]. While JHA knowledge from previous activities may be revisited for guidance, reviewing previous JHAs can be time-consuming, especially when the number of activities, their steps, and their associated hazards are significant [2]. Additionally, construction personnel creating JHAs must often review fragmented information across various references, such as safety regulations, incident records, best practices, and personal experiences [11]. As a result, the completion of JHAs is an error-prone, time-consuming task [13][10]. Furthermore, the inconsistent use of terminology, lack of detailed information, and inappropriate storage of data may result in knowledge being inadvertently omitted during the development of future JHAs, potentially even creating a false sense of security in documentation.

This paper proposes the design of a web-based system capable of addressing the knowledge management problem inherent to traditional JHA practice. This system uses a dual database approach that allows practitioners to quickly and easily combine pre-defined, task-level JHAs to best suit the specific needs of a project. Implemented as a web-based system, the proposed approach is capable of efficiently managing historical data, unifying JHA knowledge of various experts, facilitating the creation of new JHAs, and easily sharing JHA knowledge between workers.

2 Literature Review

The process of conducting JHAs (reviewed in [2], [4], [13], [14], and [15]) consists of three main stages, as detailed in Figure 1 and detailed as follows:

1. *Identification*: The identification of hazards is performed for a specific job or activity by segmenting the activity into a sequence of stages, resulting in the identification of all possible hazards that may occur during the work. Currently, construction personnel conducting JHAs rely on brainstorming sessions to identify steps within different construction jobs and to identify associated hazards [14].
2. *Assessment*: The assessment is carried out by evaluating the severity level and probability of all identified hazards.
3. *Mitigation and Control*: Strategies for mitigating or controlling hazards are identified and proposed.

Before beginning the job onsite, JHAs are typically read and explained to workers in a pre-task work meeting. To ensure that each worker is familiar with the hazards associated with each task as well as the proposed mitigation strategies, each participant may be required to acknowledge its content by signing a form [10]. Notably, JHAs may also be used by certain project teams or owners for legal purposes [10].

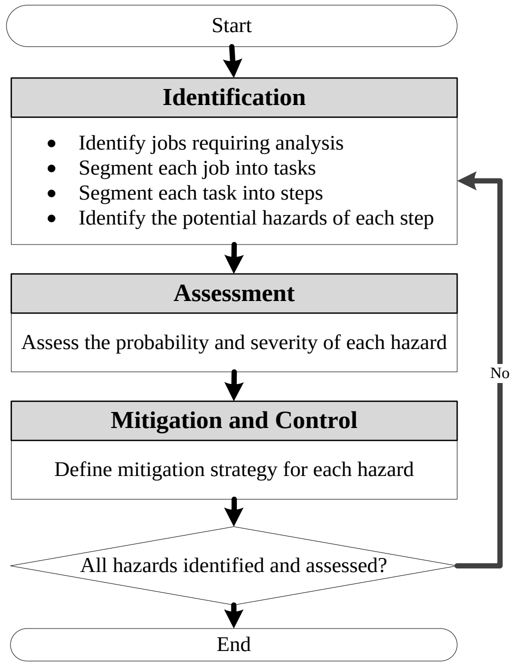

Figure 1. Traditional JHA process

2.1 Enhancing JHA Practices in Construction

Several studies have focused on automating the generation of JHAs. Chi et al. [12] presented a text-classification-based approach that analyzes construction safety documents and extracts safety approaches to automate the 'mitigation and control' step of JHAs. In a separate study, Chi et al. [1] applied an ontology-based text classification to automate the matching of safe approaches identified from existing resources with unsafe scenarios to enhance the development of JHAs. Zhang et al. [10][13] used an ontological approach to capture, model, and connect safety management knowledge to building information models (BIM), enabling automated hazard analysis and safety task scheduling. An ontological approach was proposed by Wang et al. [2] for structuring knowledge regarding activities, job steps, and hazards to enhance access to safety information. Their approach includes an ontological reasoning mechanism for automatically identifying and selecting safety rules that apply to given activities.

Automated prediction of incident sites and activities associated with increased incident likelihood has been the focus of other studies. By linking the information between the CPM schedule and safety-recommendation databases, Bansal [3] introduced a geographic information system (GIS)-based, navigable 3D animation of safety planning for identifying sites and activities with an increased potential for incidents. A structured tool has also been developed for Construction Job Safety Analysis (CJSA) focusing on the identification of potential loss-of-control events for detailed staging of construction activities [15].The goal of this tool is predicting fluctuating safety risk levels and supporting safety-conscious planning and management.

Notably, while previous studies have attempted to automate the identification of hazards, none has focused on developing systems that enhance knowledge management in traditional JHA practice.

2.2 Management of Safety Knowledge

The importance of knowledge management in construction project safety has been extensively reported. By analyzing safety knowledge-sharing through social networks, Fang et al. [6] have examined how construction employees selected their social relations on the basis of safety knowledge. Finding that safety knowledge-sharing through social networks was a significant source of knowledge transfer, the authors concluded that safety education was more critical than tenure during the safety knowledge sharing process. Observing an influence of knowledge exchange systems on safety compliance, Gressgård [5] suggested that knowledge management and exchange systems are central for enhancing safety behavior, particularly in cases involving shift changes, varying working times, high-level subcontracting, and other factors that lead to nonsynchronous knowledge sharing.

Technologies focused on enhancing knowledge-sharing have also been proposed. Li et al. [7] investigated the ability of various technologies to share construction safety knowledge, finding that mobile apps, the Internet of Things (IoT), and Web 2.0 could provide promising solutions for the distribution of knowledge on construction sites. A conceptual, web-based safety knowledge management system designed to improve safety performance and productivity has been discussed by Kamardeen [9]. Similarly, Elzarka et al. [16] proposed a knowledge-based management system capable of integrating safety and schedule information to facilitate the inclusion of safety as an integral part of project planning and control. As an extension of this, a knowledge management tool for small and medium enterprises that allows users to easily aggregate and capitalize on information from various sources has also been developed [17]. Sherehiy and Karwowski [8] have proposed a knowledge management model for effective OSHE (occupational safety, health, and ergonomics) management, establishing knowledge as the central resource.

Although the studies mentioned above share similar objectives with this study (i.e., facilitating safety knowledge development and accessibility), none of these studies has formalized the traditional JHA in a way that can support efficient development, storage, and sharing of the JHAs in construction. A system designed to enhance knowledge management in JHA practice has yet to be developed.

3 System Design and Development

The proposed system is built on the concept of segmenting construction activities (which vary considerably from project-to-project) into a subset of repetitive tasks that can be combined to suit the specific requirements and needs of a particular construction job. Using this system, job-level JHAs are built by combining multiple segments, each containing various combinations of recurring task-level hazard assessments to suit the specific requirements of a project. This approach is expected to reduce the time and effort required to develop JHAs, decrease errors, and increase the consistency of JHAs throughout the organization.

An innovative feature of the system is its dual database design, which allows for the customization of JHAs in one database while ensuring existing knowledge is not lost during the customization process. Specifically, the *Template Database* generated by safety experts contains the entire table of tasks and associated steps, hazards, assessments, tools, and personal protective equipment (PPE), as well as all associated expert knowledge and experience. In contrast, the *JHA Database* contains modified JHAs specific for each project. Safety supervisors search the template database for the required job and pull the job to the JHA database, where the JHA is adapted and modified for the specific conditions of the new project. Since the template database is anticipated to contain all information related to a task, modifications would simply involve the removal of unnecessary safety considerations (e.g., removal of grading considerations if work is to be completed on a flat surface).

3.1 System Architecture

An overview of the proposed JHA process is illustrated in Figure 2. The system's architecture is built using *Django* [18] and a *React & Redux* framework [19]. The system is built on a cloud-based *MySQL* database, which provides a centralized, reliable means of sharing and storing JHA knowledge that is accessible to users from various locations. JHA knowledge is stored on a server, and a standard web browser is used as a gateway to exchange JHA knowledge.

The web-based JHA system is implemented using an architecture composed of the following four logical layers: a user layer, an interface layer, an application layer, and a repository layer. Figure 3 depicts the system architecture and describes the various functional activities that are carried out within the JHA extranet.

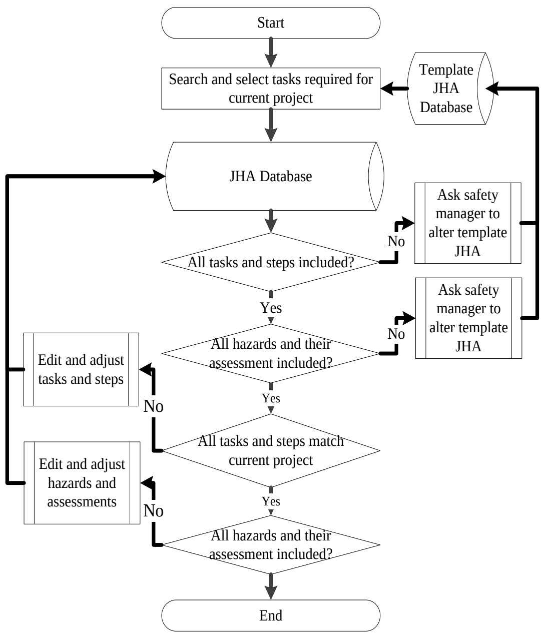

Figure 2. Proposed JHA process

The *user layer* (layer one) is installed on the user's machine and is connected to the server through the *interface layer* (layer two). The interface layer is, in turn, connected to the *repository layer* (layer four), with access to and control over the *information layer* (layer three) within the *MySQL* database, subject to access restrictions. The *interface layer* (layer two) lists the processes available to each user depending on their assigned access level. In the developed system, the following three access-levels are as follows: (1) a safety manager level, which has full access to the system; (2) a safety supervisor level, which can create, edit, view, and download a JHA but is unable to alter the template database; and (3) a worker level, which is limited to viewing and downloading existing JHAs in the system. In summary, the JHA safety knowledge is represented in the form of a relational model using *MySQL*. The relational model [20] defines a set of relations, describes the relationships between entities, and determines how these stored data interact.

3.2 System Development

The main development tools of the system include *React & Redux* [19], a *Django* REST framework (*D*RF) [18], and *MySQL*. The *D*RF connects to the database, which uses *Python* as the programming language. The database is initialized on *MySQL*. *React & Redux* uses *JavaScript* as a programming language. While *React & Redux* acts as the user interface, a cascading style sheet (CSS) layout is used to perform certain formatting functions of the user interface. *React & Redux* uses a built-in tool to connect the system's front end and back end, allowing a front end user to fetch data from the back end, and to push data to the back end.

4 Practical Application of the System

A simple, illustrative example is used to demonstrate the practical application of the proposed system. Involving the operation of an excavator on a construction site, the job is associated with the following three tasks: pre-operation, operation, and post-operation. To build a new JHA, a user logs into the system using the login interface (Figure 4). Once logged in, the user accesses the main dashboard of the system, which varies in appearance based on the user's access level (i.e., visibility of the various components will be affected by the user's access level). For example, the dashboard of a safety manager level user contains the (1) template database, which encompasses the tasks, steps, hazards, tools, and PPE tables; (2) JHA database, which contains all the JHAs of the various projects; and (3) the create button, which initiates the creation of a new JHA (Figure 5). The JHA database in the dashboard of a worker-level user, contrastingly, contains only the means to view and download existing JHAs.

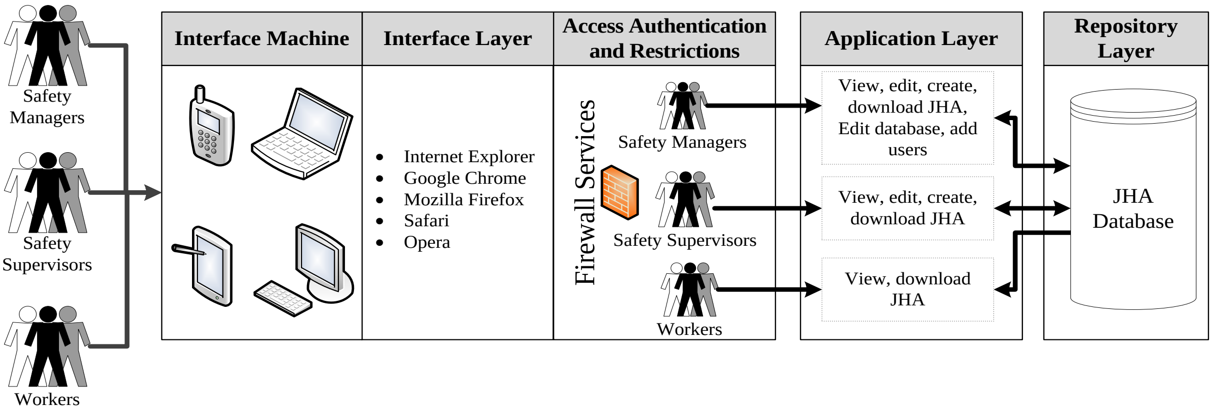

Figure 3. Structure of the JHA system

To initiate the creation of a new JHA, users click on the create button, which triggers the opening of a new window (Figure 6, *top*). This window contains eight tabs: general information, creators, editors, prerequisites, tasks, crew review, and approval tabs, which mimic the layout of a traditional JHA. Tasks are added to a job using the "Tasks" tab (Figure 6, *bottom*); importantly, only predefined tasks contained within the template database can be added to a job, ensuring that all JHAs are first populated with existing, standardized knowledge. Once the predefined tasks have been selected and imported from the template database into the JHA database, subcomponents can be adjusted according to the context of the current project (Figure 7). After all eight of the tabs have been finalized, the new JHA is created and stored in the database where it can be viewed, edited, and downloaded.

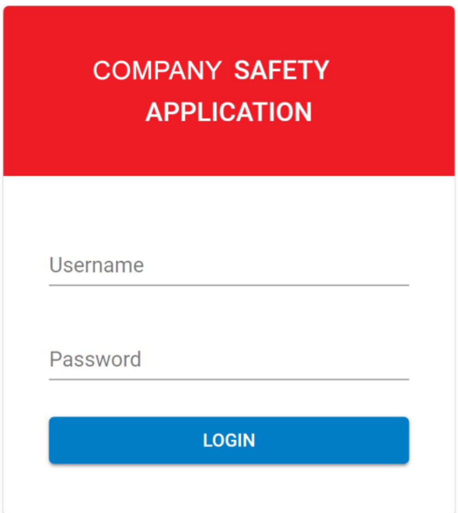

Figure 4. System login

5 System Evaluation

Subject matter experts assessed functionality and determined whether or not the proposed system had the potential to enhance JHA practices. A demonstration of the software was presented to safety managers who were then asked to provide feedback in an interview format. Specifically, they were asked (C1) if they found the system easy to use, (C2) if they thought the system would improve accuracy of generated JHAs, (C3) if the system would allow timelier access JHA knowledge, and (C4) if access to information was improved. All experts interviewed were pleased with the system functionality, indicating that it was straightforward, easy-to-use, and had the potential for improving current practices. Suggested improvements included adding a visualization component that could provide more intuitive insight regarding the number and severity of project-associated risks. In order to quantitatively assess the functionality of the system, the three experts (E1, E2, and E3) were asked to evaluate the system on Likert scale (1-5) where 1 means very low, 2 means low, 3 means medium, 4 means high, and 5 means very high. They were asked to evaluate the system based on the criteria listed above. Experts are not fully satisfied with the initial stage of the system. Future work will increase efficiency.

Table 1. Quantitative Evaluation of Expert Opinion

Criteria	E1	E2	E3	Average	Avg. %
C1	4	5	5	4.67	93.4%
C2	4	4	3	3.67	73.4%
C3	3	4	4	3.67	73.4%
C4	4	5	4	4.33	86.7%

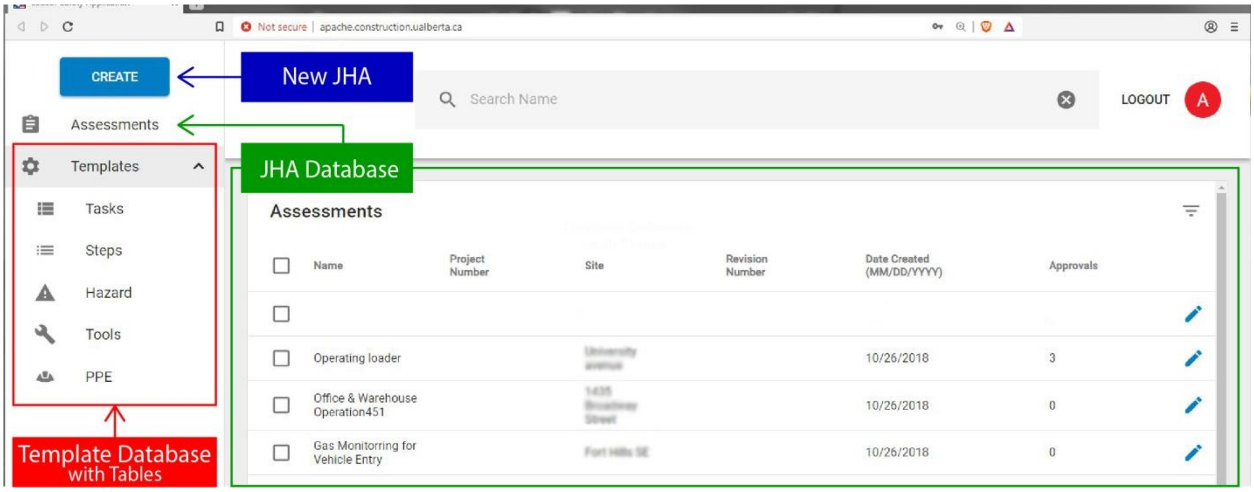

Figure 5. Main dashboard of the system

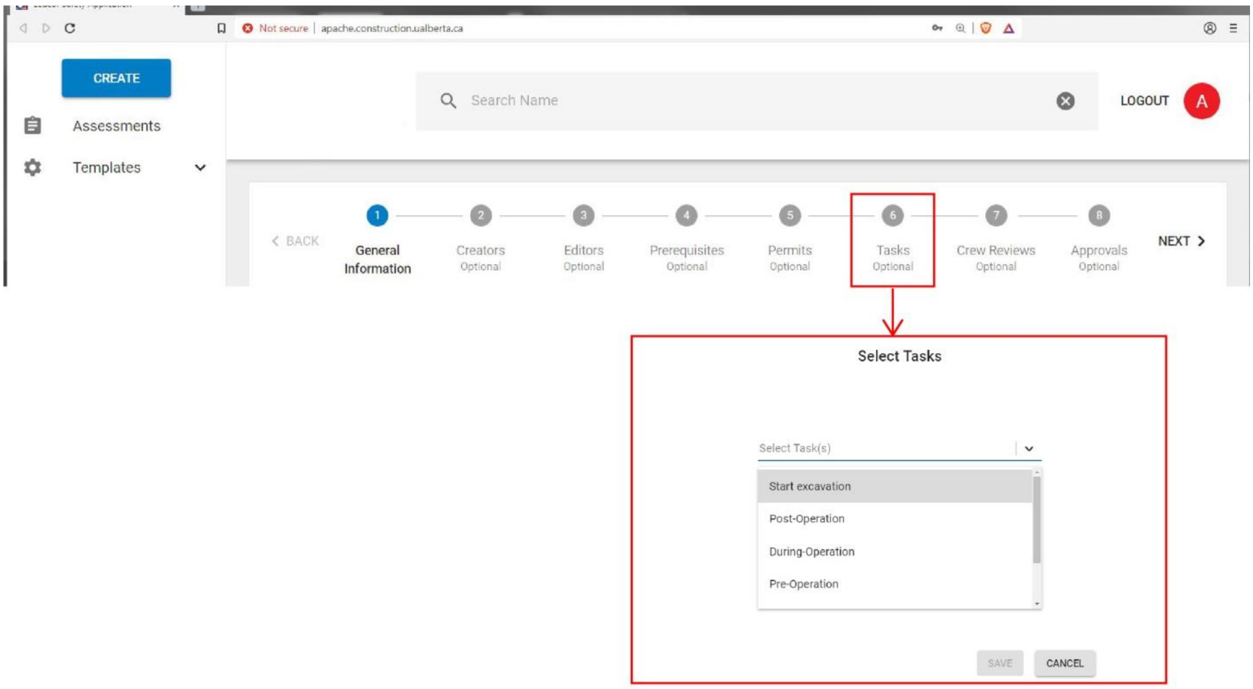

Figure 6. Components of the proposed system

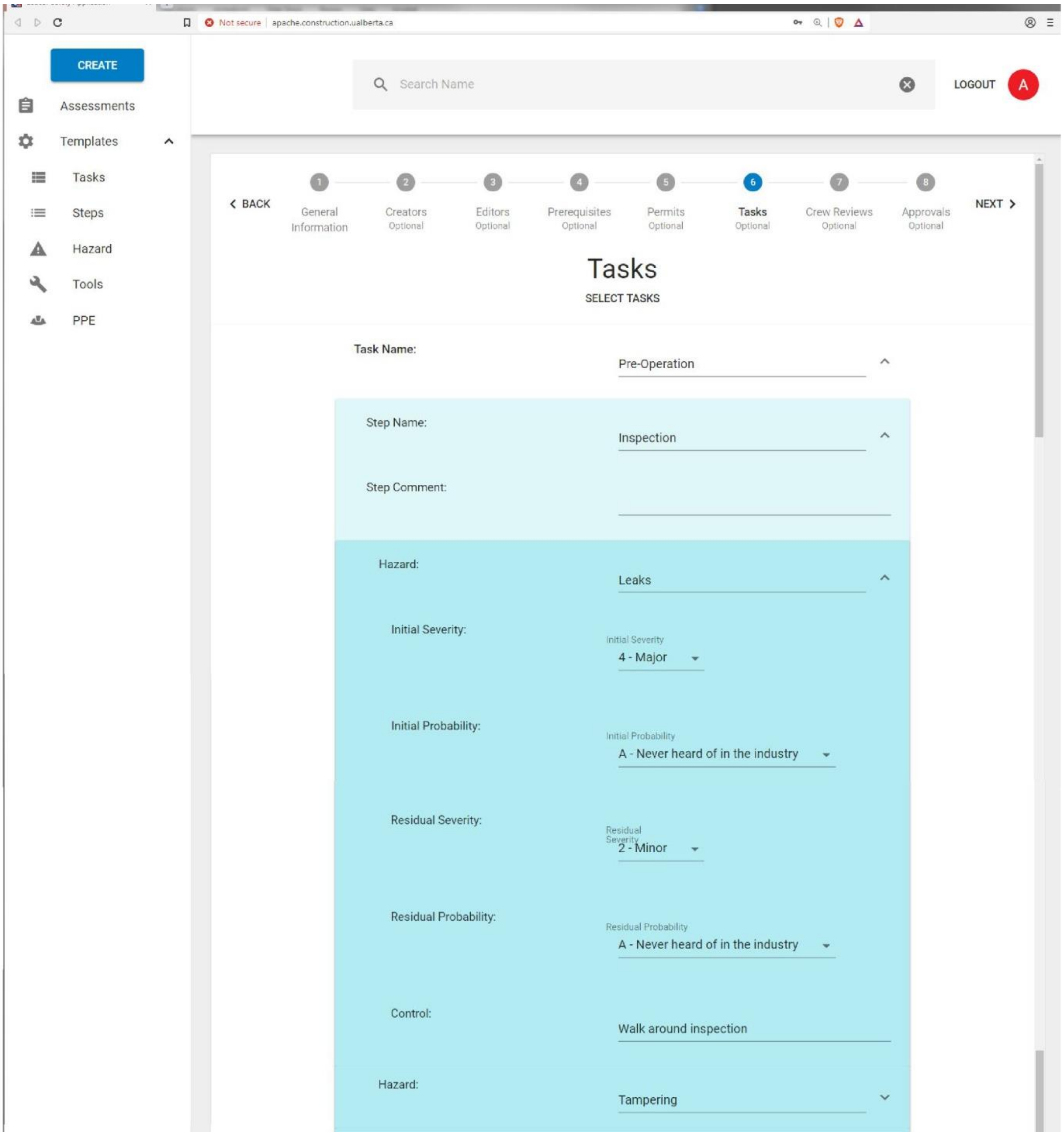

Figure 7. Hazard steps

6 Conclusion

JHA is a routine component of many proactive safety management systems in construction. Reliance on inconsistently-formatted and often fragmented information motivated the development of a web-based system. Using a dual database approach, the proposed system facilitates JHA creation, storage, and sharing. Subject matter experts found the preliminary version of the system capable of improving current practice. Future work may include the addition of graphics depicting the number and severity level of hazards, integration of the system with the project schedule to visualize the day-to-day hazard-levels, or development of text-mining algorithms. Currently, safety personnel have to search the template database to identify and assess hazards and their severity. Automation of these processes is suggested for future research. Automating the identification process is planned by applying some artificial intelligence techniques (such as case-based reasoning) to help the safety personnel easily identify and evaluate potential hazards based on current context and historical information. Real project data will later be used to quantitatively evaluate the functionality, accuracy, and efficacy of the system.

7 Acknowledgments

This work was supported by the *Ledcor* Constructors Inc. through a Collaborative Research and Development (CRD) Grant (CRDPJ 492657) from the National Science and Engineering Research Council (NSERC) of Canada.

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