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Construction Safety Document Management Framework

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Abstract:
Construction field has the strongest ability for occupational hazard events among all Asian industries. Planning the site layout of construction projects is a critical task that has a conservative impact on construction cost, productivity, and safety. It involves the placing and standard relocation of temporary facilities that are needed to support various construction activities on site such as offices, logistics industries, hotels, and parking areas. One of the major causes is construction employers or employees' negative attitudes toward safety requirements imposed by different construction safety documents, such as construction safety regulations and project safety plans. Such attitudes towards safety requirements include ignorance, negligence and disobedience and the first two can be dealt with by raising construction project participants' awareness of safety requirements through better construction safety planning. Due to the complexity of the site layout planning problem, construction managers often perform this task using old experience and first-come-first-serve basis which leads to ambiguity and even to inaccuracy. Accordingly, a number of site layout scheduled models have been developed over the past three decades to support this dynamic planning task. The large number of precautionary requirements from different construction safety documents may hinder project participants from carefully looking through them for identifying applicable precautionary requirements. In accordance with that, present approaches and tools for increasing awareness of safety requirements are not enough. Despite of the contributions of existing site layout planning models, they have a number of rules and regulations that require advance research in five main areas in order to: (1) establish international optimization of dynamic site layout planning; (2) integrate material procurement and site layout planning in a construction logistics planning model; (3) enable the usage of interior building spaces for logistics areas on congested construction sites; (4) involve automated retrieval and integration of all necessary data of construction logistics and site layout planning from already installed design and planning documents; and (5) consider security needs and constraints during the construction of critical infrastructure projects.

Keywords: Construction, Equipment, infrastructure, Project, Management, Float, Optimization, etc

1. INTRODUCTION

Construction is the industry that has the highest potential for occupational hazard events among all the different industries in the United States. It accounts for only around 5% of United States' workforce but claims around 20% of all occupational fatalities (Abdelhamid and Everett 2000). According to the statistics of the U.S. Bureau of Labor Statistics, construction industry, including private sector, government and self-employed workers, accounted for 1,282 out of 5,703 fatal work injuries recorded in 2006 – the most of any industry sector (U.S. Bureau of Labor Statistics 2007). These facts imply that improvement efforts are needed to provide a more secure working environment for all project participants on construction sites.

1.1 The Representation Model

The Representation Model aims to provide a systematic structure for modeling contextual concepts, construction safety documents, and the requirements they impose in a computer readable and interpretable format. The concepts stored in the documents may scatter over the documents. A concept that appears in one section of a document may appear multiple times in others. Since the concepts represent the application contexts of a safety requirement, it would be better to have them specifically organized elsewhere rather than scattered over the documents in order to effectively utilize them. Also, there are many different construction safety documents that specify diverse safety requirements. Only when they are modeled in a computer readable and interpretable format, can they be efficiently processed. The Representation Model consists of two sub-models: the concept ontology representation model, which models the concepts in ontology, and the textual document representation model, which models documents' texts in a structured format. The two sub-models are discussed in the following sections.

1.2 Concept Ontology Representation Model

The concept ontology representation model leverages ontological modeling to model concepts extracted from construction safety documents and to model relationships between these concepts. When tied to construction safety documents, the concepts can be used to describe contexts representing the applicability conditions and applicability exceptions of safety requirements. As input to the reasoning mechanism, the concepts can be selected to represent a list of potential situations that may occur in a project, i.e. the project specific contexts. Hence, the concepts can be viewed as a set of topological concepts of a domain knowledge base, and these topological concepts as well as the relationships between them should be well organized in order to benefit the reasoning process for identifying the applicability of construction safety requirements. The concept ontology representation model requires (1) classifications to model concepts in hierarchies, and (2) relationships to connect the represented concepts, which are discussed in the following subsections.

1.2.1 Classification of Concepts

The first step of deploying concept ontology representation model is to use classifications to model concepts in hierarchies. There are three principles guiding the hierarchical representation:

(1) Determine primary grouping concepts.

(2) Use the primary grouping concepts as the main classes and all other concepts belonging to the primary grouping concepts are made subclasses.

(3) Intermediate classifications (that is, used for secondary and tertiary grouping concepts and so on) may be necessary for the primary grouping concepts when some of the concepts can in nature be subdivision of the intermediate classifications. The first principle requires users to determine a set of concepts which are the most representative and general for all the concepts. Primary grouping concepts can be determined in different ways. If a safety document's structure comprises constituent elements that store contextual information, these constituent elements can be considered as primary grouping concepts. For example, OSHA recommended three constituent elements for a JHA document, Activity, Job Step, and Potential Hazard (as shown in Figure 3.2), to specify the concepts describing the contexts to which the safety rules apply (U.S. Department of Labor 2002). Therefore, three primary grouping concepts, "Activity", "Job Step", and "Potential Hazard" are defined and used to group JHA concepts in this research. In addition, one also can determine the primary grouping concepts empirically or consulting experienced and knowledgeable professionals. Another way is to refer to those classification systems discussed in chapter 2, such as Master Format (Construction Specifications Institute and Construction Specifications Canada 2005), to find appropriate ones as primary grouping concepts. For the second principle, the JHA's three primary grouping concepts play the role of the main classes that store the respective concepts as subclasses in this research. For instance, the concept "Frame Column" becomes a subclass of the primary grouping concept "Activity". The third principle indicates that other classifications can be incorporated to further classify the concepts of the primary grouping concepts. For example, suppose we have the following concepts which can be categorized to the primary grouping concept "Building Component" in the classification: "Bearing Wall", "Collar Beam", "Drywall", "Floating Wall", "Joist", "Nonbearing Wall", "Parapet", "Retaining Wall", and "Tail Beam". To structure the classification, it is useful to define two new classes "Beam" and "Wall" (i.e. they act as the secondary grouping concepts) as subclasses of the main class "Building Component" instead of representing all the concepts as direct subclasses of the main class *"*Building Component*"* in the classification. The new class "Beam" can act as a super class of the classes "Collar Beam", "Joist", and "Tail Beam", and the new class "Wall" can act as a super class of the others.

1.2.2 Relationships between Classified Concepts

From a reasoning perspective, only modeling a concept classification without specifying appropriate additional semantic relationships between concepts is insufficient. The developed reasoning mechanism for automated identification of construction safety requirements (discussed in the next chapter) strongly relies on semantic relationships due to their capability of stringing related concepts together. Deploying semantic relationships enables navigation through sets of concepts and thereby prevents important concepts from being unattended. For example, if an engineer forgets to identify a Potential Hazard concept "Hazardous Atmospheres" for a Job Step concept "Excavation Using Sloping and Benching as Protective Measure", the recommended safety procedure for preventing this hazard will be neglected. Using a semantic relationship to connect the Job Step concept to the Potential Hazard concept can ensure the Potential Hazard will not be ignored once the Job Step concept is identified. When concepts are modeled in a classification, superclass-subclass relationships between the concepts are specified. Additional semantic relationships, such as associations, need to be specified between the concepts as well. Associations are connections between concepts which do not have superclass-subclass relationships between them in order to specify the relatedness, exclusiveness or identicalness of meaning between them. Two main types of associations are used in this research: non-logical associations (called "association relationships") and logical associations (called "logical relationships"). Modeling associations is a highly concept-driven process. Thus, it is necessary to thoroughly review the construction safety documents from which the concepts are extracted in order to determine what associations would benefit the reasoning mechanisms and how they should be defined and established.

1.3 Textual Document Representation Model

Textual document representation aims at modeling the construction safety documents in a computer readable and interpretable format. The representation has to be flexible because it may be used for diverse construction safety documents and it should be able to accommodate the differences between these documents' skeletons. This representation also has to be maintainable since it should let document users edit the documents without difficulties. In addition, the computer readable and interpretable format should be capable of facilitating the process of accessing the information within the documents in order to automate the identification and classification of safety requirements. I decide to use Extensible Markup Language (XML) to model the construction safety documents in the developed document representation approach as it is a modeling language which can fulfill the aforementioned requirements. If a document is modeled in XML format, its content is well organized in an ordered hierarchy and marked up with human-readable, descriptive tags. Document users can easily edit the document in any text editor without requiring a specific software application by following the content hierarchy and self-explanatory tags. In this section, I will discuss the developed textual document representation approach for modeling construction safety documents. To model a construction safety document in XML format, the steps to be taken consists of: (1) analyzing the document, (2) defining a schema, and (3) representing the document in XML format according to the specification of the schema. In the following sections, I first propose a general structure for construction safety documents and then discuss the three aforementioned steps in turn.

1.3.1 A General Structure of Construction Safety Documents

In this section, I first look into two construction safety documents to identify the common characteristics of these safety documents and propose a general structure for construction safety documents based on the identified characteristics.

In the first study, I focus on an OSHA construction safety document.

(1) The document, subpart Q, is composed of multiple safety requirements, i.e. from 1926.703(a)(1) to 1926. 703(e)(2).

(2) Each requirement can comprise sub-requirements, such as 1926.708(b)(8) having three sub-requirements from 1926.708(b)(8)(i) to (iii).

(3) Each requirement contains the information of conditions, which specify the circumstances under which the specification is applicable or not applicable. For example, the standard 1926.703(a) (1) is applicable to “Cast-In-Place Concrete” and “Framework”, which are specified respectively in the title of the standard 1926.703 and 1926.703(a).

(4) In addition to the information of conditions, each requirement mostly contains the rules that describe necessary actions that should be taken when its conditions are satisfied. For example, the rules of the standard 1926.703(a)(1) are “Formwork shall be…to the formwork” and “Formwork which is designed,……of this paragraph”.

Additional, I focus on JHA documents in another document study. I use the JHA document shown as an example of illustration and shows part of the JHA document. First, I found that the document is composed of multiple safety requirements, which are represented in 4-tuples of activity, job step, potential hazard and safety rules. Second, each safety requirement contains the Information of conditions, which are the activity, job step and potential hazard information. For example, the first safety requirement in applies to the activity “Frame Column”, job step “Fly forms to area to be installed” and potential hazard “Material dislodgement”. Third, each safety requirement also contains safety rules in addition to the information of conditions. For example, there are five safety rules in the first safety requirement. The *Conditions* can be further classified into two parts: *Applicability Conditions*, which are the conditions in which their corresponding rules apply, and A*pplicability Exceptions*, which are the exceptions in which their corresponding rules do not apply. In this research, each *Condition* is represented through one *Context* and the *Context* is described through *Concepts*, i.e. the concepts from the developed ontology or their logical concatenation. That is, the three primary grouping concepts, Activity, Job Step and Potential Hazard, discussed in the previous section and their sub-concepts can be used as *Concepts* to describe the *Contexts* for the applicable conditions and exceptions of the *Safety Requirements*. Figure 1 shows a UML diagram that illustrates the decomposition of the *Conditions* for JHA documents.

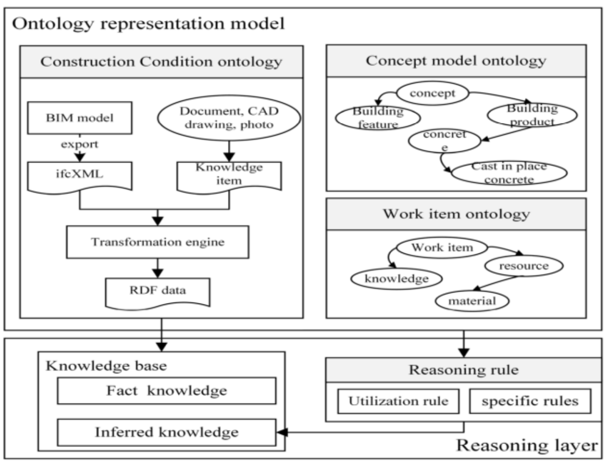

Figure.1. Decomposition of the condition for JHA documents

1.3.2 Modeling Documents in XML Format

In this research, the contexts for the applicability conditions and applicability exceptions of a JHA document are described through the concepts representing the activities, job steps and potential hazards. In other words, these contexts for the applicability conditions and applicability exceptions shall expand with the development of the nesting structure from tag *Activity* to tag *PotentialHazard* of a JHA document. For instance, only one context “Frame Columns” is needed in the nesting level of tag <Activity/> while another context “Fly Forms to Area to Be Installed” is added into the applicability condition and disjunctive to the first context in the nesting level of tag <JobStep/>, as shown in Figure 1. This characteristic of context expansion not only allows for different applicability conditions that each nesting level possesses but also facilitates the reasoning process to faster identify the applicability of safety requirements.

2. CONCLUSIONS

In this chapter, I start with the overview of the developed Construction Safety Document Management Framework, including brief introduction of its two constituent parts: Representation Model and Reasoning Engine, and then discuss the Representation Model in detail.

The Representation Model consists of two sub-models:

The concept ontology representation model illustrates the steps for modeling concepts in ontology, which are classification of concepts, definition of relationships between the classified concepts and ontological modeling of the concepts and relationships.

[1] The number assigned to each tag here is only for the convenience of indicating nesting relations in “Inner Element” column.

[2] Column “Inner Element” shows the content inside a tag, which is a tag or a set of tags or a string.

I also discuss the considerations of developing a comprehensive concept ontology, in which a heuristic approach is proposed to help evaluate the integration of classifications. On the other hand, the textual document representation model portrays the steps of preparing construction safety documents in XML format, which are document analysis, schema definition for modeling documents. In addition to these steps, a general structure of construction safety documents demonstrated in an object-oriented manner is also proposed. The structure indicates the basic framework a construction safety document should have in order to be modeled in XML format and therefore allows facilitating the document modeling process. The Representation Model presented in this chapter helps the development of the Reasoning Engine. In the next chapter, I discuss in detail how the Reasoning Engine is developed and works on the foundation of the Representation Model.

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