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AN ONTOLOGY-SUPPORTED INFRASTRUCTURE TRANSACTION MANAGEMENT PORTAL IN INFRASTRUCTURE MANAGEMENT

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SUMMARY: *In current practice, infrastructure organizations exchange data about their infrastructure systems (tangible capital assets) on a manual and ad hoc basis. The growing trend is to transform these manual data exchanges (transactions) to more structured, computer-to-computer based communications that are based on formalized transaction specifications. The core question in this research is "how to manage these transaction specifications? Existing standards focus on the development and not on the management of these transaction specifications in the domain of infrastructure management, which emphasizes the motivation to develop a web-based tool—Infrastructure Transaction Management Portal. An ontology-based approach was devised to develop the portal using the SharePoint platform. The portal was developed based on the knowledge represented in the Transaction Domain Ontology built as part of this research work. The transaction specification developed for the asset inventory and condition assessment reporting was used to demonstrate how a transaction specification can be managed using the proposed portal.*

KEYWORDS: *Portal, Infrastructure Management, Transaction, Transaction Domain Ontology, Ontology, Asset Inventory and Condition Assessment Reporting. Tangible Capital Assets, Communication.*

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1 INTRODUCTION

Municipal infrastructure organizations use a diverse range of information systems to manage their infrastructure. These information systems range from paper-based systems to advanced standalone propriety systems. There are some challenges associated with the Tangible Capital Asset (TCA) data generated through these information systems: heterogeneity of the TCA data format, non-uniformity of various classes of the TCA data, lack of infrastructure component-based aggregation of the TCA data (Felio, 2012), and manual or paper-based TCA data. These issues hamper the exchange of the TCA data between the collaborating infrastructure organizations. As a result, the TCA data exchange between the partners is typically accomplished in an *ad hoc* and manual-basis, which requires human interpretation at the receiving end. The growing trend is to transform these manual communications (i.e. transactions) to a more formalized computer-to-computer-based communications. For computers to talk to each other, these transactions need to be formally defined. The formalized transaction is called a transaction specification in this research work. Previous work by the authors proposed a protocol for formalizing transactions (Zeb and Froese, 2014a), in which transaction specifications are comprised of three elements: a set of completed forms that describe the features of the transaction, a to-be transaction map (To-be TM) that governs the sequence through which atomic (single) data exchanges are to take place between the collaborating partners and message templates representing the information that the collaborating partners need to exchange in a given atomic transaction.

Transactions can be specified for different domain levels: they can be developed by standards bodies to apply across an entire industry, created within a company as a corporate standard, developed as a convention within a specific project, or developed by individual end-users for their own customized use. This creates the potential for large collections of transaction specifications that lead to the issue of how best to manage them. Standards that currently exist for formalizing work processes and communications, such as buildingSMART's Information Delivery Manual (IAI-IDM, 2007 and IAI-IDM, 2012) provide specifications of specific transactions, but they do not specify the way the newly created specifications are to be managed. The development of a transaction specification means defining To-be transaction map, actor roles and information for a business process; however, the management of these specifications means how to organize, store and retrieve them in an efficient and effective manner.

The solution proposed in this research is a web-based tool to collect and manage libraries of transaction specifications—an Infrastructure Transaction Management Portal (ITMP). The ITMP makes up one key element of a larger set of research activities intended to support the computerization of information exchange in the infrastructure industry. The larger project involved the following components:

- The formalization of information exchange knowledge in the Transaction Domain Ontology (Zeb and Froese 2011 and 2012)
- The development of a protocol and tool for formalizing transactions (Zeb and Froese, 2014a), and
- The creation of a web-based portal for managing collections of transaction specifications (the ITMP reported in this paper).

To test this approach, it was applied to the task of reporting infrastructure information (tangible capital asset reports) that is required of Canadian municipalities. This involved the following elements:

- Formalizing infrastructure information in the tangible capital asset ontology (Zeb and Froese, 2014b)
- Producing a transaction specification for tangible capital asset reports (Zeb and Froese, 2014a and Zeb *et al.*, 2014) and collecting them through the proposed ITMP, and
- Developing an infrastructure reporting tool that used the transaction specification to allow end users to exchange infrastructure information (Zeb *et al.*, 2015).

The proposed portal provides information technology specialists with the ability to manage and coordinate potentially large collections of transaction specifications that could arise from many different sources. This task is related to, but distinct from, the preceding tasks of developing transaction specifications, and the subsequent tasks of implementing the transaction specifications using some form of information system in order to support end-users communications (which could be manual and paper-based, but would more likely be a computer-based information system). The proposed ITMP is to be used to manage a collection of transaction specifications regardless of the approach used to implement them. However, there is an opportunity to leverage the functionality of the portal within a system that implements the transaction specifications, and this is the approach followed in this research, which developed two distinct, but related, prototypes. The proposed prototype ITMP was developed and implemented using the SharePoint platform for managing transaction specifications based on the knowledge represented in the Transaction Domain Ontology (Trans_Dom_Onto) developed as part of this research. Then, another prototype system—Asset Information Integrator System (AIIS) for implementing one specific infrastructure transaction specification was created using the SharePoint platform to allow end users to exchange information about infrastructure assets (the AIIS is described in detail in Zeb *et al.*, 2015).

To demonstrate the ITMP, it was used to register a transaction specification related to the task of Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting, identified as a high-priority area in an IT survey (Zeb *et al.*, 2012) conducted as part of this research work. According to PSAB (2009), the TCAs are "non-financial assets having physical substance that are acquired, constructed, or developed and: are held for use in the production or supply of goods and services; have useful lives extending beyond an accounting period; are intended to be used on a continuing basis, and are not intended for sale in the ordinary course of operations."

In this transaction, municipal governments send the TCA information to the provincial government for financial planning and fund allocations. This transaction was selected for three reasons: (i) the transaction is currently performed on a manual basis; (ii) to standardize heterogeneous TCA information being exchanged through developing a transaction specification; and (iii) to comply with regulatory requirements. Using the proposed ITMP, the AI&CAR/TCA Reporting transaction was formalized in three steps: (i) a transaction specification was developed and stored in the proposed portal; (ii) users from various municipalities accessed the portal and downloaded the standardized transaction specification developed for the AI&CAR/TCA Reporting; and (iii) end users filled the templates and send them to the provincial government using the AIIS that is beyond the scope of this paper).

This paper focuses on the development of the prototype ITMP that the following sections. The first section introduces the topic area while the second section establishes the points of departure from previous research work. The third section describes the development and evaluation of the Trans_Dom_Onto. The fourth section describes the development and implementation of the proposed prototype portal. The fifth section discusses the portal application to a real-life scenario and sixth section describes the conclusions.

2 RELATED RESEARCH WORK

A literature review was conducted from two perspectives. (i) A review of the related state-of-the-art standards and methodologies to identify gaps and establish the points of departure; and (ii) a review of the related existing ontologies in the domain of transaction design and management to justify the use of the Trans_Dom_Onto for developing the proposed portal.

2.1 State-of-the-art standards and methodologies

There are a number of standards and methodologies currently in use to formalize work processes and communications in the different industries including the Architecture, Engineering, Construction and Facilities Management (AEC/FM) industry. All of these existing standards and methodologies identify several important elements that are required for work process and communication formalization. However, they mostly focus on the development of the formalized work processes and communications (i.e. specifications) but they do not identify the way by which these work processes and communications are managed (or archived) for future implementations into software applications.

In the non-AEC/FM industry, the Open Electronic Data Interchange (Open-EDI) is one of the initial standards developed to design and implement communication standards (ISO, 1995). This standard was developed to model and standardize business documents that are exchanged between the collaborating partners. The drawbacks of this standard are: high implementation cost, high transaction cost and complexity. The United Nation's Centre for Trade Facilitation and Electronic Business (UN/CEFACT) Modelling Methodology (UMM) develops specifications for commercial transactions (UN/CEFACT, 2003). The Electronic Business Extensible Markup Language (ebXML) enables organizations of any size located in any geographical area to conduct business over the internet using XML-based standardized message templates (ISO, 2004-05). RosettaNet develops partner interface processes (PIP) for the supply chain organizations of the electronic industry (Damodaran, 2004). All of these standards focus on developing specifications for commercial transactions;

however, they lack the ability to elaborate on how to manage (i.e. archive) these specifications for any future use as part of the transaction specification management.

In the AEC/FM industry, the agcXML contains XML-based schemas for the reliable and efficient exchange of electronic building information between heterogeneous proprietary applications that improve interoperability and integration of the information systems (Zhu, 2007). This standard includes a format for transaction use cases and a use case for generic document distribution. The Information Delivery Manual, IDM (IAI-IDM, 2007 and IAI-IDM, 2012) is a requirement specification methodology that formalizes work processes based on 3D object-based exchange of information between the collaborating partners. As a result of the IDM application, a set of specifications were developed: process map, exchange requirements, functional part and business rules. The Model View Definitions, MVD (IAI-MVD, 2005) is a methodology developed to specify a specific view (i.e. subset) of the Industry Foundation Classes (IFC) model for implementation into a software application. The MVD specifies model views, but not the way that the views are to be managed for any future use. The Voorwaarden Scheppen Voor Invoering Standaardisatie, VISI (VISI, 2007 and VISI, 2011) is a Dutch communication standard that provides "the terms and conditions for the implementation of standardization in the information and communication technology, (ICT)", developed to define communications in the AEC/FM industry. The VISI standard defines communications in the domain of infrastructure management in the form of a set of Extensible Markup Language (XML)-based standardized message templates. The standard doesn't elaborate on how to manage these standardized communications for future implementation into software applications. Similarly, another related Dutch standard, the COINS Engineering Method, CEM (Schaap *et al.*, 2008), was developed to create specifications or agreements on working methods and organization of production processes and information.

In summary, all of the existing methodologies and standards focus on the development of the work processes and transaction specifications, but not on the management of these specifications; thus emphasizing the need to develop a portal where the transaction specifications can be stored for any future use.

2.2 Transaction design and management ontologies

The Open-Electronic Data Interchange Transaction Ontology, Open-edi Onto (ISO, 2006) represents transaction knowledge to support the design of transaction specifications for commercial transactions (i.e. buying/selling transactions). The Open-edi Ontology was based on the Resource-Event-Agent Ontology, REA-Onto (Allen and March, 2006) that evolved from an accounting model Resource-Event-Actor (McCarthy, 1982). The Open-edi Onto represents knowledge based on three main categories: financial (exchanging something of value), commercial (business markets), and industrial (diversified industries in various geographic locations). The core emphasis of the Open-edi Onto is to support the development of the transaction specifications for commercial transactions. The Infrastructure and Construction Process Ontology, IC-Pro-Onto (El-Gohary and El-Diraby, 2010) represents work processes over the life cycle of projects. This ontology represents four main categories of the work processes: core, management, knowledge integration and support processes. Turki *et al.* (2013) analyzed the ontological foundations of the organizational processes and developed a comprehensive ontology of organizational processes to represent the static aspects of organizations and their behaviors. Fathalipour *et al.* (2014) emphasized that the development of applications is dependent on process and society's knowledge for which they developed two ontologies: process ontology and society ontology. These ontologies were used to build a process-oriented and society-independent agent system to help organizations to manage and automate their processes. Deshpande *et al.* (2014) developed an ontology-based framework that makes use of the Building Information Models to support organization-wide knowledge management processes. Similarly, Trento and Fioravanti (2013) developed a method to link process and product ontologies to improve both the quality of building performance and user experience. This method supports improved interoperability between planning and design software. The focus of most of these ontologies or ontology-based frameworks is to support the formalization of the work process in the construction industry; however, they lack detailed classification of diversified transaction domain knowledge to support the design, management and implementation of transaction specifications in the domain of infrastructure management. This emphasizes the need to develop a Trans_Dom_Onto to represent the transaction knowledge to support the design of the proposed portal as part of the transaction specification management.

3 TRANSACTION DOMAIN ONTOLOGY

3.1 Ontology architecture

The Trans_Dom_Onto was developed using a layered architecture approach as proposed by Gomez-Perez *et al*. (2005). Creating ontologies in layers have two benefits: reusability and interoperability (Fensel, 2001). The Trans_Dom_Onto was developed at two levels of abstraction as shown in Fig. 1, representing a conceptual model of the transaction domain knowledge to support the design, management and implementation of transactions in the area of infrastructure management.

The Transaction Upper Ontology (Trans_Upper_Onto) was developed at the top layer (Level-1), representing the most generic and abstract concepts that are same across all industries. The knowledge in the Trans_Upper_Onto is organized into core and support concepts. The core concepts are the key concepts forming the foundation of the transaction domain knowledge, including: project, action, product and resources. As the name implies, the support concepts assist modeling, organization, classification and definition of the core knowledge: attribute, modality, mechanism, constraint, and relationship. A detailed description of these concepts are given in Zeb and Froese (2011).

Similarly, the Trans_Dom_Onto was developed in the second layer (Level 2) representing transaction-related concepts at two levels of abstraction. Level 2-1 shows the Transaction Domain Kernel Ontology (Trans_Dom_Kernel_Onto) representing core concepts (transaction, message, actor, actor-role and information) and support concepts (attribute, modality, relationship, constraint, mechanism and axiom) related to the design, management and implementation of transactions in the area of infrastructure management. These abstract core and support concepts were further extended to create detailed taxonomies at Level 2-2, which were integrated with existing infrastructure domain ontologies. This paper discusses a portion of the transaction taxonomy (see Fig. 1, box with gray background) that is used in the development of proposed portal; however, other related facets of this ontology are given in Zeb and Froese (2012).

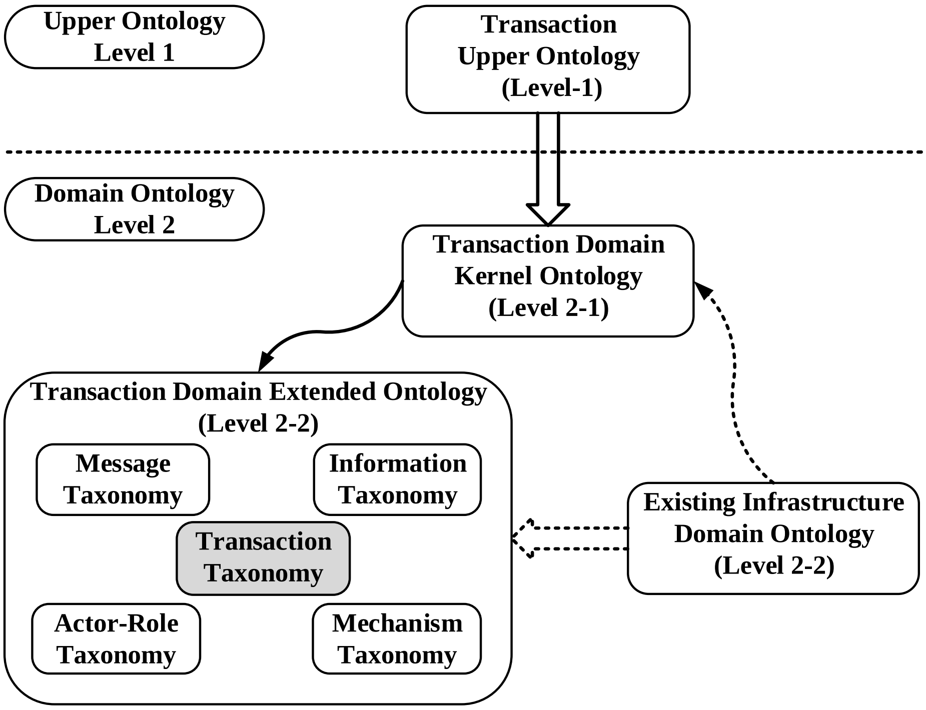

FIG. 1: Transaction ontology architecture—a conceptual model illustrating how the ontology models have been organized into hierarchical sub-models to improve reusability and interoperability.

3.2 Methodology to develop ontology

The Trans_Dom_Onto was developed using a ten-step procedure that is a hybrid version of the various approaches developed by Fernandez-Lopez *et al.* (1997); Uschold and Gruininger (1996); and Noy and McGuinness (2001).

- Step 1: The purpose, use, and users of the ontology were defined.
- Step 2: A set of competency questions was developed that the ontology should be able to answer.
- Step 3: A preliminary taxonomy of various concepts was developed.
- Step 4: Use was made of the existing ontologies and relevant concepts were captured.
- Step 5: A Transaction Domain Kernel Ontology was developed first representing concepts at the very abstract level to easily categorize and integrate diversified knowledge in infrastructure management.
- Step 6: Abstract concepts represented in the kernel ontology were extended to develop detailed taxonomies.
- Step 7: Soft and hard axioms were developed representing explicit declarations of concepts using Description Logic Syntax (DLS).
- Step 8: The knowledge represented in the ontologies was formally coded in Ontology Web Language using Protégé Ontology Editor (Protégé, 2015).
- Step 9: The knowledge represented in the ontology was validated through industry experts.
- Step 10: The knowledge was finally documented for future use.

3.3 Transaction domain ontology—transaction taxonomy

The Trans_Dom_Onto represents taxonomies of the core concepts (transaction, message, actor, actor-role and information) and support concepts (attribute, modality, relationship, constraint, mechanism and axiom) to support the design, management and implementation of transactions in infrastructure management (Zeb and Froese, 2012). The Trans_Dom_Onto includes 486 classes, 247 properties (relationships) and 929 axioms. Axioms are an explicit and unambiguous declaration of concepts coded in formal language—Web Ontology Language (OWL) Description Logic Syntax (DL). In Trans_Dom_Onto, hard axioms are of three types: disjoint axioms, subsumption/is-a axioms and property restriction axioms, including; existential, universal and cardinality restrictions.

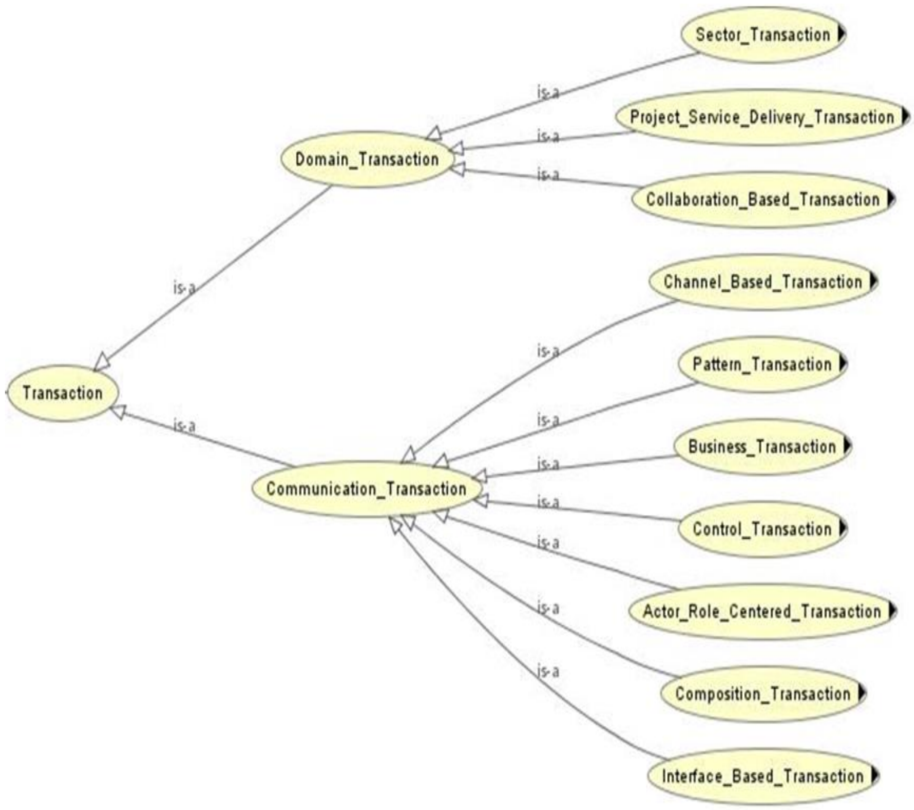

FIG. 2: A portion of the transaction taxonomy developed and visualized in the Protégé ontology editor

As part of the Trans_Dom_Onto development, this paper presents an abstract taxonomy of various transactions to support the development of the ITMP to manage transaction specifications in the area of infrastructure management. A portion of the transaction taxonomy is presented in Fig. 2, which was used to develop the proposed portal. The taxonomy describes a number of different ways of classifying transactions, expressed within the taxonomy as subclasses of the general "transaction" class. These classifications are not mutually exclusive—any given transaction may be classified according to many or all of these different classification dimensions. The classification dimensions are organized under two broad subclasses: characterizations based on the generic communication properties are represented as subclasses of "Communication Transaction" while characterizations based on properties that are specific to the infrastructure domain are represented as subclasses of "Domain Transaction".

3.3.1 Communication transaction

The communication transactions are classified based on how they are communicated between the sender and receiver roles. Various classes of communication transactions are as follows.

Pattern transaction—based on the interaction patterns of the collaboration partners in a transaction. A pattern describes the way a single or a set of atomic transactions (single transaction) are arranged in a given transaction that is to be followed consistently. Pattern transactions have five sub-classes. (i) One action with acknowledgement transaction (pattern 1)—is composed of a single action and acknowledgement message. (ii) Two action with acknowledgment transaction (pattern 2)—includes two action and two acknowledgement messages (Dietz, 2006). (iii) One action without acknowledge transaction (pattern 3)—includes a single action message that doesn't require an acknowledgement message to be transmitted between the collaborative partners. (iii) Two action without acknowledgement transaction (pattern 4)—includes two action messages that don't require any acknowledge message to be transmitted between the parties. (iv) Information without acknowledgement transaction (pattern 5)—includes a single message that is exchanged between the sender and receiver roles for information dissemination.

Business transaction—based on the type of physical, financial or informational resource being exchanged or transferred between the sender and receiver roles in a given transaction. It has three types: (i) Commercial transaction—results in the exchange money (financial resource) for products (physical resource) and services, e.g. buying/selling transactions. (ii) Financial transaction—results in the exchange or transfer of possession of financial resources, e.g. bank transactions. (iii) Information transaction—results in the exchange or transfer of possession of information resources, e.g. request for information.

Interface-based transaction—based on the way that information is exchanged between the parties in terms of the organizational boundaries; i.e. external and internal transactions. (i) External transactions—in which parties from different organizations exchange information across organizational boundaries, e.g. a municipality sends asset information to the provincial government. (ii) Internal transactions—in which parties within the same organization exchange information, e.g. an engineering department sends asset information to the finance department.

Composition transaction—based on the way a transaction is composed in a given context. It has three sub-classes. (i) Atomic transactions—in which a conversation or dialogue between the two collaborating parties is completed in a single interaction. (ii) Compound transactions—in which a conversation or dialogue between two parties is completed in more than one single communication using either one action with acknowledgement or two actions with/without acknowledgement transactions. (iii) Composite transactions—is a conversation or dialogue between two or more parties is completed in more than one single communication using a set of compound transactions.

Actor-role-centered transaction—based on the interaction, location, and response timings of the actor-roles. It has the following sub-classes. (i) Agent-person transactions—based on the type of actor (either a person or a computer agent) who is sending and receiving the information. According to Anumba and Evbuomwan (1999), it has three types: person-to-person (P2P), person-to-computer (P2C), and computer-to-computer (C2C). (ii) Role-location transactions—based on the geographic location of the parties exchanging information in a given transaction. According to Anumba and Evbuomwan (1999), it has two types: co-located (same place) and distributed (different geographic locations) transactions. (iii) Synchronism transactions—based on response timings of the communication between two or more parties. According to Ashley (2003), it can be either synchronous or asynchronous.

Channel-based transaction—based on the modes of transmission (channels) being used for the exchange of information between the sender and receiver roles; e.g. web transaction, face-to-face transaction, postal transaction, telephone transaction, and fax transaction (Anumba and Evbuomwan, 1999).

Control transaction—based on the control imposed on the transaction transmission. It has the following two types. (i) Accessibility transactions—based on the accessibility of the user to the transaction execution (publicly accessible, or privately accessible where only authorized personnel have access to transaction execution). (ii) Security transactions—based on whether messages are exchanged via secured or unsecured networks.

3.3.2 Domain transaction

The domain transactions are defined based on the range of civil engineering fields or domains to which transactions belong. It has the following three sub-classes. (i) Sector transactions—based on the civil engineering sector to which they belong. Typically, these sectors include: transportation, water, wastewater, gas, telecommunication, electricity, and building/facility. (ii) Project service delivery transactions—based on the mode of project service delivery, which includes: design-bid-build; design-build; design-build-operate; design-build-operate-finance, and construction management. (iii) Collaboration-based transactions—based on the number of parties involved in a given transaction. It has two sub-classes: bilateral collaboration transaction and multilateral collaboration transaction. The bilateral collaboration transactions take place between two parties. It has four sub-classes: owner-related transaction, consultant-related transaction, agency-related transaction (agency refers to a government agency), and general contractor-related transaction. On the other hand, multilateral collaboration transactions take place between three or more parties as represented in Fig. 6. below.

3.4 Ontology evaluation

There are three types of ontology evaluation methods: gold standard, task-based and criteria-based. The gold standard evaluation is used to select an ontology among a set of existing ontologies (Dellschaft and Staab, 2008), the task-based evaluations are used to judge the knowledge representation with respect to a specific task or application (Yu *et al.,* 2007) and the criteria-based approaches are used to validate domain knowledge (Gomez-Perez, 2001). In this research, a criteria-based approach was selected since the Trans_Dom_Onto represents transaction domain knowledge in the area of infrastructure management. According to Gomez-Perez (2001), evaluation refers to judging the content of the ontology with respect to a real-world model of the domain of interest (i.e. ontology validation). The Trans_Dom_Onto validation was completed using expert interviews.

The following three criteria were used to evaluate the Trans_Dom_Onto: clarity, completeness (Yu *et al.,* 2007) and correctness (Guarino, 1998). According to Yu *et al.* 2007, *clarity* measures how clear and understandable a knowledge representation is. Class description communication errors measure clarity of a knowledge representation. *Completeness* measures how complete a knowledge representation is. According to Yu *et al.* (2007), there are no measures developed yet to prove completeness of an ontology, rather it can be demonstrated in terms of incompleteness. According to Guarino (1998), *correctness* measure how correct a knowledge representation is, compared to the real world model of the domain of interest. Identity errors measure correctness in terms of semantic compliance with the WorldNet or real-world context.

The Trans_Dom_Onto was validated through three domain experts using a structured interview approach. Each of them had more than 15 years of experience in different civil engineering fields. They were extremely familiar with the transportation sector while moderately familiar with the water, wastewater and solid waste management sector. In addition, they were moderately familiar with data or information modeling and the process of communication formalization. A structured questionnaire was presented to respondents wherein questions were organized according to three assessment criteria: clarity, completeness and correctness. For each question, a multi-sheet table was developed to reflect various concepts in rows and respondent's responses in the columns. Respondents were asked to rate a given concept on a scale of 1 (strongly disagree) to 5 (strongly agree) on each of the three assessment criteria. The average score ranged from 4 (agree) to 5 (strongly agree) indicating that all the respondents were in universal agreement on the clarity, completeness and correctness of the knowledge represented in the Trans_Dom_Onto. An overall ontology validation assessment was conducted. The overall average rating of the Trans_Dom_Onto was 4.67 on a scale of 5 shows that the results are satisfactory and respondents are in full agreement on the clarity, completeness and correctness of the knowledge represented in the transaction ontology.

4 INFRASTRUCTURE TRANSACTION MANAGEMENT PORTAL

4.1 Methodology

In line with the methodology proposed by Parren *et al.* (2010) for system development, the following four core tasks were used to develop the proposed portal:

Task 1: Requirement specification—a set of requirements was captured by consulting various stakeholders. Various requirements represent different functionalities that the proposed application should include for effective management of transaction specifications.

Task 2: Design/development—the proposed prototype system was designed to represent various activities and the flow of information between stakeholders using a flow diagram. The design shows the flow of various activities (how), roles (by whom) and data/information (what) being exchanged as a result of the interaction with the portal.

Task 3: Implementation/deployment—A four-step approach was used to implement the prototype system using Microsoft SharPoint. According to Microsoft (2014), SharePoint is a platform that is used to create websites, helps communities of people to collaborate, provides a place to put information content, allows searches of the content stored on the SharePoint server, helps in bringing all the information together to provide better insights and allows extension and customization without having extensive programming skills and knowledge. The prototype ITMP was implemented using the following "4C" approach:

- Step 1: Create virtual directory—a virtual directory for the prototype ITMP was created on an Internal Information Server (IIS). A Universal Resource Locator (URL) was assigned to the virtual directory. All subsequent sub-sites and web pages of the portal were created in this directory and all information relating to transaction specifications were stored at this location on the SharePoint server.
- Step 2: Create collection site—a collection site was created in the IIS that includes all sub-sites and web pages. This site was created as a web application, named as Infrastructure Transaction Management Portal.
- Step 3: Create sub-sites—sub-sites were created as per class hierarchy defined in the Trans_Dom_Onto.
- Step 4: Create web pages—three web pages were created to store the following; (i) transaction specification—filled forms; (ii) transaction specification—To-be TM; and (iii) transaction specification—MTs defined for the To-be TM.

Task 4: Testing—the proposed ITMP was tested to assess successful implementation of various functionalities, specifically with regards to uploading transaction specifications to respective web pages for any further use and integrating with the proposed prototype AIIS system developed as part of this research work.

4.2 Portal development and implementation

4.2.1 Task 1—Requirement specification

The ITMP is developed to illustrate how transaction specifications could be managed in the domain of infrastructure management. As a prototype application, the required feature set was basic. The required functionality included: (i) store and save transaction specifications for future use; (ii) upload transaction specifications with minimum attributes such as name, title, date created, status (i.e. draft, approved, deprecated), developer identities and version; (iii) delete transaction specifications; (iv) navigate between interfaces; and (v) edit the attributes of the transaction specifications.

4.2.2 Task 2—Design/development

4.2.2.1 Design approach

When information is exchanged through human-to-human communications (whether it is face-to-face or through paper or electronic documents), there is no need for a formal specification to prescribe the detailed process and content of the exchange. The context of this research; however, addresses the trend towards computer-to-computer information exchange, which do need to be formally designed and agreed-upon between the sending and receiving parties. As introduced earlier, this can be achieved through the process of creating formal transaction specifications. Elsewhere, the authors have addressed several facets of this process: ontologies that formally model the required information (Zeb and Froese, 2012), a protocol that defines the design steps (Zeb and Froese, 2014a) and a tool that supports the creation of individual specifications.

As computer-to-computer information exchange increasingly becomes the norm, transaction specifications could proliferate, developed by many different parties at many different levels for many different audiences. For example, transaction development personnel (including; transaction analysts, transaction designers, transaction modelers, software developers and industry experts) could develop transaction specification standards (create new or adapt existing standards) at each of the following four levels.

- Industry level—transaction specifications can be developed and approved by a relevant authority to be used as optional or regulated industry standards. These are generic industry-specific transaction specifications that are independent of the organization, project, or user requirements and can be used across the industry.
- Organization level—individual companies may develop transaction specifications aligned with corporate objectives and practices, for use both with internal and external communication along their supply chains.
- Project level—since infrastructure projects bring together large teams of people from many different companies on large scale ventures, it may often be appropriate to formalize communications that are specific to the individual project teams, products and processes.
- End-user level—not only can transaction specifications be standardized across industrial, corporate or project domains, but they can be developed to support a single type of recurring transaction that takes place between any two parties.

The transaction specification standards could be applied at all four of the above levels simultaneously, leading to the significant management challenge of collecting, organizing and accessing these specifications. The research reported in this paper addresses this challenge by proposing and designing a tool to support the management of a collection of transaction specifications. The proposed tool takes the form of a web-based portal where transaction specifications from all four levels can be collected, organized and accessed by all of the parties involved in developing, using and managing the specifications. By providing a system that helps information specialists to work with transaction specifications, the research was also intended to help demonstrate and validate the utility of the earlier work on transaction specification ontologies, protocols and tools.

4.2.2.2 Portal design

The design of the prototype portal is presented in Fig. 3. The transaction development personnel login to the portal using secured control access. Different individuals will be given a specific level of administrative control. Every individual will access the portal using a unique user name and password. The proposed ITMP is hosted on an Internet Information Server (IIS).

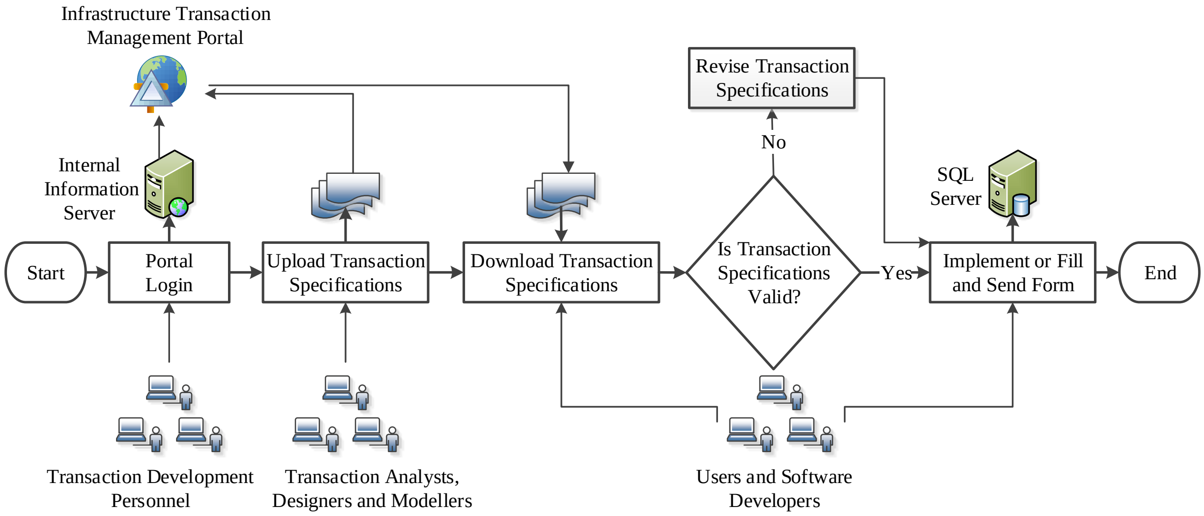

FIG. 3: Infrastructure transaction management portal design/development

The transaction analysts, designers and modelers are responsible for defining transaction specifications in the domain of infrastructure management. Once specifications are developed, these need to be stored in the portal for any future use. As part of the transaction specification management, these are uploaded to the portal, which is composed of various subsites created in the line with the class hierarchy defined in the Trans_Dom_Onto. Each of the three parts (i.e. filled forms, To-be transaction map and message templates defined for To-be transaction map) of a transaction specification are stored in separate web pages in a subsite as explained in the implementation section.

For future use, general end users (i.e. industry experts) and software developers will access the portal and download the transaction specifications. The software developers will use these specifications for implementation in software applications, (e.g. in the proposed prototype Asset Integrator Information System in this research work); however, end users can also use the transaction specifications by downloading them, entering the required information in the appropriate forms and sending the information to the recipient parties according to the transaction requirements described in the specifications. The communication records are stored in the SQL server for future reference.

4.2.3 Task 3—Implementation/Deployment

4.2.3.1 Portal architecture

The proposed ITMP implementation followed the architecture presented in Fig. 4.

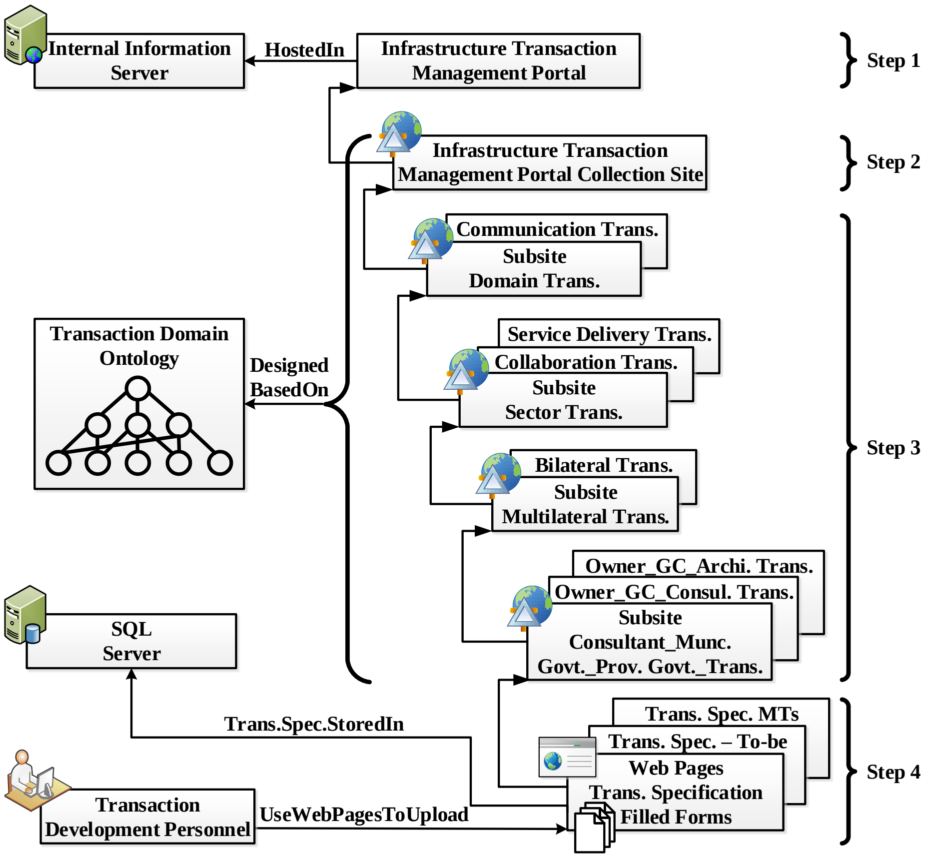

FIG. 4: Infrastructure transaction management portal architecture

4.2.3.2 Step 1—The main portal directory

As part of the prototype portal development, a virtual directory for the ITMP was created in the IIS with the name “TransactionManagement.” The proposed portal was hosted at this location so that it can be accessed through the SharePoint Central Administration using the assigned username and password. All the contents, including; the collection site, sub-sites, web pages and information content are stored at this location.

4.2.3.3 Step 2—The transaction specification collection site

A collection site—the Infrastructure Transaction Management Portal, was created to store the transaction specifications according to the transaction class hierarchy represented in the Trans_Dom_Onto. The collection site welcome page is shown in Fig. 5. The purpose of the proposed portal is to help the transaction development personnel to archive transaction specifications according to two main transaction types: domain and communication transactions. The content of the collection website can be changed using the editing tool identified in Fig. 5.

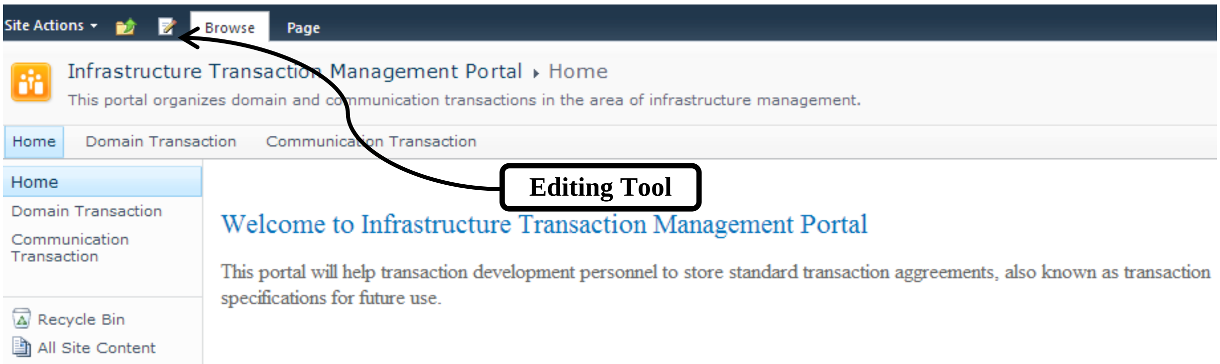

FIG. 5: Create a collection site of the prototype portal

4.2.3.4 Step 3—Individual transaction specification sub-sites

A set of sub-sites were created in the prototype ITMP for each main category of transaction represented in the Trans_Dom_Onto as shown in Fig. 6.

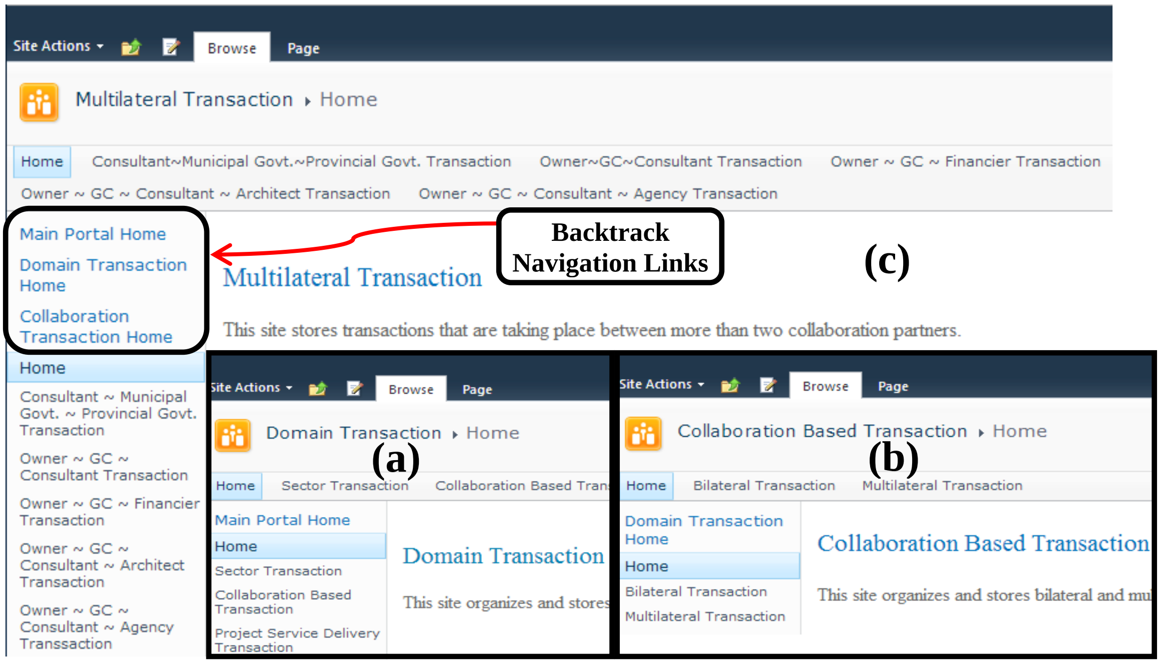

FIG. 6: Create subsites of the prototype portal; (a) Subsite for the domain transaction; (b) Subsite for collaboration transaction; and (c) Subsite for multilateral transaction

The domain transaction sub-site displays three sub-classes of the domain transaction as shown in Fig. 6 (a). These sub-classes are: sector transaction, collaboration transaction, and project service delivery transaction. A sub-site for collaboration transactions can be seen in Fig. 6 (b); it displays two types of transactions: bilateral and multilateral transactions. A sub-site for multilateral transactions can be seen in Fig. 6 (c), displaying six different types of transactions: (i) Consultant_MunicipalGovt_ProvincialGovt_Transaction; (ii) Owner_GC_Consultant_Transaction; (iii) Owner_GC_Architect_Transaction; (iv) Owner_GC_Financier_Transaction; (v)

Owner_GC_Financier_Transaction; (vi) Owner_GC_Consultant_Architect_Transaction; and (vii) Owner_GC_Consultant_Agency_Transaction. All of these different types of transactions are explicitly defined in the Trans_Dom_Onto and a brief definition of each type is presented on the respective sub-sites interface. In each sub-site, backtrack navigation links were established to navigate between different sub-sites. Moreover, if required, a transaction specification can be associated with more than one sub sites.

4.2.3.5 Step 4—Transaction specification component web pages

Various web pages were created to archive transaction specifications, which are a combination of three elements: a set of forms filled as part of the process of transaction formalization (i.e. Excel-based forms), the To-be TM (i.e. interaction or sequence diagram) and MTs (i.e. message templates created in InfoPath) defined for each atomic transaction. The portal implements three web pages within each sub-site. The web page for the transaction specification—forms stores the complete specification while the transaction specification—To-be TM and the transaction specification—MTs web pages store separately the To-be TMs and defined MTs respectively.

Web page for transaction specification—forms: In the transaction specification—forms web page, a transaction specification document is uploaded to the web page using the "add document" functionality as shown in Fig. 7. Multiple versions of the document can be added, along with comments identifying each version. After uploading a transaction specification document, a follow-up window opens, as shown in Fig. 7 (a), which records the meta-information about the transaction specification document. The meta-information includes: name, title, and status of the transaction specification, in addition to the date and the name of the specification developer. The status of a transaction specification shows whether the specification is in draft, reviewed or approved state. When the meta-information is recorded and saved, the transaction specification document is saved and uploaded to the web page. For example, a transaction specification document along with meta-information for the TCA reporting transaction is uploaded to the web page as shown in Fig. 7 (b).

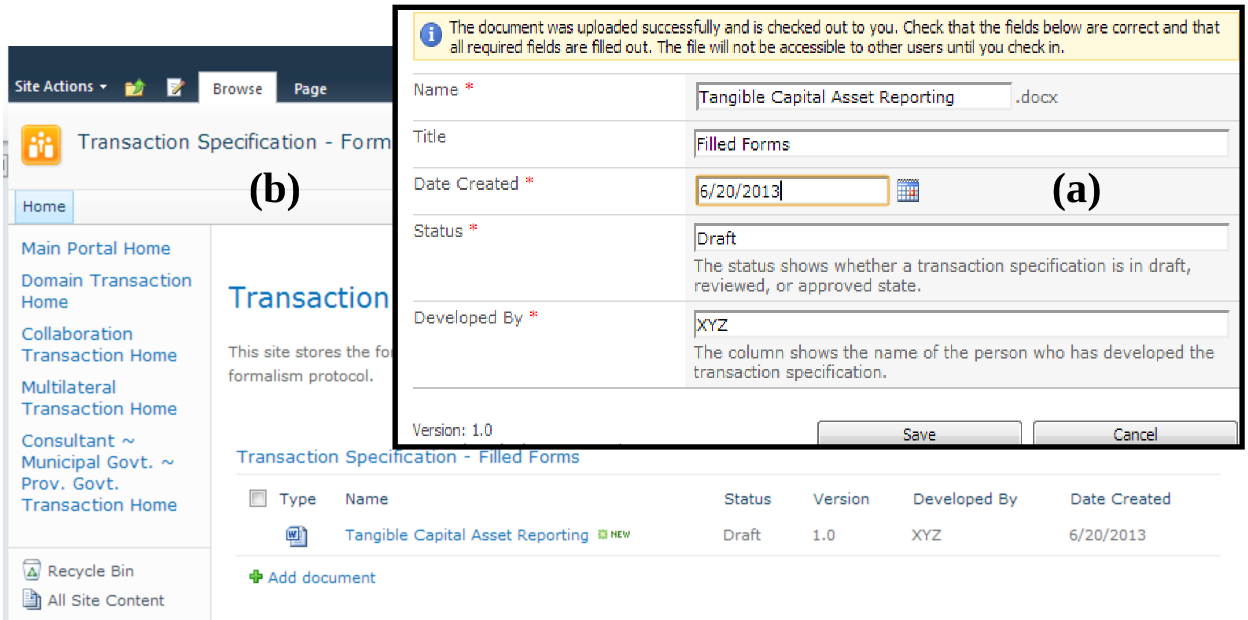

FIG. 7: (a) Shows the recording of the specification meta information; (b) Shows the attached tangible capital asset reporting transaction specification file

Web pages for the To-be transaction map and message templates: A web page was created to store the To-be transaction maps and formalized message templates as part of the transaction specification. A set of the message templates defined for different atomic transactions of the TCA reporting was saved to a single document that was uploaded to the web page using the "add document" functionality. An inline editing tool is also available, as shown in Fig. 8 (a) that enables the transaction development personnel to make changes to meta-information as shown in Fig. 8 (b). A file or transaction specification can also be searched in the portal by name using a search feature.

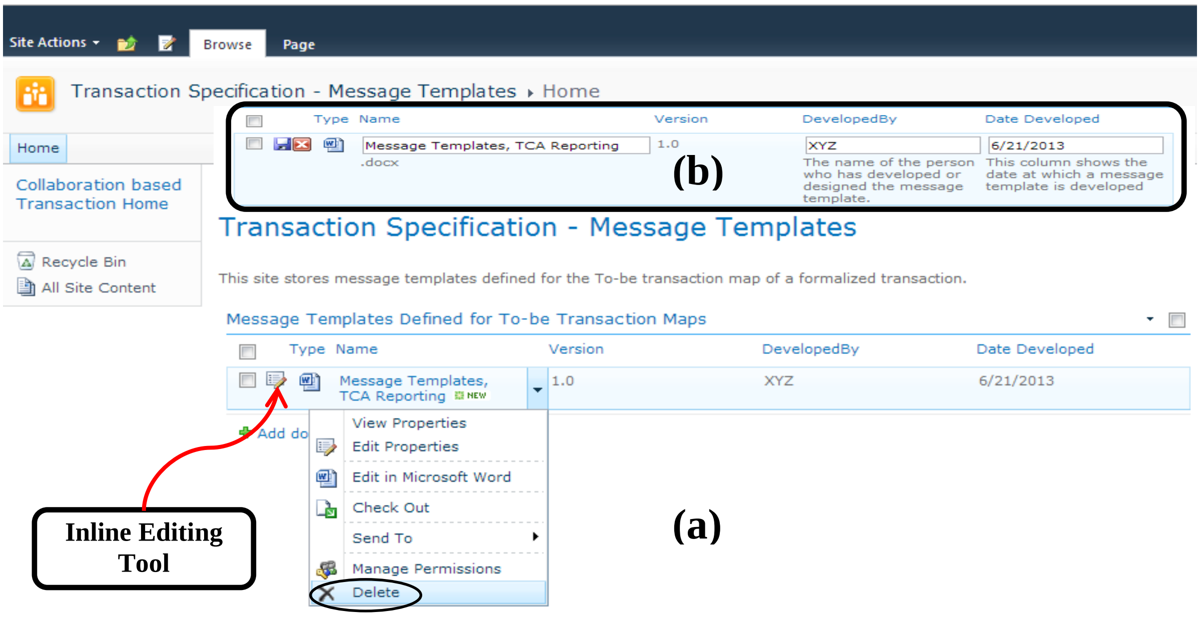

FIG. 8: (a) Create a web page for transaction specification—message templates; and (b) Inline editing of attached file metadata

4.2.4 Task 4—Testing and demonstration

The following three criteria were used for testing and demonstrating the proposed prototype portal: implementation of functionality, demonstration through uploading and downloading transaction specifications and exchanging filled forms through integration with the AIIS system.

First, all the capabilities identified in the requirement specifications were successfully implemented in the prototype system, including storing, saving, uploading, deleting transaction specifications and navigating between interfaces. Second, the transaction specification developed for TCA reporting between the municipal and provincial government was successfully uploaded to web pages defined in line with the various transaction classes represented in the Trans_Dom_Onto. Third, the message templates defined for TCA reporting were successfully downloaded from the portal, filled and transmitted to the recipient through integrating with the AIIS. As a prototype system, no failures were encountered with regards to the specified requirements.

5 INFRASTRUCTURE TRANSACTION MANAGEMENT PORTAL APPLICATION

In the AI&CAR/TCA Reporting scenario shown in Fig. 9, municipalities report their AI&CAR/TCA information to the provincial government for financial planning and funds allocation in accordance with PSAB-3150 regulations. The AI&CAR/TCA Reporting requirement was identified during an IT survey (Zeb *et al.*, 2012) and selected as a potential case study in this research work for three reasons.

- Manual processing—As-is reporting is currently manual as the TCA information is exchanged as a Word or PDF file/reports attached to an e-mail. In these reports, human interpretation is required at the receiving end, which makes the whole process time-consuming and prone to errors.
- Heterogeneity—the provincial government receives the TCA information in different formats because different municipalities (cities, districts, towns, and villages) use different information systems to manage their infrastructure systems.
- Non-compliance with regulatory requirements—As-is reporting process doesn't comply with the PSAB-3150 reporting requirements for the asset inventory (PSAB, 2009) or SORP reporting requirements of condition assessment (SORP, 2008).

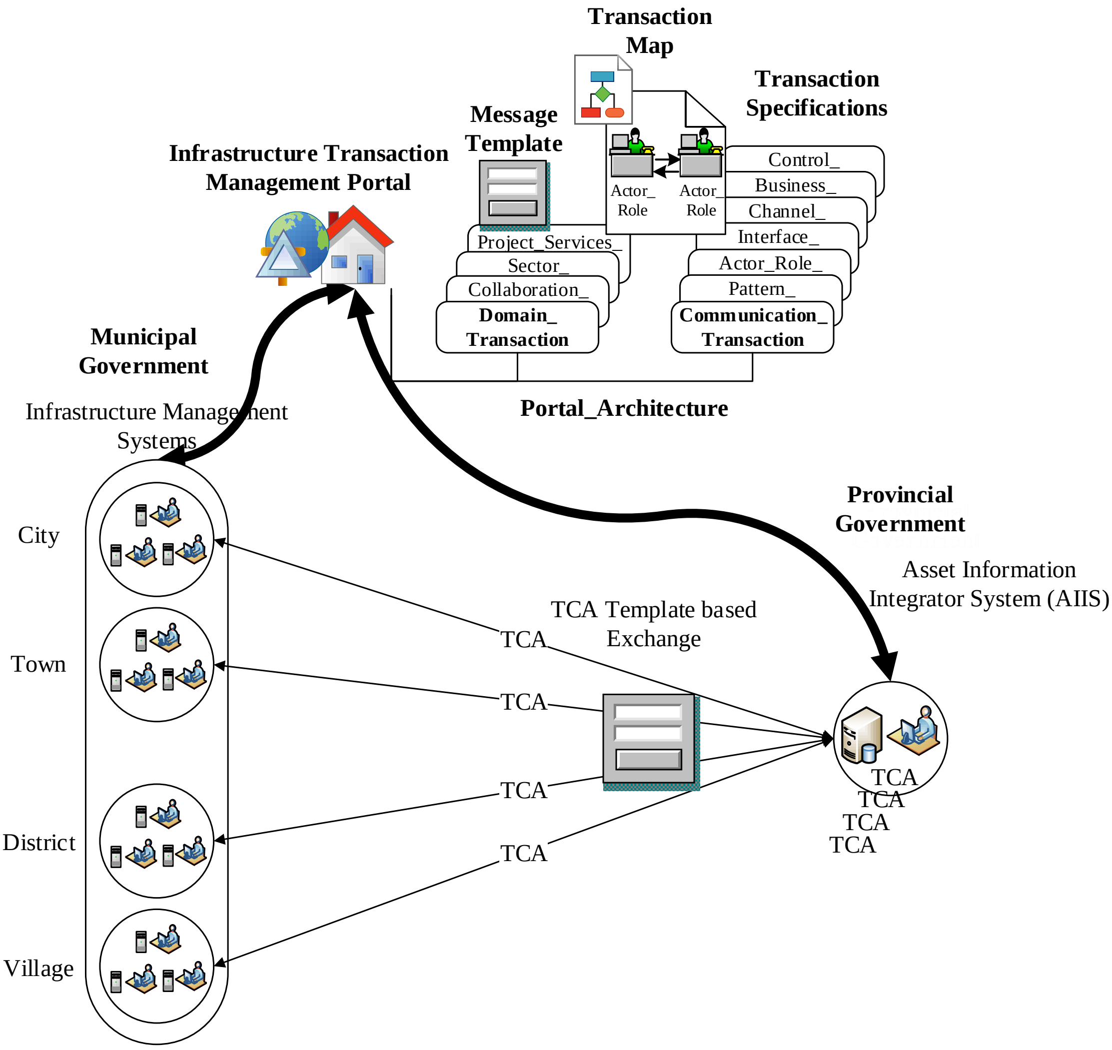

FIG. 9: Infrastructure transaction management portal application

The proposed scenario improves upon the current situation by developing a formal transaction specification for the AI&CAR/TCA Reporting, placing this transaction specification into the ITMP and implementing this specification into the prototype AIIS. Various municipalities will use this system to submit their infrastructure asset information in a standardized way and the provincial government will use it to receive and aggregate the TCA information. Implementation of the proposed scenario is presented in following three steps:

In the first step of the implementation scenario, the transaction specification for the AI&CAR/TCA Reporting was developed using the Transaction Formalization Protocol Tool. This transaction specification was then stored into the proposed ITMP that is illustrated in the top-left portion of Fig. 9.

In the second step of the implementation scenario, the prototype AIIS was developed that the receiving organization (here, the provincial government) could use to receive municipal tangible capital asset reports in a standardized format, collect the reports, aggregate the results, produce analysis and reports from the aggregate data set. The AIIS is illustrated in the bottom-right portion of Fig. 9, which was also implemented using the SharePoint platform. In creating the AIIS, the system developer (who in this case is the first author of this paper), made use of the AI&CAR/TCA Reporting transaction specification stored in the ITMP as a key reference to provide information requirements for system development. While much of the information requirements contained in the transaction specification are consumed manually by the system developer, some of the elements of the message template were in a computer-interoperable format that could be read directly by the AIIS system to implement portions of the AIIS.

In the third step of the implementation scenario, municipalities must implement an information system for creating their tangible capital asset reports according to the transaction specification requirements. They have several alternatives for doing this: they can use the AIIS system to produce their reports; they can download the MT from the ITMP and use a simple form-filling application (Microsoft InfoPath Filler) to create the reports, or they can implement a customized solution that automatically extracts the necessary data from their local infrastructure management systems and assemble it according to the requirements of the transaction specification contained in the ITMP, which is not yet implemented. Regardless of each municipality's solution, they can produce their reports and submit them to the provincial government's AIIS system in accordance with the transaction specification, as illustrated in Fig. 9.

6 CONCLUSIONS

Municipal organizations must exchange accurate data in order to provide efficient management of the infrastructure systems. This data exchange is currently performed manually and on an *ad hoc* basis. The growing trend in the infrastructure community is to transform these manual communications to a more formalized computer-to-computer based exchange of information. In this research work, these transactions are formalized as transaction specifications. One of the research questions was, "how to manage transaction specifications?" The management of specifications is identified as an important issue in the industry as all of the state-of-the-art, work process and communication formalization standards and methodologies focused on the development of the specifications, and not on its management. This gap in the current research provided an opportunity to explore the domain with respect to management of transaction specifications. To respond to the question, an ontology-supported ITMP was developed.

The ITMP was developed and implemented using a four task approach: requirement specification, design, implementation and testing. In requirement specification, a set of functions was identified that the transaction development personnel intended to include in the proposed web-based system. Accordingly, the system was designed to represent various data flows between transaction development personnel. A four-step (i.e. 4C) procedure was used to implement the portal using the SharePoint platform. The prototype portal was tested to demonstrate the proposed approach is working and functionalities are included. The results of the testing demonstrated that all functionalities were successfully implemented.

The prototype ITMP was implemented according to a layered architecture where each layer represents a specific step. The portal architecture was organized according to the 4C approach devised for this research work. Following this layered architecture, the proposed portal was implemented using the transaction domain knowledge represented in the Trans_Dom_Onto built as part of this research work. The Trans_Dom_Onto was validated through industry experts using criteria-based approach. Three criteria were used for validation: clarity, completeness and correctness. All the three experts were in universal agreement on the clarity, completeness and correctness of the knowledge represented in the ontology. The portal sub-sites were created based on two abstract transaction classes: domain and communication transactions. Each sub-site represent a specific class of a transaction defined in the domain and communication transaction types. Three web pages were created in each sub-site to manage (archive) the three elements of the transaction specification separately. The two main contributions of this research work include the development of the Trans_Dom_Onto and the proposed ITMP for transaction management in the domain of infrastructure management.

An application of the proposed ITMP was presented to demonstrate how the transaction development personnel and industry experts will use the portal. As an example, the AI&CAR/TCA Reporting transaction between the provincial and municipal government was used to demonstrate successful implementation of the prototype portal.

The practical implications and challenges of the proposed ITMP are as follows. *Implications*—the ITMP enables the transaction development personnel to archive and manage libraries of transaction specifications in a web-based repository. The proposed portal enables the transaction management personnel to search for and retrieve transaction specifications as needed. These transaction specifications can then be used in both human and machine-readable ways to implement standardized computer-to-computer information exchange systems. The primary purpose of the prototype ITMP within this research is to demonstrate the use of formal transaction specifications and, by doing so, to contribute to the validation of the Trans_Dom_Onto and the protocol—TFP developed as part of this research work. *Limitations/challenges*—the proposed portal is a prototype only showing a limited number of sub-sites, web pages, and functionalities. The portal can easily be extended when more specifications are developed in the future. Due to the current focus of this research work, only corporate-wide transaction specifications have been developed; industry-wide, project-wide and user-wide transaction specifications are yet to be developed.

In the future, the Trans_Dom_Onto will be extended and accordingly the prototype portal will be transformed to a full fledge portal representing a complete set of transaction classes (sub-sites), web pages, and functionalities to accommodate the growing number of transaction specifications in the domain of infrastructure management.

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