ICCEPM 2022
The 9th International Conference on Construction Engineering and Project Management
Jun. 20-23, 2022, Las Vegas, NV, USA

Development of Semantic Risk Breakdown Structure to Support Risk Identification for Bridge Projects

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Abstract: Risk identification for bridge projects is a knowledge-based and labor-intensive task involving several procedures and stakeholders. Presently, risk information of bridge projects is unstructured and stored in different sources and formats, hindering knowledge sharing, reuse, and automation of the risk identification process. Consequently, there is a need to develop structured and formalized risk information for bridge projects to aid effective risk identification and automation of the risk management processes to ensure project success. This study proposes a semantic risk breakdown structure (SRBS) to support risk identification for bridge projects. SRBS is a searchable hierarchical risk breakdown structure (RBS) developed with python programming language based on a semantic modeling approach. The proposed SRBS for risk identification of bridge projects consists of a 4-level tree structure with 11 categories of risks and 116 potential risks associated with bridge projects. The contributions of this paper are threefold. Firstly, this study fills the gap in knowledge by presenting a formalized risk breakdown structure that could enhance the risk identification of bridge projects. Secondly, the proposed SRBS can assist in the creation of a risk database to support the automation of the risk identification process for bridge projects to reduce manual efforts. Lastly, the proposed SRBS can be used as a risk ontology that could aid the development of an artificial intelligence-based integrated risk management system for construction projects.

Key words: Risk identification, bridge projects, risk breakdown structure, semantic modeling

1. INTRODUCTION

Bridge projects play a crucial role in developing transportation networks for urbanization. As the global transportation need continues to grow, various scales of bridge projects have emerged to connect different isolated regions on the globe [1]. Moreover, the design of bridges is becoming complex due to the introduction of new materials and construction technologies coupled with the involvement of many project stakeholders pose threats to smooth project delivery. Also, a large-scale bridge construction process is complicated given the long construction period affected by various levels of uncertainties and risks [2]. Moreso, risks associated with bridge construction projects are higher than the risk in any other construction projects as they are constructed over obstacles such as water bodies, valleys, or roads to provide passage over the obstacles. Hence effective risk management is imperative to enhance good decision-making so that the bridge projects are delivered successively.

Risk identification is the most critical process in risk management in that it facilitates the holistic understanding of the potential risks in a project. Risk identification is the process of identifying individual project risks, the sources of overall project risks, and documenting their characteristics so that the project team can plan the appropriate risk responses for the project to succeed while enhancing effective project decision-making [3]. Further, the objective of risk identification is to generate a comprehensive list of risks based on those events that might create, enhance, prevent, degrade, accelerate or delay the achievement of project objectives [4].

Although numerous methods and techniques for risk identification of bridge projects exist in the literature, a formalized risk breakdown structure (RBS) is lacking to support effective risk identification for bridge projects. This is because risk information related to bridge projects is unstructured and stored in different sources and formats, requiring substantial human effort to extract this information for the proper conduct of risk management. Thus, a formalized and comprehensive risk breakdown structure is needed to support effective risk identification and enhance informed decision-making. Consequently, this study intends to develop a semantic risk breakdown structure (SRBS) to support risk identification for bridge projects. We adopted a semantic modeling approach with the aid of the python programming language to develop SBRS. The proposed SRBS is a hierarchical searchable RBS that consists of comprehensive and possible risks that may affect a bridge project.

2. LITERATURE REVIEW

2.1. Risk identification in bridge projects

Risk can be defined as the effects of uncertainty on project objectives leading to positive or negative consequences or both [5]. Risks in construction projects, including bridge projects, are inevitable, but their impacts can be reduced [6]. The impacts of the risks can be minimized by carrying out risk management. Risk identification is the first step in risk management because it helps identify the risk sources, area of impacts and events, and their causes and potential consequences. Also, it facilitates the effective analysis and evaluation of the identified risks while aiding appropriate risk responses.

Previous studies have proposed and used various methods for the risk identification of bridge projects. [7] adopted questionnaire and expert survey approach for identifying and analyzing risk in bridge construction projects. The authors identified and analyzed seven categories of risks through a face-to-face expert interview. In the same way, [6] developed a risk breakdown structure to determine the bridge project's risk. The study identified six categories of risks consisting of 36 risks and the corresponding risk-response strategies. Further, [2] proposed a combination of expert surveys, fuzzy analytical hierarchy process (F-AHP), and grey entropy correlation analysis (GECA) to identify the significant risk of the bridge projects. Based on the literature review conducted during this research, it was observed that a comprehensive list and formalized risk breakdown structure (RBS) for bridge projects are lacking. A formalized RBS would assist the project team in identifying, assessing, and planning adequate risk responses for the project. Therefore, the objective of this study is to develop a semantic risk breakdown structure (SRBS) that can serve as the basis for risk identification and a database for developing integrated risk management systems for bridge projects while minimizing manual efforts used in risk management processes.

2.2. Semantic Modeling in Construction Management

Semantic modeling is used to show the relationship between specific data of a domain. A semantic model (SM) is a form of ontology that supports and guides the information extraction and matching in an automated way for a specific domain [9] that can be linked to a relational database. Further, SM can be used as a conceptual database model, which can provide a basis for supporting a variety of powerful user interface facilities [11]. The application of semantic models is not new to the construction management domain. For example, [8] proposed an ontology and semantic model for knowledge presentation in a computer-interpretable and semantically inferable way to support construction safety risk management. The authors stressed that the risk-oriented ontology model developed can be used as the fundamental structure of a knowledge-based risk management system. In a recent study, [9] developed a semantic model to support the design information extraction and matching in an automated fashion for cost estimation of building projects. Similarly, [10] presented a sematic industry foundation classes (IFC) data model for automatic safety risk identification under the BIM environment for deep excavation projects. The authors highlighted that the proposed model could be used as the data storage standard for field sensors and monitoring databases while facilitating decision-making to promote safety risk management in deep excavation. To the best of our knowledge, there is very little research on the semantic data modeling approach to support risk identification of bridge projects. Thus, we propose a semantic risk breakdown structure (SRBS) to facilitate effective risk identification and management of bridge projects.

3. METHODOLOGY

This study aims to develop a semantic risk breakdown structure (SRBS) for risk identification in bridge projects using a semantic modeling approach. The development of the proposed SRBS involves four steps, namely data collection, extraction of bridge project risks, creating risk breakdown structure, and semantic modeling, as shown in Figure 1.

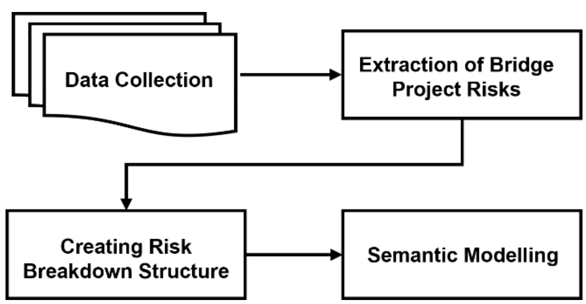

Figure 1. Research methodology

3.1. Data collection

This step involves reviewing data sources such as academic research literature, bridge construction standards, technical manuals, bridge risk assessment reports, bridge construction historical records, etc., to identify and extract potential risks associated with bridge projects. In this study, the significant sources of data collection were the academic research literature, project risk management guideline, and risk assessment reports for completed bridge projects.

3.2. Extraction of project risks

All the documents collected were carefully reviewed, and the risks related to bridge projects were extracted manually from the sources mentioned in 3.1. Although, it is not practicable to identify all the potential risks associated with a particular project at the early stage of the project. Thus, in this study, we initially identified a total of 126 potential risks for bridge projects from the documents reviewed. However, ten (10) risks were removed from the risk list after the list was reviewed by fifteen (15) construction and risk management experts in bridge projects through an online survey conducted in the Republic of Korea. The experts believed that the risks were repetitions and unnecessary in the list. Also, the experts agreed that the revised list consists of 116 potential risks for bridge projects categorized into eleven (11) risk categories falling under two main risk types; internal and external risks. The internal risks are under the control of the project owner and project team. These include construction, material and equipment, construction management, design, insurance, contractual, project management, time management, and human resources risks. On the other hand, the external risks are the risks that are not under the project team's control. These risks consist of environmental and economic risks.

3.3. Creating risk breakdown structure

Based on the output obtained from section 3.2, we created a risk breakdown structure (RBS) in MS excel to facilitate the semantic modeling. Table 1 depicts an excerpt of the risk breakdown structure. Table 1 contains the serial number of the main risk types considered in this paper. Also, it consists of 11 risk categories, i.e., risk sources, a list of risks identified under each risk category, and the risk code for each risk. The RBS is made up of 116 risks for bridge projects. The complete RBS can be viewed in the GitHub repository link (Murry01/Semantic-RBS).

Table 1. An excerpt of the risk breakdown structure

No.	Risk Type	Risk Category	Risk	Risk Code
I	Internal Risks	1. Construction Risks	Falling to the ground during equipment transportation	BR1
			Incorrect installation of drill frame	BR2
			…....	…
		2. Materials and Equipment risks	Material Shortage	BR32
			Material Error on form, function, and specification	BR33
		…..	…....	…
II	External Risks	10. Environmental Risks	Earthquake	BR100
			Landslide	BR101
			Bad weather	BR102
			…....	…
			…....	…
		11. Economic Risks	Inexperience when pricing tenders	BR108
			Unrealistic cost estimates and schedules	BR109
			Loss due to fluctuation of interest rate	BR110
			…....	…
			…....	…
			Loss due to fluctuation of interest rate	BR116

3.4. Semantic Modeling

The final step is semantic modeling which entails developing a semantic tree model for the risk breakdown structure based on outputs from the previous steps. The semantic model can be modeled based on a hierarchical tree structure consisting of four processes: (1) root node creation; (2) parent node creation; (3) creation of child node; and (4) creation of the properties or attributes of the nodes also known as leaves. Figure 2 shows a partial hierarchy of a semantic tree modeling. In hierarchical tree modeling, the relationship between the nodes is equivalent to a parent-child relationship. In other words, a parent can be related to several children while the children can only be related to a parent. Also, a node without a parent is referred to as the root node. In this study, the semantic risk breakdown structure (SRBS) for the bridge project risk was developed with the aid of the python programming language using a python library called *Anytree* [12]. We chose python for this study because it is an open-source programming language and is accessible to users for free. Figure 3 shows the partial python implementation code of the SRBS. The complete Python code can be found in the GitHub repository link (Murry01/Semantic-RBS).

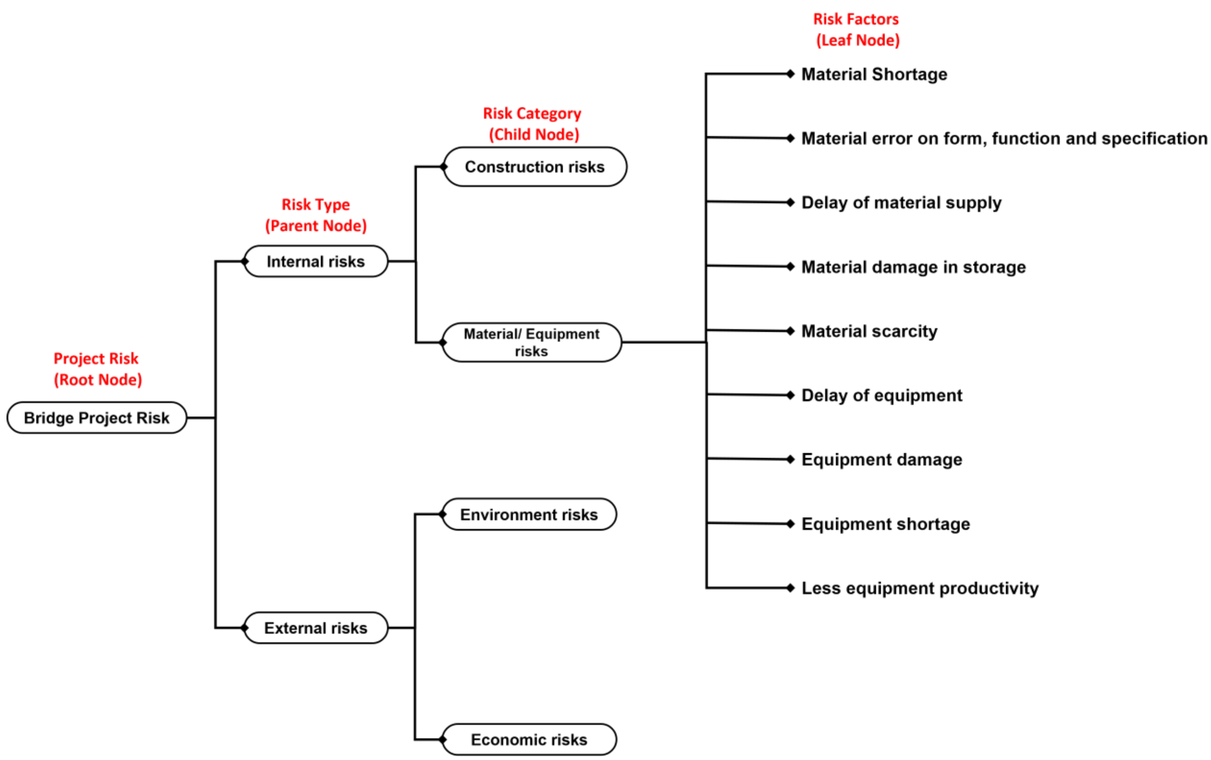

Figure 2. Semantic tree modeling representation

4. EXPERIMENTATION

The proposed SRBS is not project-specific but a generalized RBS for bridge project risk identification. In this section, we tested the proposed SRBS by using it to identify a specific risk category for a bridge project. We used SRBS to search and visualize human resources risks, a category under the internal risk. Based on the search result, four risks, namely (1) less professional, (2) less labor, (3) low labor ability, and (4) low labor productivity, were identified. Figures 4(a) and 4(b) show the python code and the graphical result. As mentioned earlier, not all risks associated with a project can be identified as different risks may occur at various stages of the project life cycle. Thus, the proposed SRBS can be edited and updated when new risks not in the

RBS are identified. In other words, the present SRBS for the bridge projects allows for continuous database updates depending on the project's complexity. Moreover, since the proposed SBRS is a searchable risk database, it can be integrated with other external databases to support query languages such as structured query language (SQL), object query language (QOL), and graph query language (GraphQL) to develop an integrated risk management system for bridge projects.

```
[ ] # Root Node
    # level_1 ##########################################
    Bridge_Project_Risk = Node("Bridge project risks")

[ ] # Parent Node
    # level_2 #########################################
    I_Risk = Node("Internal Risks", parent=Bridge_Project_Risk )
    E_Risk = Node("External Risks", parent=Bridge_Project_Risk )

[ ] # Child Node
    # level_3 #########################################
    Cons_Risk = Node("Construction Risks", parent=I_Risk)
    ME_Risk = Node("Materials and Equipment Risks", parent=I_Risk)
    CM_Risk = Node("Construction Management Risks", parent=I_Risk)
    D_Risk = Node("Design Risks", parent=I_Risk)
    Ins_Risk = Node("Insurance Risks", parent=I_Risk)
    Cont_Risk = Node("Contractual Risks", parent=I_Risk)
    PM_Risk = Node("Project Managament Risks", parent=I_Risk)
    TM_Risk = Node("Time Management Risks", parent=I_Risk)
    HR_Risk = Node("Human Resourses", parent=I_Risk)

    Env_Risk = Node("Environmental Risks", parent=E_Risk)
    Eco_Risk = Node("Economic Risks", parent=E_Risk)

[ ] # Leaf
    # level_4 #########################################
    BR1 = Node("Falling to the ground during equipment transportation", parent=Cons_Risk)
    BR2 = Node("Incorrect installation of drill frame", parent=Cons_Risk)
    BR3 = Node("Insufficient insertion depth of the protective tube", parent=Cons_Risk)
    BR4 = Node("The seam of the protective tube is not dense", parent=Cons_Risk)
    BR5 = Node("The protective tube is inclined and leaking", parent=Cons_Risk)
    BR6 = Node("Unstable water head in the protection tube", parent=Cons_Risk)
    BR7 = Node("Borehole collapse", parent=Cons_Risk)
```

Figure 3. Python implementation for the SBRS

Where Cons_Risk = Construction Risks, ME_Risk = material and equipment risks, CM_Risk = construction management risk, D_Risk = Design risks, Ins_Risk = Insurance risks, Cont_Risk = Contractual risks, PM_Risk = Project management risk, TM_Risk = Time management risk, HR_Risk = Human resources risks, Env_Risk = Environmental risks and Eco_Risk = Economic risks, BR1-BR7 = Risk code.

```
[11] # Render the Human Resources Risks
     print(RenderTree(HR_Risk).by_attr(),)
```

```
Human Resourses
├── Less professional
├── Less labor
├── Low labor ability
└── Low labor productivity
```

```
✓   [12] # Visualization
0s       from anytree.exporter import DotExporter
         # graphviz needs to be installed for the next line!
         DotExporter(HR_Risk).to_picture("HR_Risk.png")
```

Figure 4 (a). Experimentation result

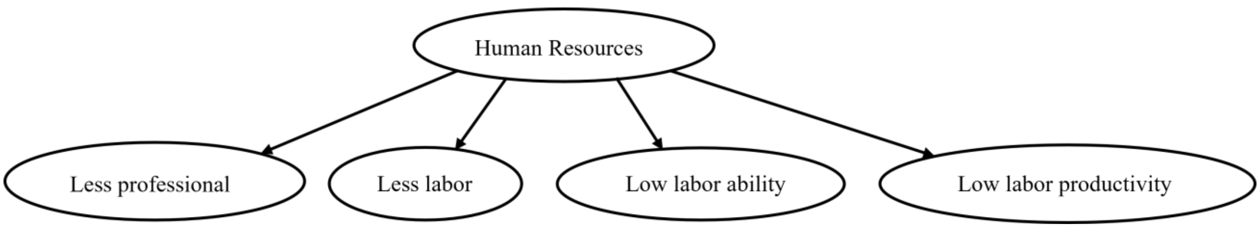

Figure 4 (b). Experimentation result

5. CONCLUSION

Bridge construction is a complex undertaking with many risks. Identifying the risks associated with bridge projects is a knowledge-based and labor-intensive task due to the involvement of many processes and stakeholders. Currently, risk information related to bridge projects is unstructured and stored in different sources and formats, requiring substantial human effort to extract this information during the process of risk identification. Therefore, this study developed a semantic risk breakdown structure (SRBS) to support the risk identification process for bridge projects using a semantic data modeling approach. The proposed SRBS is a searchable hierarchical RBS for risk identification of bridge projects consisting of a 4-level tree structure (i.e., the root node, parent node, child node, and leaf node) with 11 risk categories and 116 potential risks associated with the bridge projects. We used the proposed SRBS to search for human resources risks for bridge projects. The SRBS identified four potential risks related to the project.

The proposed SRBS can serve as a basis for identifying risks related to bridge projects. Also, the SRBS can aid the development of a risk database to support an automatic risk identification system. In addition, the proposed SRBS can assist in developing an ontology for creating an AI-based integrated risk management system for bridge and other construction projects while enabling knowledge sharing and reuse among construction risk management researchers and professionals. Finally, it should be noted that this study is a part of ongoing research that focuses on developing an artificial intelligent-based integrated risk management system for construction projects. The authors are currently working on gathering more risk information on other civil engineering projects (such as highways, tunnels, deep foundations, etc.) and the development of a framework and algorithm for the automation of the entire risk management processes based on the project management body of knowledge (PMBOK) and ISO risk management guidelines (ISO31000:2009).

ACKNOWLEGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea Government (MSIT) (NRF-2021R1A2C1014267).

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