Modeling HiBrinto Ontology to Develop Knowledge Management Portal for Highway Bridge Construction

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***Abstract*—Highway bridges play an important role in traffic reduction in main cities. Constructing, maintaining and repairing highway bridges is a knowledge-intensive activity that inputs knowledge from different sources to take timely and correct decisions. Since these are knowledge-intensive activities, the proper knowledge management (KM) system can help to make the proper decisions, knowledge sharing, knowledge capturing, etc. easier. The base for the KM system is the ontology which is an explicit specification of conceptualization. In this paper, we introduce a novel HiBrinto, a highway bridge ontology for developing a KM portal for highway bridge construction, maintenance, and repair. The field study of the KM portal clearly emphasizes that the developed KM portal will pave the way for seamless knowledge sharing and quick decision making for highway bridge-related activities.**

Keywords-Highway Bridge, Knowledge, Management, Ontology, HiBrinto, Semantic Web.

I. Introduction

Bridges are part of the road infrastructure and are an important link in a road network [1]. In this context, highway bridges play an important role in reducing traffic. Highway bridges are made of steel, reinforced concrete, or wood. Girders are most often used in building steel highway bridges. The preferred design of a highway bridge is with driving in the upper part (Deck Bridge); this creates better traffic conditions for automobiles and makes the bridge easier to maintain [2].

The Semantic Web is an extension of the current web to allow computers and persons to share information (not data) based on context (not hypertext). Ontology is one of the core web features [3]. Knowledge Management (KM) is the process of making the effective use of information and knowledge in an organization to achieve the goals [4]. It allows people to access and use the best knowledge when it is necessary and facilitates learning [5, 6].[7].

For the creation of information systems, the development, distribution, and use of common communication principles, vocabulary and ontologies are essential. Therefore, we discuss certain key topics in this paper relevant to our research such as highway bridges and ontologies [7]. The overall objective of our research is to develop a KM portal that can cater to the needs of people who are related to highway bridge construction. The key to achieving this objective is the ontology which we named as HiBrinto (**Hi**ghway + **Br**idge + O**nto**logy)

The remainder of the paper is organized as follows. Section 2 discusses the literature review and related works. Section 3 describes the complete research design for the HiBrinto ontology. Finally, Section 4 concludes this paper with directions for future work.

II. Literature Review and Related Works

Construction companies engaged in more routine and repeatable work should also strive to make more effective output of products, uniform procedures, preparation and so on [8]. Information needs to be quickly and easily communicated and beneficial to others. Project teams and people within a company should be empowered and be able to share their experiences with others [3, 9].

Three areas of consideration that must be addressed for the effective construction of highway bridges are; (i) artistic and esthetic, (ii) analytical and (iii) scientific and realistic. Given that most bridge projects currently being undertaken by multidisciplinary teams, it is fairly easy to address the first two concerns. The last one is often the most complicated. [2]. Project periods for these bridges will have to shorten to respond to public demand to minimize road congestion and the flow of traffic during project, often within a few feet of workers and equipment [8].

In, “Building an ontological knowledgebase for bridge maintenance” by Ren, et al.[7], they have developed a system that caters to all the phases in the bridge maintenance life cycle. It covers the maintenance-related knowledge for all types of bridges. In the work of J France-Mensah, et al. [10], they developed Integrated Highway Planning Ontology (IHP-Onto) which is a shared representation of knowledge about pavement assets, M&R planning, and inter-project coordination. This is work is done in high ways.

III. Research Design

Our research design consists of two major parts; (i) Modeling of HiBrinto ontology, (ii) Development of Highway Bridge KM Portal. The high-level methodological roadmap for the development of the KM portal for highway bridge decision making is shown in Figure 1.

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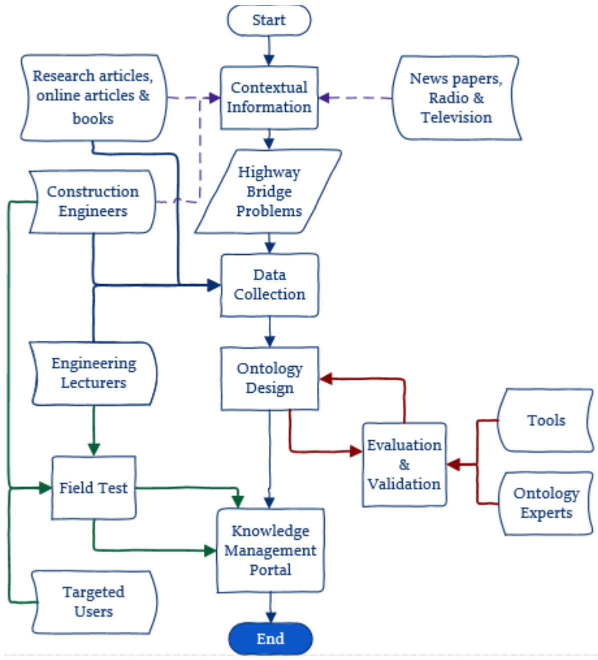

Figure 1. The high-level methodological roadmap for the development of the KM portal for highway bridge decision making

A. Ontology Modeling

In this section, we present how the HiBrinto ontology is developed which is going to act as the base for KM Portal development in the next stage.

1) Data collection

Context refers to a representative item that enables the external environment of a concept to be represented [11]. If any data that gives information context to a person, entity or event is known as contextual information. In our research, the targeted users are; construction engineers, maintenance engineers, quality engineers, RDA management, academic staff, researchers, engineering undergraduates.

The data collection was done by using grounded theory [12]. Grounded theory is a technique that involves building hypotheses through methodical data collection and analysis. In comparison to the hypothetical-deductive model of the scientific method, this approach employs inductive reasoning. Research with the grounded theory is likely to start with a query or even with qualitative data collection [13].

Since the researchers' are not experts in the construction domain, the relevant data were obtained through formal and informal expert collaboration and extensive literature surveys. Five construction engineers who mainly deal with the highway bridge construction over many years under different projects and three academic lecturers from the reputed university of Sri Lanka participated in the process of data collection. They have been interviewed formally and informally several times during the whole research period. Besides, thirty personalities from the construction site with different job roles and thirty academic students also participated in the process of identifying the problems faced by them (i.e., the actual need for the research is realized by them). Further, construction manuals [14-17] and several works of literature [3, 8, 18-24] were surveyed throughout the research period.

2) Competency Questions

The Competency Questions (CQs) are questions of natural language which define and limit the scope of knowledge that is represented in the ontology. [6]. CQs play a major role in the lifecycle of ontology modeling as they reflect the ontology requirements [25]. CQs work as a requirement's specification of the HiBrinto ontology. Table 1 shows part of the formulated CQs

TABLE I. COMPETENCY QUESTIONS

Competency questions for the HiBrinto ontology
What are the different types of highway bridges available?
What are the major components of a bridge?
What are the special components of a particular type of highway bridge?
Which are quality checks used to check the quality of a particular type of highway bridge?
What are the activities conducted under each quality check?
In which duration each quality check procedures should be applied?
Which maintenance techniques can be the most suitable for a particular type of?
What are the environmental concerns to be considered in the highway bridge management process?
What are the remedies/actions to be taken if the quality check results fail?

3) Taxonomy Development

An extensive taxonomy had to be developed as a common platform for interacting ontologies. Taxonomic relations ("is-a", "is-part-of", "is-kind-of", "is-a-type-of") allow any sub-concept to inherit the characteristics of its super-concept [3]. Computers may derive new knowledge from existing knowledge by using taxonomies [22].

At the end of the data collection, the taxonomy for HiBrinto was created. Eleven super-classes were identified; Activities, Actors, HighwayBridges, BridgeComponent, Divisions, Equipment, Materials, ProsCons, Maintenance, Construction, and Parameters. The sub-classes for the superclasses are also identified. For example, "EnvironmentalConcerns", "QualityCheck", "Duration", "MaintenanceTechniques", "RepairTechnique", "ManagementPractices" are sub-class of "Maintenance" class. Further, the "QualityCheck" class contains "QCCode" and "QCItem" as its sub-class. The high-level class hierarchy of HiBrinto ontology is shown in figure 2.

Figure 2. The high-level class hierarchy of HiBrinto ontology

A glossary of about 3500 terms was compiled from well-established sources, like building manuals, textbooks, research papers, and informal expert interviews. It is not feasible to list all taxonomy here. Some of the major domains are explained below.

a) Bridge Components

Every bridge will have some basic components known as "basic-components" such as "Superstructure", "Bearings" and "Substructure". Each basic components will have some sub-components. For example, "Superstructure" will have "Bearing", "Parapet wall", "Flooring" etc. Further, some bridges will have specific components. For example, "Arch" which is a sub-component of "Superstructure" is used for arch bridge construction and "cable" which is a sub-component of "Superstructure" is used for suspension, cable-stayed bridge, etc. [16].

b) Actors

There are many actors in the scene of bridge construction. We broadly categorize them into Executive (Engineering and professional), Semi Executive / Officer (Administration, Finance, Developing program/ Duty concerning, Implementation), and so on [26].

c) Divisions

Each actor identified is assigned to one or more "division". Some of the divisions identified are Planning Division, Engineering Service Division, and Maintenance Management & Construction Division, etc. [26].

d) Quality checks

Each bridge has to undergo some quality checks in certain durations. Some of the quality checks identified are; tension check for beam, bearing pad durability, foundation settlement check, deck roughness, etc. If the results quality check fails, a proper repair plan will be executed according to the severity case. Each quality check has a quality check code and quality check item.

4) Ontology Modeling

Modeling the ontology manually is a complex and time-consuming task [27]. According to Vasanthapriyan [28], the principles, methods, and tools for initiating, developing and maintaining ontologies are investigated in the ontology engineering approach. There are many different methodologies proposed to model the ontologies in many works of literature [29-32]. After reviewing all, we selected Grüninger and Fox's methodology [30] for our work as it publishes a formal approach for designing the ontology and also it provides a framework for evaluating the developed ontology [33]. Grüninger and Fox's methodology [30] focuses on building ontology-based on first-order logic by providing strong semantics.

a) Classes

An ontology is a systematic definition of the architecture. The concept is defined by classes and relationships. The classes comprise category; subclass, superclass, intersection class, union class, and complement class [34].

The taxonomies identified were converted into classes. During the modeling of HiBrinto ontology, some special types of axioms such as Instantiation, Assertion, Subsumption, Domain, Range, and Disjointness are included. The classes have been created in Protégé OWL Ontology Editor 5.5. Figure 3 shows the part of high-level classes modeled using Protégé OWL Ontology Editor 5.5.

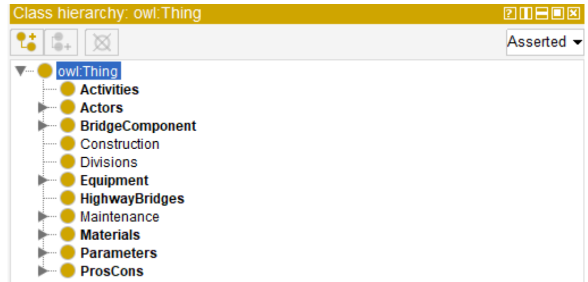

Figure 3. Part of high-level classes modeled using Protégé OWL Ontology Editor 5.5

b) Object properties & Datatype properties

The associative relationships (object properties) are to identify the concepts and relationships with meaningful relations and to define the relationships and their inverse relationships. For example, "BridgeComponent" isComponentOf, "HighwayBridges". The inverse isComponentOf of is hasComponent. Another example is "QualityCheck" hasDuration "Duration".

A datatype property is defined as an instance of the built-in OWL class owl:DatatypeProperty. The needed datatype properties are also defined such as qualityCheckStatus, hasDuration, hasLength, hasMinWorkers, hasMinSiteEngineer, and hasMinSurveyor, etc.

c) Individuals

Various individual instances were added to the class hierarchy. To use the reasoner to test our rules, we instantiated 3,857 individuals. Individuals which we created include bridges, activities, equipment, actors and so on. To create them, we used names such as bridge101, check_sealability, driller, environmental_officer and so forth

d) Axioms

These major concepts (classes and sub-classes) and relationships (properties) are also bound by some axioms. A set of axioms have been also developed. The following sample process illustrates some of the axioms used quality check.

- Each highway bridge has to conform highway bridge quality check

$$\forall HighwayBridges \exists Qualitycheck \supset conforms(HighwayBridges, QualityCheck)$$

- Each highway bridge quality check has a quality check safety standard

$$\forall QualityCheck\ \exists SafetyStandard \supset has(QualityCheck, SafetyStandard)$$

- Each highway bridge quality check has a checking method that is either destructive or nondestructive method

$$\forall QualityCheck\ \exists Method \in (desctructive, nondestructive) \supset has(QualityCheck, Method)$$

- Each highway bridge quality check has quality check code (QCCode) and quality check item (QCItem)

$$\forall QualityCheck\ \exists (QCCode \wedge QCItem) \supset has(QualityCheck, QCCode, QCItem)$$

e) DL Queries

Since we were designing with OWL 2 Web Ontology Language [32] for the semantic web, we used Description Logic (DL) which is a decidable fragment of FOL for our scenario. We have evaluated the competency questions to see whether the ontology meets the users' requirements during the internal design process. The DL expressions have been used to query the ontology. For this purpose, we used the DL query facility which is available in Protégé-OWL Ontology Editor 5.5.

B. KM Portal Development

Ontology and semantic web systems have strong logic capabilities [35]. This segment discusses the construction of a knowledge platform to share knowledge regarding highway bridges. It was developed on the distributed system framework of Java J2EE. The five layers of our knowledge framework are; Ontology, Experience Sharing and Knowledge Validation, Storage, Reasoning, and Knowledge Sharing Layer and they are shown in Figure 4.

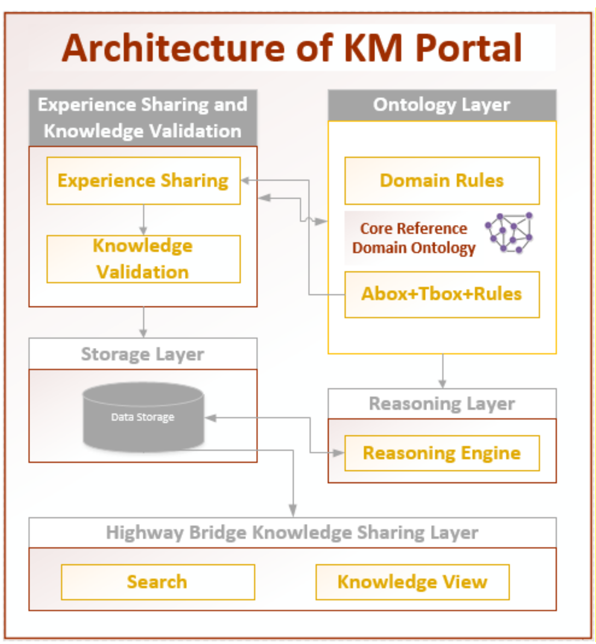

Figure 4. The architecture of KM Portal

1) Ontology Layer

Our developed HiBrinto ontology including its domain rules, axioms, etc. is in the ontology layer. Using the Protégé-OWL Ontology Editor 5.5, these concepts and their relationships were partly described in section "Ontology Modeling".

2) Experience Sharing and Knowledge Validation Layer

Through the Experience Sharing layer, the construction engineers can annotate their highway bridge knowledge with the support of the construction standard terms. The shared knowledge is then transformed into the semantic data in a machine-understandable format of the triple structure by the semantic data generator.

3) Storage Layer

We used Triple-store, which stores RDF triples. Using SPARQL the queries were made. Since Jena TDB is a component of Jena for RDF storage and query, it was selected in this study. It supports the full range of Jena APIs and can be used as a high performance of the RDF store on a single machine.

4) Reasoning Layer

Highway bridge rules were generated with Protégé-SWRL Editor. It is a plugin in the Protégé-OWL Ontology Editor 5.5 environment. It supports the Jess Rule Engine. The Semantic Web Rule Language (SWRL) is based on a combination of OWL with the Rule Markup Language. It provides inference capabilities from existing OWL ontology.

5) HiBrinto Knowledge Sharing Layer

Knowledge Sharing Layer includes two functionalities that use Semantic Web technologies: (1) basic search, and (2) Advanced Search. SPARQL has been used as the query language to retrieve highway bridge knowledge from the semantic data storage. The basic search provides a simple triple pattern matching service, which is one of the most frequently used functions for searching documents in the Semantic Web. Besides, Advanced Search Option includes, logical operators (AND or NOT or OR), so that users can combine different options to retrieve knowledge.

C. Evaluation of HiBrinto and KM Portal

The quality of the ontology is very much important for its usefulness. To avoid the defects when using the ontology, its quality should be verified and validated. We verified and validated our ontology in different ways; (i) OOPS! - Online ontology evaluator, (ii) Reasoner – Inbuilt tool in Protégé OWL Ontology Editor 5.5, (iii) Ontology experts. We did not incorporate domain experts fully in this phase because the ontology can be understood by who is having computer science knowledge. But whenever issues were identified they were contacted to clarify the issues. The developed KM portal was evaluated using field tests.

1) Tools

a) OOPS!

OOPS! is a web-based method for detecting possible mistakes that could lead to modeling errors, independent of any context for ontology development. This method is intended to support ontology developers in the ontology validation process, which can be separated into diagnostics and repairs. OOPS! helps to identify some of the most common pitfalls in ontological developments OOPS, for example

- Warns of when: the domain or range of a connection is described as a two or more class intersection. In case such classes could not exchange cases, this alert may deter thinking issues.
- No naming convention is used in the ontology element identifiers. In this situation, maintenance, usability, and ontology consistency could be enhanced.
- In ontology, a loop between two classes is included in the hierarchy. The identification of this condition may avoid problems with modeling and reasoning.

Table 2 describes the part of the pitfalls identified for the modeled ontology, description and solution proposed. Three layers existed, including critical, important and minor. The critical degree is very vital and must be fixed to prevent ambiguity in the ontology. Both minor and important instances have been updated to render ontology better.

TABLE II. PITFALL DESCRIPTION AND SOLUTION PROPOSED

Pitfall	Description	Solution
Missing annotations (4850 cases | Minor)	Creating an ontology element without providing understandable annotations to it.	Included the ontology annotations
Missing domain or range in properties (65 cases | Important)	Object and (or) datatype properties without domain or range	Added the missing domain and range
Inverse relationships not explicitly declared (186 cases | Minor)	Except for the symmetric properties, others do not have an inverse relationship.	Included missing inverse relationships
Defining multiple domains or ranges in properties (6 cases | Critical)	More than one domain or range is defined for a property.	Modified the multiple domains and ranges

b) Reasoner

A semantic reasoner (also known as reasoning engine, rules engine, or simply a reasoner), is a software able to infer logical consequences in the modeled ontology from a set of asserted facts or axioms. We utilized the FaCT++ inbuilt reasoner tool available in the Protégé OWL Ontology Editor 5.5. According to Tsarkov and Horrocks [36], "FaCT++ is a new sound and complete DL reasoner designed as a platform for experimenting with new tableaux algorithms and optimization techniques".

2) Ontology Experts

With the support of two ontology experts we tested the ontology with the deficiencies of the artifacts we used. The expert is not an author and is not associated with our research team. Several approaches for testing ontologies were present in the literature. Our ontology experts considered (a) syntax (b) structure, (c) semantics, (d) terminology, (e) meaning and (f) representation to conduct the assessment. The primary goals of the expert evaluation are: (a) whether the HiBrinto ontology meets the requirements, norms, (b) coverage of the Highway Bridge and (c) internal quality control. The remarks of the ontology experts have also been revised.

Some of the comments given by the experts are; Manchester syntax was followed, all concepts follow is-a relationships, the whole ontology was viewed using OntoGraph, thirty-two concepts and eight object properties do not have understandable names, very few CQs were needed to be modified as highlighted and so on.

3) Field Test

One of the most important tools to determine the validity of the suggested ontology was the actual implementation and testing with the end-users. Different categories of 20 end users were selected for this purpose. First, a training session was carried out with system end-users. The end-users were given a brief introduction to the project and what is expected from them. Then the demonstration for using the system was done. Finally, they were allowed to use the system. Since we hosted the system in the localhost, end-users were allowed to use the system in a restricted environment. Proper facilities were made for their comfort. The end-users were allowed to use the system for 4 hours.

Then, a survey was conducted which consists of a set of questions to check whether developed ontology was able to (i) express highway bridge knowledge (ii) support highway bridge knowledge sharing (iii) support highway bridge knowledge retrieval and (iv) user satisfaction. The survey uses a Likert scale of 1 to 5, with 1 (worst) and 5 (best). Their assessment was largely positive. More than two-thirds of the end-users participated in the survey responded with 4, and 5 ratings. Some of the questions asked and Mode (Likert scale) is shown in the Table 3

TABLE III. QUESTIONS ASKED AND MODE (LIKERT SCALE)

Question	Mode (Likert scale)
How easy was it to navigate in the system?	5
How representative are the terms used?	4
Can the system be used by the persons who do not know the highway bridge construction field?	5
How did the system responsible for your search?	4
Are you satisfied with the system?	4

IV. CONCLUSIONS AND FUTURE WORKS

The otology has been utilized in many types of research in different domains such as agriculture, medical, dental, software testing, economics, etc. But a very few researches have been done in the construction domain [3, 22]. But none of the researches has been conducted in the highway bridge domain. In this paper, we presented the HiBrinto ontology to represent highway bridge domain knowledge which includes highway bridge concepts, properties, and their relationships that can be used to help decision making for the whole lifecycle of the highway bridge. The full version of our ontology has 427 entities, 726 properties which include both object properties and datatype properties, and 3,857 individuals.

Since our focus in this research was on highway bridges, the HiBrinto ontology can be expanded further for the other types of bridges as well. Further, reasoning engine with Query-enhanced Web Rule Language (SQWRL) can be incorporated into

HiBrinto knowledge searching to support more accurate and effective knowledge sharing.

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