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Ontology-based knowledge modeling for automated construction safety checking

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ABSTRACT

Safety management is the most important part of the construction management on building engineering which has dynamic work environment and complicated construction procedure. Safety checking which identifies hazards before they occur is a core process of safety management on construction sites. However, the traditional construction safety checking which is operated by the experienced manager is manual and time-consuming. In order to integrate new technology into the construction safety checking system, a meta model for construction safety checking i.e. CSCOntology (Construction Safety Checking Ontology) has been developed in this paper. This model is formalized using an ontology language, OWL for encoding knowledge over the Web. Safety checking constraints which can extract from construction safety regulation provisions are represented with a rule language, SWRL. Then the construction safety checking processes are implemented in the JESS, a rule engine for the Java platform by transforming OWL knowledge into JESS facts, and SWRL constraints into JESS rules. A real-world example has been demonstrated in Protégé 3.4 beta to show the proposed safety checking process, according to the regulation examples taken from "29 CFR 1926 OSHA Construction Industry Regulations".

1. Introduction

Safety checking is an essential step in construction safety management. As a traditional safety checking method, Job Hazard Analysis (JHA), which is also named Job Safety Analysis, is an efficient preventive measure for safety management (Rozenfeld et al., 2010). A job hazard analysis focuses on the relationship among the task, the tools, the worker and the work environment. It is a kind of technique to identify hazards on job tasks before they occur. Subsequently, relevant hazards controls can be selected to eliminate or reduce the hazards identified (OSHA, 2002). However, the manual job hazard analysis is complex and time-consuming. Safety personnel cannot react quickly to take measures in the construction and the schedule (Wang and Boukamp, 2011). Therefore, integrating an automated procedure to assist safety checking is very useful (Lu et al., 2013).

Generally speaking, new safety checking task must be processed every once in a while. Building a new safety checking model is the most important content of the task. Instead of being built from scratch, safety checking model can be quickly built using safety knowledge modeling which represents the order of safety knowledge. Hence, it needs a systematic safety knowledge modeling to represent concepts and their relations on construction safety domain. Ontology is a method of sharing, exchanging and reusing domain knowledge (Fensel, 2002; Gruber, 1991). Zhang et al. (2014) developed three main domain ontology models, including Construction Product Model, Construction Process Model and Construction Safety Model. It aims to integrate safety planning and construction execution planning by linking safety knowledge to construction processes and products which is designed in Building Information Modeling (BIM). So it focuses on the process of safety planning. In order to consider the real-time condition on construction site, this paper introduces the concept "precursor" in the new ontology model. The safety checking constraints are developed with "precursor", "hazard" and "solution". Once the precursors are identified, the automated safety checking process will play a role. Le et al. (2014) proposed a Social Network System for Sharing Construction Safety & Health Knowledge (SNSS). It consists

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of three components: safety information module (SIM), safety knowledge module (SKM), and safety dissemination module (SDM). The ontology knowledge model is developed based on accidents information. To expanding the safety knowledge sources, this paper uses the safety checking constraints which can extract from construction safety regulation provisions. Therefore, this paper explores a new ontology-based knowledge modeling, CSCOntology for automated construction safety checking. The automated construction safety checking would quickly obtain checking result and reduce manual hazard identification errors.

2. The construction safety checking ontology

Ontology is defined as a formal, explicit specification of conceptualization (Gruber, 1993). It can describe a set of concepts and relationships among these concepts within a knowledge domain (Wang and Boukamp, 2011). Although there is no clearly-established methodology to build the construction safety checking ontology, methods used by several researchers (Uschold and Gruninger, 1996; Noy and McGuinness, 2001) who are well-respected for their work in knowledge engineering can provide some insights into the required fundamental framework (Chi et al., 2012).

2.1. Classification of concepts

In construction safety domain, the construction solution database (CPWR, 2013) provides rich information to define classifications for structuring safety checking concepts. The database focuses on the four concepts "Line of work", "Task", "Hazard" and "Solution". The specific task which is part of a line of work has own hazard and solution. The database allows stakeholders to provide their knowledge about construction safety on the website (Chi et al., 2012). Currently, the types of construction activities are various, including: (1) Roofing; (2) Residential Construction; (3) Reinforced Concrete; (4) Pipes & Vessels; (5) Paints & Coatings; (6) Masonry, Tile, Cement & Plaster; (7) Structural Steel; (8) Heavy Equipment; (9) General Labor; (10) Excavation & Demolition; (11) Electrical Excavation & Demolition; (12) Drywall, Glass & Floor Coverings; (13) Carpentry; (14) Insulation & Lagging; (15) Sheet Metal & HVAC. Each activity has a short paragraph description and is composed of a number of tasks (e.g. "install asphalt roofs" for the roofing activity). Each task comes with a list of potential hazards. The types of potential hazards are also various. For example, the task "install asphalt roofs" has 8 types of hazards, including: (1) fall from heights; (2) hand-arm vibration; (3) construction dust; (4) noise; (5) stooped postures; (6) heat and sun exposure; (7) lifting and carrying; (8) kneeling & squatting. The hazard of "fall from heights" has 3 types solution, including: (1) Personal Fall Arrest Systems; (2) Hole Covers; (3) Guardrails.

To make the knowledge modeling more perfect, precursors which defined as the conditions, events, and sequences that preceded and led up to an accident (Phimister et al., 2004) are also important for safety checking. They can be monitored on construction site. Similar precursors which appear in construction tend to occur as similar accidents (Lu et al., 2013). The US National Academy of Sciences has a study which found that many organizations had developed programs to identify precursors (Phimister et al., 2004). Although the experts of the study have different profession, including practitioners, policy makers, and engineers, they all pay attention to the accidents research. A historical accident record is a vast early warning system. A rich set of precursors can be collected from the accident record. Fig. 1 indicates a logical method to classify precursors on construction sites (Wu et al., 2010; Lu et al., 2013).

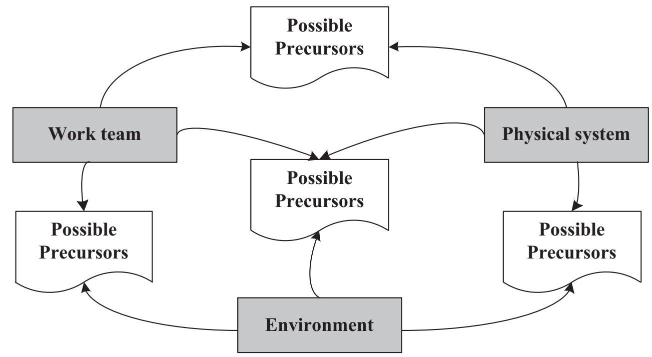

Fig. 1. Classification of precursors on construction sites.

Therefore, five primary grouping concepts, "Line of work", "Task", "Precursor", "Hazard" and "Solution" are used to express safety checking concepts. Based on the CPWR construction solution database and the possible precursors, a meta model for construction safety checking i.e. CSCOntology is proposed. Five information categories should be developed for the user to retrieve necessary safety information easily.

2.2. Semantic relationships between concepts

Semantic relationships among the classified concepts and sub-concepts also need to be specified to represent the interactional semantic connections. How reasoning mechanism for automated construction safety checking is processed especially depends on semantic relationships due to their capability of stringing related concepts together. For example, if an safety personnel forgets to identify a Precursor concept "a hole which has size 6 cm without cover and guardrail system" for a Task concept "Install asphalt roofs", the Hazard concept "Fall from heights" and recommended Solution concept "Hole covers" and "Personal fall arrest systems" for preventing this hazard will be neglected. Semantic relationship is a means to connect the Line of work concept, Task concept and Precursor concept to the Hazard concept and Solution concept. It makes sure that the potential hazard and recommended solution can be automatic generated once the Task concept and Precursor concept is inputted.

The primary concept "Line of work" has an association relationship "hasTask" connecting the primary concept "Task" in representing the concept of "The Line of work hasTask Task". An inverse relationship, "isTaskOf", for the relationship "hasTask" also can be set up in order to represent the inverse relation between the concepts, i.e. "A Task isTaskOf the Line of work". Similarly, the association relationship "hasPrecursor" and its inverse relationship "isPrecursorOf" are set up to demonstrate the connection of the concepts "Task" and "Precursor". The association relationship "hasHazard" and its inverse relationship "isHazardOf" are set up to demonstrate the connection of the primary concepts "Precursor" and "Hazard". The association relationship "hasSolution" is set up to demonstrate the connection of the primary concepts "Hazard" and "Solution".

2.3. An illustrative example

As an ontology instance, each new construction safety checking modeling can be quickly built based on CSCOntology in the construction process. Fig. 2 shows the CSCOntology instance for Roofing 1 safety checking.