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KNOWLEDGE ENABLED TECHNOLOGY SELECTION FOR SEWER CONDITION ASSESSMENT

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To improve the quality of life of communities, local government provides municipal services, including the sewer collection, effectively and efficiently employing asset management best practices. The condition assessment of assets (including the sewer collection system) is one of the core elements of implementing effective asset management across the utility organizations. Availability of sophisticated and complex condition assessment technologies, lack of common understanding about them and related high cost associated with sewer condition assessment requires the technologies and related knowledge to be explicitly defined in a neutral format—the ontology, to support the development of applications for technology selection. An ontology of condition assessment technologies for sewer network, CATS_Onto was developed following a seven-step approach at two levels of abstraction: meta-model and detailed ontology. This paper presents the development and verification of the meta-model. The proposed ontology will be used to develop a tool for the selection of the most appropriate technology for sewer condition assessment. The knowledge representation was verified while validation is underway.

Keywords: Ontology, Criteria, Inspection, Application, Asset management.

1 INTRODUCTION

The local government provides basic municipal services to communities through infrastructure systems (assets), which plays a vital role in the local, state and national economic development. Infrastructure assets are critical for the safety, welfare, and public health of communities (ASCE 2017). To provide uninterrupted services, these assets need to be maintained and managed to employ a comprehensive asset management planning. One of the core elements of effective asset management planning is to assess the condition of assets on a regular basis using appropriate technology to support maintenance and rehabilitation decision making. Although asset management of all types of assets is equally important; however, this paper focuses on wastewater (sanitary and storm) assets because most of these assets are at least 60 years old and many communities have sewers that are older than 100 years (US EPA 2015).

A number of technologies are currently available to assess the condition of the sewer network. Each technology has specific strengths and weaknesses and due to the complexity of these technologies, the utility management experts find it difficult to select a suitable, feasible and cost-effective technology. According to Agarwal (2010), these experts choose technologies that are not suitable to collect the data required for accurate condition assessment. This emphasizes the need to develop a tool that the utility experts can use to select an appropriate technology for sewer condition assessment using an ontological approach. The underlying knowledge model was created in a neutral format (the Ontology of Condition Assessment Technologies for Sewer network, CATS_Onto). An "ontology is an explicit specification of a conceptualization." (Gruber 1995). Following a layered architecture proposed by Gomez-Perez (1996), the CATS_Onto was developed at two levels: (i) an abstract Meta-Model of Condition Assessment Technologies for Sewer Network, CATS_MM, and detailed CATS_Onto. This paper discusses the meta-model and is divided into 7 sections. The background information and related literature are discussed in section 1 and 2 respectively. Section 3 discusses the methodology and section 4 explains the development of the meta-model. A potential area of application is discussed in section 5 and evaluation is depicted in section 6. Finally, conclusions are discussed in section 7.

2 LITERATURE REVIEW

2.1 Infrastructure Management and Asset Management Ontologies

In the area of infrastructure management, Osman (2007) developed the Infrastructure Product Ontology to represent infrastructure product knowledge in the water, wastewater, electrical, telecommunication, and gas sector. Zeb and Froese (2014, 2015b) created a Tangible Capital Asset Ontology to represent Tangible Capital Assets in the transportation, water, wastewater, and solid waste management to develop an Asset Information Integrator System (Zeb *et al.* 2015). These ontologies represent engineered or man-made assets in the built-environment. In the natural environment, an Eco Asset Ontology was built to represent natural assets (e.g., ditch, storm channel, ponds, etc.) (Zeb 2017). El-Gohary (2008) developed the Infrastructure and Construction Process Ontology to represent construction processes. To support the seamless exchange of information between the systems of the utility organizations, a Transaction Domain Ontology was developed (Zeb and Froese 2012, 2016, 2017). These ontologies represent product and process knowledge lacking the knowledge required to support the development of applications for the selection of an appropriate technology for sewer condition assessment. In asset management domain, Frolov *et al.* (2009) developed an Asset Management Ontology to integrate product (asset) and process (best practices) knowledge. In the condition assessment domain, a model was developed to monitor the condition of industrial assets (Campos 2007).

2.2 Condition Assessment Ontologies and Technology Selection Considerations

To assess sewer networks, a set of condition assessment technologies and selection considerations are available. The utility experts don't have adequate knowledge about the capabilities and limitations of these technologies (Agarwal 2010). Tuccillo *et al.* (2010) classified technologies into four categories: screening, internal pipe surface, wall integrity, and pipe bedding and void conditions and identified selection criteria including; inventory of pipes and operating conditions, data needs, cost and implementation issues. Similarly, Lee (2017) categorized technologies into eight sub-classes: pitting depth measurement, visual inspection, electromagnetic inspection, acoustic inspection, ultrasonic testing, laser profiling, flow meters, and innovative technologies. Presently, the technology selection process is manual, which is a very time-consuming task and requires a lot of technology-related know-how. The lack of such a knowledge results in poor decision-making regarding technology selection. This requires the need to develop a tool to select an appropriate technology for sewer condition assessment.

The existing literature lacks; (i) a formal classification system of condition assessment technologies for sewer network; (ii) explicit description of the technologies and selection criteria; and (iii) a framework for condition assessment technology selection. The proposed CATS_Onto will address these issues.

3 METHODOLOGY

The following seven-step approach was used to develop the proposed ontology. A similar methodology was adopted for the development of Infrastructure Product Ontology (Osman 2007), Infrastructure and Construction Process Ontology (El-Gohary, 2008), Tangible Capital Asset Ontology (Zeb and Froese 2015a and 2015b) and Eco Asset Ontology (Zeb 2017).

- Step 1: Define scope —The scope represents the purpose, use, and users of the ontology
- Step 2: Develop a meta-model—The meta-model represents the knowledge at the abstract level to ease knowledge categorization and improve understanding of the knowledge.
- Step 3: Define taxonomy—The abstract concepts represented in the meta-model were extended to develop detailed taxonomies of concepts.
- Step 4: Code ontology—The knowledge was formally coded in the Ontology Web Language (OWL) using the Protégé Ontology Editor (Protégé 2018).
- Step 5: Capture ontology—All concepts were explicitly defined in the plain English language (soft axioms) and OWL Description Logic Syntax (hard axioms).
- Step 6: Evaluate ontology—As part of the evaluation, the knowledge was verified using the built-in Protégé Reasoners and validation is underway through industry experts.
- Step 7: Document ontology—The knowledge was documented for future use.

4 ONTOLOGY DEVELOPMENT – META-MODEL

According to Gomez-Perez (1996), ontologies are developed using a layered architecture with the top layer representing generic concepts, which are further specialized at the lower levels. The CATS_Onto was developed using this approach with the top layer representing the core concepts related to technology selection at the abstract level and is called as CATS_MM. A detailed CATS_Onto was developed through specialization of core concepts. This paper discusses the development and verification of the knowledge representation at the meta-model level. Figure 1 shows the key concepts (entities, things) and relationships between them to formalize the knowledge required for the technology selection.

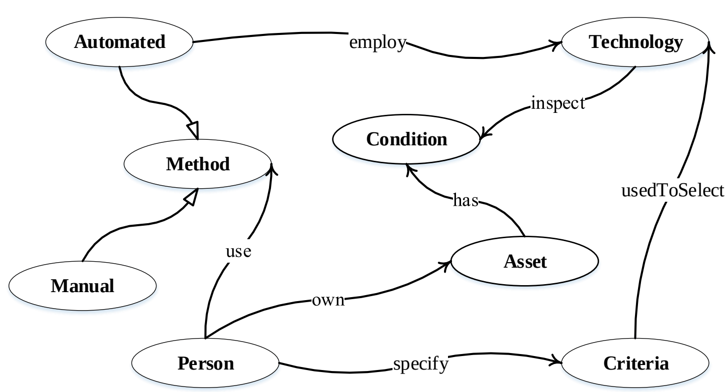

Figure 1. Meta-model of condition assessment technologies for sewer network.

4.1 Key Concepts

The “concepts are key entities in the production, services and manufacturing systems”, (Fox and Gruninger 1998). A brief definition of each concept is as follows:

Asset is defined "as an item, thing or entity that has potential or actual value to an organization", (ISO55000 2014). The asset refers to the sanitary and stormwater pipe network, including collectors, interceptors, and force main.

Condition is a measure of the physical, capacity and operational health of the sanitary and stormwater pipe network. The utility organizations usually employ automated technologies to inspect the condition of the pipe network that depends on the age, environment, maintenance, history and how well it is used by the community.

Person includes individuals and organizations who own, operate and manage sanitary and stormwater systems. The organization refers to public and private utility agencies and corporations responsible for providing uninterrupted municipal services.

Method is a generic concept covering all such means, mediums, and techniques used to assess sewer condition. These methods are either manual or automated. The manual methods include physical observation of the pipe network through visual inspection. The automated methods include physical observation of the pipe network using a set of fully automated machines and devices without the aid of human beings.

Criteria are rules, principles, aspects, elements, and factors used to identify the most appropriate technology for sewer inspection. According to Agarwal (2010), technology selection criteria include; affordability, detectability, feasibility, suitability, and usability.

Technology refers to the capabilities given to a machine, device or a piece of equipment created as a result of the practical application of knowledge (Merriam-Webster 2018) for sewer inspection. Tuccillo *et al.* (2010) categorized technologies into the following four types: Bedding and Void Inspection Technologies, Internal Surface Inspection Technologies, Screening Technologies, and Wall Integrity Inspection Technology.

The knowledge in the meta-model was conceived based on the notion that the person (individuals and organizations) own, operate, and manage infrastructure systems including sewer systems to provide services effectively and efficiently. These persons inspect and assess condition of assets as part of effective asset management using manual and automated method. In an automated method, a technology is employed to inspect the sewer network. To select a technology, an evaluation criteria is needed. The utility organizations specify the criteria to select the most appropriate technology for sewer condition assessment.

5 ONTOLOGY APPLICATION

The meta-model was used to develop the detailed CATS_Onto. The software developers will use the CATS_Onto to develop applications for the selection of appropriate technology. Such applications are lacking in the asset management domain, which need to be developed for effective decision-making regarding technology selection. The CATS_Onto provides a common understanding of the terms in the area of asset management and ensures applications are developed consistently across the industry. The proposed applications will be implemented using a multi-step exclusion protocol in which technologies will be excluded based on technical feasibility and technical suitability criteria. After screening, the selected technologies will be compared against a set of performance and cost parameters to determine performance and cost. Work is in progress to develop the application and is beyond the scope of this paper.

6 EVALUATION

The ontology was verified and validated using a set of criteria. In verification, the knowledge is verified against a set of criteria to assess that the knowledge model is built right. In ontology validation, the knowledge is validated through industry experts to assess that the right knowledge is built. The following criteria were used to evaluate the ontology including; consistency, conciseness (Gomez-Perez 1996), clarity, completeness (Yu *et al.* 2007), and correctness (Guarino 1998). Consistency measures uniformity in the knowledge representation. Conciseness measures redundancy in the knowledge representation. Clarity measures understandability of knowledge representation. Completeness measures the extent of coverage of knowledge representation. Correctness measure accuracy of knowledge representation. The CAT_Onto was verified for consistency and conciseness using Protégé Reasoners: ELK 0.4.3, FaCT++ 1.6.5, HermiT 1.3.8, Mastro DL-Lite Reasoner, Ontop 1.18.1, Pallet and jcel (Protégé 2018) as shown in Figure 2. These reasoners were run to check consistency and conciseness of the knowledge representation. The reasoning analysis results are shown in Figure 2 (image on right), where a superclass "Nothing" under the inferred class hierarchy (an automatically generated class hierarchy) represents classes with errors. There was no class found under the superclass "Nothing", indicating that the knowledge representation is consistent and concise.

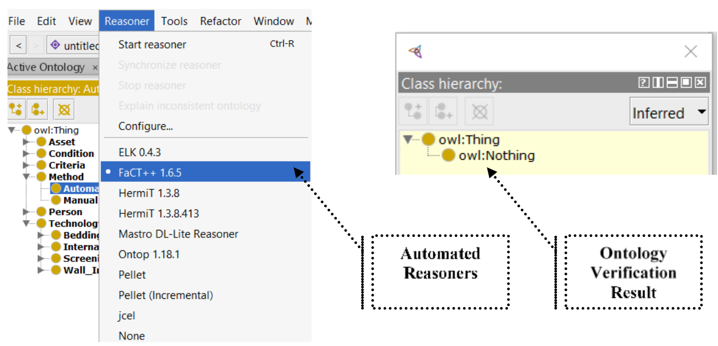

Figure 2. CATS_Onto verification.

7 CONCLUSIONS

The CATS_Onto was developed at two levels of abstraction: meta-model and detailed ontology using a seven-step approach. This paper discusses the development and verification of the meta-model. The meta-model represents the core concepts at the abstract level to ease knowledge categorization and navigation. As part of the evaluation, the knowledge in the meta-model was verified using a set of criteria. The ontology verification was accomplished using automated reasoners in the Protégé Ontology Editor. The verification results indicate that the knowledge representation was consistent and concise. The ontology validation is currently underway and beyond the scope of this paper. The proposed CATS_Onto will be implemented in a prototype stand-alone or web-based application to demonstrate the validity of the approach. From a theoretical perspective, the CAT_Onto has a significant contribution to the body of knowledge in the area of asset management. From a practical perspective, the knowledge representation; (i) provides a common understanding of the terms for software developers and industry experts; (ii) eases consistent implementation in applications; and (iii) eases knowledge base extensions in case more sewer technologies and criteria are added in future. The research limitations include the lack of a full fledge implementation in an application to test and validate the proposed approach. In the current state, the most common technologies are represented in the CATS_Onto. In future, the knowledge represented in the CATS_Onto will be implemented in a stand-alone or web-based application. The proposed ontology will be extended once more technologies are identified.

References

Agarwal, M., *Developing a Framework for Selecting Condition assessment Technologies for Water and Wastewater Pipe*, M.Sc. Thesis, Virginia Polytechnic Institute, Virginia, USA, 2010.

ASCE., Infrastructure Report Card, *A Comprehensive Assessment of America's Infrastructure*, American Society of Civil Engineers, USA, 2017.

Campos, J., *An Ontology for Asset Management*, 1st IFAC Conference on Cost Effective Automation in Networked Product Development and Manufacturing, IFAC Proceedings, 40(19), 36-41, 2007.

El-Gohary, N., *Semantic Process Modeling and Integration for Collaborative Construction and Infrastructure Development*, Ph.D. Thesis, Dept. of Civil Eng., Univ. of Toronto, Canada, 2008.

Fox, M. S. and Gruninger, M., *Enterprise Modeling*, AI Magazine, AAAI Press, 109-121, 1998.

Frolov, V., Megel. D., Wasana, D., Yong, S., and Lin, M., *Building an Ontology and Process Architecture for Engineering Asset Management*, Proceeding of 4th World Congress on Engineering Asset Management, Athens, Greece, 2009.

Gómez-Pérez, A., Towards a Framework to Verify Knowledge Sharing Technology, *Expert Systems with Applications,* 11(4), 519-529, 1996

Gruber, T. R., Towards Principles for the Design of Ontologies Used for Knowledge Sharing. *International Journal of Human-Computer Studies*, Academic Press Ltd, 43(5-6), 907–928, 1995.

Guarino, N., *Some Ontological Principles for Designing Upper-Level Lexical Resources*, Proceedings of the 1st International Conference on Lexical Resources and Evaluation, 1998.

ISO55000., *Asset Management—Overview, Principles, and Terminology*. International Standard, 1st Edi., Ref. #., ISO 55000:2014(E), International Organization for Standardization, USA, 2014

Lee, A., *Condition Assessment Technologies for Water Transmission and Sewage Conveyance Systems*, A Collaborative Project of the University of British Columbia Sustainability Scholar Program 2017 and Metro Vancouver, Vancouver, Canada, 2017

Merriam-Webster., *Definition of Technology from Merriam-Webster*, retrieved from, https://www.merriam-webster.com/dictionary/ technology on September 18, 2018.

Osman, H. M., *A Knowledge-Enabled System for Routing Urban Utility Infrastructure*, Ph.D. Thesis, Department of Civil Engineering, University of Toronto, 2007

Protégé., *Protégé is a National Resource for Biomedical Ontologies and Knowledge*, Developed by Stanford Center for Biomedical Informatics Research, Stanford University, USA, 2018.

Tuccillo, M. E., Jolley, J., Matel, K., and Boyd, G., *Report on Condition Assessment Technology of Wastewater Collection Systems*, National Risk Management Research Laboratory–Water Supply and Water Resources Division, U.S. Environmental Protection Agency, Ohio, USA, 2010.

US EPA., *Condition Assessment of Underground Pipes*, Excerpt from Condition Assessment of Wastewater Collection Systems, EPA/600/R-09/049, Water Infrastructure Outreach, US Environmental Protection Agency, Cincinnati, Ohio, USA, 2015.

Yu, J., Thom, J. A., and Tam, A., *Ontology Evaluation Using Wikipedia Categories for Browsing*, Proc. of 6th ACM Conf. on Information and Knowledge Mgt., Lisbon, Portugal, 223–232, 2007.

Zeb, J., An Ontology of Eco Assets Towards Effective Eco Asset Management, *Built Environment Project and Asset Management Journal*, Emerald Publishing Ltd., UK, 7(4), 388-399, 2017.

Zeb, J. and Froese, T. Transaction Ontology in the Domain of Infrastructure Management, *Canadian Journal of Civil Engineering*, Published by NRC Research Press, 39(9), 1-12, 2012.

Zeb, J. and Froese, T., Tangible Capital Asset Ontology in Infrastructure Management, *Infrastructure Asset Management Journal*, Institution of Civil Engineers, ICE Publishing, UK, (3), 81-92, 2014.

Zeb, J. and Froese, T., *Transaction Formalization in the Infrastructure Management Using an Ontological Approach*. Chapter 8, Ontology in the AEC Industry: A Decade of Research and Development in the Architecture, Engineering, and Construction, ASCE, USA, 169-192, 2015a.

Zeb, J. and Froese, T., *An Ontology-Supported Transaction Formalism Protocol in Infrastructure Management*, 5th Intl./11th Construction Specialty Conference, CSCE, Vancouver, Canada, 2015b

Zeb, J. and Froese, T., An Ontology-Supported Infrastructure Transaction Management Portal in Infrastructure Management, *Journal of Infor. Technology in Construction*, 21, 100-118, 2016.

Zeb, J. and Froese, T., Transaction Formalism Protocol Tool in Infrastructure Management, *Construction Innovation Journal*, Emerald Group Publishing Ltd., UK, 17(2), 180-203, 2017.

Zeb, J. Froese, T., and Vanier, D., An Ontology-Supported Asset Information Integrator System in Infrastructure Management, *Built Environment Project and Asset Mgt.*, 5(4), 380– 397, 2015.