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## AN ONTOLOGY-SUPPORTED TRANSACTION FORMALISM PROTOCOL IN INFRASTRUCTURE MANAGEMENT

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**Abstract:** Infrastructure organizations use diversified information systems to exchange data (transaction). Presently, data exchange in the area of infrastructure management is accomplished in a manual and *ad hoc* basis. The growing trend is to transform these manual data exchanges to a computer-to-computer based exchange of information. “How to formalize these data exchanges or transactions?” is the core research question, which was dealt with developing and applying an ontology-supported Transaction Formalism Protocol (TFP). The proposed solution is composed of two parts: ontology and protocol. Two ontologies, the Transaction Domain Ontology and Tangible Capital Asset ontology, were developed using an eleven-step methodology to represent transaction knowledge and Tangible Capital Asset knowledge respectively to support the design and implementation of transactions in infrastructure management. The proposed TFP is an eight-step procedure developed using a four-step methodology from two perspectives: the TFP Specification modelled each step of the protocol as a function for which inputs, controls, mechanisms, tools/techniques, and outputs were defined, whereas the TFP Tool includes a set of forms and guidance developed for specific steps of the protocol. The TFP was applied to develop transaction specifications for the Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting, which was implemented in the Asset Information Integrator System for the exchange of Tangible Capital Asset information between the municipal and provincial governments. The main contributions of this research work include the development of the two ontologies, protocol, and Asset Integrator Information System.

### 1 INTRODUCTION

Infrastructure agencies, including shallow utilities own, operate, and manage infrastructure systems using a wide range of information systems, each based on different proprietary data models. Various agencies and utilities interact with each other and exchange infrastructure information to accomplish a wide range of collaborative tasks. As infrastructure agencies increasingly rely on computer-based systems to manage infrastructure data, much of the information that was traditionally exchanged using manual and *ad hoc* communications can now be exchanged electronically through computer-to-computer data exchange. This allows for more extensive, rapid, and error-free exchange of information, but it requires more formal specifications to govern these data exchanges (i.e. transactions). A transaction is defined “as any communication or interaction between the sender and receiver roles that make up the information flow through a single or collection of a sequenced set of messages” (Zeb and Froese, 2012). Transaction example includes: communications during a disaster response (“Is power available in this area?” “Who is responsible for this section of roadway?” “When will water to be restored to this area?”); coordination between buried utility agencies; aggregation of data from multiple infrastructure management software with regards to the asset inventory and condition assessment reporting and formalized transactions used in the multi-agency situational awareness system wherein the provincial government requires information

from many other organizations outside the provincial jurisdiction to prepare for and mitigate the impacts of emergency incidents (Stewart, 2010).

Although the inevitable trend in the communication technology is towards increasing computerization, which requires transaction formalization, but there are many challenges that prevent this formalization from being an easy or efficient process. These challenges include: lack of an appropriate process for carrying out this formalization; heterogeneity in data formats, data (class) definitions, and data aggregation (Felio, 2012). These issues were dealt with developing an ontology-supported Transaction Formalism Protocol (TFP) in the domain of infrastructure management.

The TFP is a procedure developed to formalize transactions and create transaction specifications effectively and efficiently. To support the development and application of the TFP, two ontologies were built: the Transaction Domain Ontology (Trans\_Dom\_Onto), and the Tangible Capital Asset Ontology (TCA\_Onto). According to Gruber (1995), an ontology is a “formal explicit specification of a shared conceptualization.” The Trans\_Dom\_Onto represents transaction related knowledge to support the design, management, implementation of transactions, and development of the TFP. The TCA\_Onto represents the Tangible Capital Assets (TCAs) to support the design of message templates in a neutral data format to address message-based interoperability between information systems of the infrastructure organizations. 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.”

The proposed TFP protocol is an eight-step procedure that was developed from two different perspectives. The TFP Specification represents each step of the protocol as a distinct function for which inputs, controls, mechanisms, tools/techniques, and outputs were defined. The TFP Tool is comprised of a set of Excel-based forms and guidance developed for specific steps of the protocol that the transaction development personnel can use to define transaction specifications for IT based solutions.

The proposed TFP was applied to develop transaction specifications for the Asset Inventory (PSAB, 2008) and Condition Assessment (SORP, 2008) Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting. The formalized transaction specification was implemented in a prototype Asset Information Integrator System (AIIS). The prototype system collects, stores, visualizes, and analyzes the asset inventory and condition assessment information received from different municipalities to help the provincial government to: understand long-term financial needs of municipalities for infrastructure management; develop a consistent and planned approach for funds allocation; and present the case to the federal government for additional funding, if required.

This paper is divided into the following seven sections. Background information and related literature are discussed in section 1 and 2 respectively. Section 3 describes the methodology used, whereas section 4 briefly explains the development of the ontologies and TFP. Application of the TFP is presented in section 5 and evaluation is elucidated in section 6. Conclusions and contributions are discussed in section 7.

## **2 LITERATURE REVIEW**

The literature review is discussed from two perspectives: ontologies in the domain of infrastructure management and related work process and communication formalization standards and methodologies.

*Ontologies in infrastructure management*—three ontologies in the domain of infrastructure management are of particular importance: Infrastructure Product Ontology, IPD-Onto (Osman, 2007); Infrastructure and Construction Process Ontology, IC-Pro-Onto (El-Gohary, 2008); and Actor Ontology, Actor-Onto (Zhang and El-Diraby, 2009). The IPD-Onto (Osman, 2007) represents infrastructure product knowledge (e.g. pipe, valve, pump, etc.). The IC-Pro-Onto represents process knowledge, e.g. core design and construction processes, management processes, knowledge integration processes, and support processes (El-Gohary, 2008). The Actor-Onto represents knowledge related to various actors and actor-roles in the construction industry (Zhang and El-Diraby, 2009). While these three core formalism

dimensions have been completed, there remains a need to formalize information exchange processes (transactions) to enable computer-to-computer, message-based exchange of information. Transaction formalism involves specifying and defining not only the process, actor and infrastructure system information, but also the specification of information exchange details, which is to be addressed through the development of the Transaction Domain Ontology (Trans\_Dom\_Onto). In addition, these ontologies do not completely support the design of the message templates that are required to be exchanged in the AI&CAR/TCA Reporting (information transaction). The IPD-Onto doesn't represent a complete set of the infrastructure products, and it was extended in this research in terms of the TCAs to provide payload information for the design of the message templates for the AI&CAR/TCA Reporting, which led to the development of the TCA\_Onto. The header information in these message templates, meanwhile, was captured from the Trans\_Dom\_Onto that was developed as part of this research work.

*State-of-the-art standards*—some process and communication formalization techniques currently exist in the Architecture, Engineering, Construction and Facilities Management (AEC/FM) industries, but these standards do not fully address the requirements for transaction formalism in the domain of infrastructure management. In the AEC/FM industries, the Information Delivery Manual (IDM) formalizes work processes in the construction industry (IAI-IDM, 2012). It is a requirement specification methodology focusing on model-based exchange of information between different parties using building information models (BIM). The IDM defines information in terms of informational elements (objects and their attributes) rather than informational products (documents), hence the methodology is BIM specific. In addition, the exhaustive nature of the IDM makes it time-consuming to develop and difficult to share with others on projects (Berard and Karlshoej, 2012). Because of the IDM's explicit focus on BIM, it does not meet the requirements for a general communication formalism technique for the infrastructure sector, but it is a very relevant exemplar for this research work, and therefore, some features of the IDM specifications were adopted with modifications. The Model View Definition (MVD) is a methodology developed to formally define a subset of an Industry Foundation Class (IFC) BIM model (IAI-MVD, 2005). The MVD is relevant since it is typically used to formally specify the particular BIM information to be exchanged during a specific type of data transaction, but again, it is BIM specific and it lacks a step-by-step procedure describing how to capture requirements. The Voorwaarden Scheppen Voor Invoering Standaardisatie (VISI), which means "Terms and Conditions for the Implementation of Standardization in ICT" is a Dutch communication management standard developed to define transactions in the AEC/FM industry (VISI, 2011). The VISI standard lacks a step-by-step process to capture transaction requirements and define transactions, and it depends on an Extensible Markup Language (XML) based model representing information in a local context (i.e. the Dutch construction industry). A related standard, the Construction Objects and Integration of Processes and Systems Engineering Method (COINS-EM/CEM), is a Dutch standard developed to create agreements on working methods and organization of production processes and information (Schaap *et al.*, 2008). As with the IDM, COINS-EM/CEM focuses on exchange of model-based/3D object data rather than communication in general, and it also lacks a systematic procedure for requirement specification. Another initiative, the agcXML, focused on developing a set of XML schemas to enable industry experts to exchange electronic building information reliably and efficiently between heterogeneous proprietary software applications to improve interoperability and integration of the information systems (Zhu, 2007). The agcXML doesn't include a general data transaction specification, it does include a format for transaction use cases and a use case for generic document distribution (Froese, 2007), but does not include a procedure for transaction design.

In summary, none of the standards discussed above fully meet all of the objectives of this research work in terms of developing a step-by-step procedure to define transaction specifications in the domain of infrastructure management. Most of the standards are work-process-centric rather than communication-centric. Most do not address how to assess needs and capture information that is required in a given communication. Most of the standards are IT-expert-centric and are not suitable for the end users. These shortcomings led to the development of the proposed ontology-supported TFP.

### **3 METHODOLOGY**

*Methodology to develop ontologies*—a ten-step methodology was devised to build the Trans\_Dom\_Onto and TCA\_Onto, which was a hybrid version of the various approaches developed by Fernandez-Lopez *et*

*al.*, (1997); Uschold and Gruininger (1996); and Noy and McGuinness (2001). (i) Define ontology coverage—purpose, use, and users of the ontologies are defined in this step. (ii) Capture competency questions—a set of competency questions were developed that the ontology should be able to answer. (iii) Generate/create taxonomy—a preliminary taxonomy of various concepts was developed. (iv) Reuse existing ontologies—as long as possible, use was made of the existing ontologies and relevant concepts were captured from existing ontologies. (v) Develop Transaction Domain Kernel Ontology, (Trans\_Dom\_Kernel\_Onto) and Tangible Capital Asset Kernel Ontology, (TCA\_Kernel\_Onto)—representing concepts at the very abstract level to easily categorize and integrate diversified knowledge in the domain of infrastructure management. (vi) Extend Trans\_Dom\_Kernel\_Onto and TCA\_Kernel\_Onto to develop Transaction Domain Extended Ontology (Trans\_Dom\_Extended\_Onto) and Tangible Capital Asset Extended Ontology (TCA\_Extended\_Onto)—abstract concepts represented in the kernel ontologies are extended to develop detailed taxonomies. (vii) Capture ontology—represents explicit declaration of the concepts in terms of soft and hard axioms. (viii) Code ontology—the knowledge represented in both the ontologies was formally coded using Protégé Ontology Editor (Protégé, 2014). (ix) Evaluate ontology—the knowledge represented in both the ontologies was verified using Protégé Ontology Editor and competency questions, and validated through industry experts. (x) Document ontology—the knowledge was finally documented for future use.

*Methodology to develop the protocol*—the proposed TFP was developed using a four-step methodology devised based on the approach formulated by Adesola and Baines (2005) for the development of business process improvement methodologies. The approach involves reviewing and analyzing current frameworks/methodologies and then selecting the relevant candidates based on the key selection criteria. These steps include: (i) select the candidate standards; (ii) benchmark existing standards; (iii) link and build on existing standards; and (iv) develop the proposed TFP.

## **4 ONTOLOGY-SUPPORTED TRANSACTION FORMALISM PROTOCOL**

The development of the proposed ontology-supported TFP includes two parts: development of ontologies and development of the protocol.

### **4.1 Ontology Development**

#### **4.1.1 Transaction Domain Ontology**

To support the design, implementation, and management of transactions in the domain of infrastructure management, the Trans\_Dom\_Onto was developed. The knowledge represented in the ontology was organized according to the core and support concepts totaling to about 420. The core concepts represent the core building blocks of the transaction domain knowledge in the area of infrastructure management. The core concepts are: transaction, message, actor/actor-role, and information. The transaction is the complete communication between two parties. The message or message template represents the information that is required to be exchanged in a given transaction between the actor-roles. Actors are either organizations or individual that plays a specific role (i.e. sender or receiver) in a given transaction. The information is the discrete processed data that the actor-roles need to exchange to accomplish a transaction successfully. Detailed taxonomies of the core concepts were developed based on the concept of modality (i.e. a specific view of the concept categorization) while the explicit declaration of each concept is presented in Zeb and Froese (2012).

On the other hand, the support concepts support or assist in modelling the core transaction domain knowledge and is the focus of this paper. The support concepts encompass modality, attribute, mechanism, constraint, axiom, and relationship. The *modality* is a “characteristic that describes a thing and denotes it’s belonging to a particular group or category”, (El-Gohary, 2008).

According to Osman (2007), an attribute is a characteristic, feature, or property that describes a thing, entity, or concept. The transaction has five transaction attributes. *Transaction function attribute*—is a characteristic that describes a transaction based upon the function it performs in a given communication. *Transaction dependency attribute*—is a characteristic that describes a transaction based on the logical,

geographic, and cyber dependencies. Dependencies govern the design and implementation of transactions in practical scenarios. *Transaction performance attribute*—is a property that describes the performance of a transaction in terms of transaction efficiency. *Transaction cost attribute*—is a property that describes the transaction design, implementation, and operational cost. *Transaction control attribute*—is a characteristic that describes the transaction security in terms of transaction authorization.

According to El-Gohary (2008) and Osman (2007), the mechanism is an umbrella concept that has three sub-classes: guide, method, and measure, which includes all the tools and means required to accomplish a transaction successfully. The *guide* is a basic information or instructions needed to support the work of an actor role in all communications. It has the following four sub-classes: theory, best practice, strategy, and algorithm. The *method* is a generic concept that covers all such means, mediums, and techniques used to exchange and store transactions. In the Trans\_Dom\_Onto, methods for transaction transmission and transaction archiving are represented. According to Osman (2007), the *measure* is an abstract concept used to gauge conformance of an entity's attribute to a pre-defined requirement as prescribed by specifications and codes. It has two types: test and metric. The *test* is used to measure conformance of the characteristics of a physical entity to the desired specification and code requirements. The *metric* is used to gauge conformance of the attribute of an abstract entity with respect to predefined requirements. The metric for the transaction (abstract entity) efficiency (attribute) is represented in the Trans\_Dom\_Onto. *Objective metric*—captures quantitative measurement of the transaction efficiency. It has two sub-classes: transaction cost savings and transaction time savings. *Subjective metric*—captures qualitative measurement of the transaction efficiency. The quality of a transaction is measured in terms of user convenience (Zott *et al.*, 2000) and transaction righteousness.

The transaction is controlled by a set of transaction constraints, which refer to the conditions, factors, requirements, and obligations that restrict the way transactions are to be designed, implemented, and managed in the domain of infrastructure management. It has two sub-classes: internal and external constraints. The *internal constraints* are the requirements and obligations of the collaboration partners in a given transaction. It is categorized into two sub-classes: user requirement and contractual constraints. The *external constraints* are those constraints that are beyond the control of the collaboration partners. It has two sub-classes: regulatory and environmental constraints.

According to (Osman, 2007 and El-Gohary, 2008), *axiom* unambiguously defines the concept represented in the ontology and constrain its interpretation. According to Gruninger and Fox (1995), axiom specifies unambiguous definitions of the concepts in a specific domain. The transaction axioms were classified as soft and hard axioms. The *soft axioms* define the concepts in plain English Language, whereas the *hard axioms* explicitly define the concepts using a formal language—Ontology Web Language (OWL) based Description Logic Syntax (DL). The hard axioms are of three types. *Subsumption axiom*—explicitly defines classes in hierarchies with parent-child relationship. *Disjoint axiom*—explicitly describes that the concepts are disjointed from each other, which mean an individual as a member of class “x” cannot be an instance of another class. *Property restriction axiom*—According to Horridge (2009), *properties* describe the binary relationship between the concepts, whereas the *datatype properties* describe the relationships between the individuals and data values, where individuals in OWL represent the instances of a class. In OWL, classes are defined in terms of the property restrictions, which states that “a restriction describes a class of individuals based on the relationships that members of the class participate in” (Horridge, 2009), and therefore, a property restriction represents a class of individuals. The property restrictions are of three types: quantifier restriction (i.e. existential and universal), cardinality restriction (i.e. minimum, maximum, and exact), and has value restriction. A total 1726 axioms were defined in the Trans\_Dom\_Onto.

According to Osman (2007), *relationships* are the associations between the concepts to enrich knowledge representation. It has the following two types. The *hierarchal relationships* include the generalization-specialization and aggregation-composition relationships. The generalization-specialization relationships—represent is-a or type-of or parent-child relationship between concepts and has two types: hyponymy and hypernymy, (El-Gohary, 2008). The aggregation-composition relationships—are whole-part relationships that represent the relationship between the whole and its parts, which is also known as partonymy (El-Gohary, 2008). It has two sub-classes: aggregation and composition relationships which

are further classified as meronymy and holonymy. The *association or directed association* represents other than “is-a” or “part-of” relationships in a knowledge representation. It has the 13 sub-classes: formalize, characteristic, restrict, devise, human function, relational, communicate, reveal, facilitate, cumulate, partake, ingest, and consequence relationship.

#### 4.1.2 Tangible Capital Asset Ontology Development

To support the design of message templates for the AI&CAR/TCA Reporting, the TCA\_Onto was developed. The message templates represent header (meta information, e.g. name, from, to, etc.) and payload information (actual information content that actor-roles requires in a given transaction). The header information was captured from Trans\_Dom\_Onto and the payload information was captured from the TCA\_Onto. The knowledge in the TCA\_Onto was organized from four different perspectives or modalities. The *individual asset* represents the TCAs based on the type of the individual asset. According to PSAB (2009) and TCA (2012), individual asset has eight sub-classes: land, land improvement, building, building improvement, infrastructure, machinery and equipment, vehicle, and work in progress. The *function based asset* includes the TCAs based on the function they perform. Osman (2007) defined six such functions: control, access, protection, measuring, storage and conveyance assets. Commuting and processing was defined as part of this research work. The *composition based asset* represents the TCAs based on their aggregation in a given infrastructure system. For instance, system, sub-system, and component level (Osman, 2007). The sector based asset classifies the TCAs based on the sector to which they belong. It has two sub-classes: facility and infrastructure sector assets. The infrastructure sector asset has seven sub-classes: transportation, water, wastewater, solid waste management, gas, electricity, and telecom sector assets. The facility and infrastructure sector assets; specifically, the transportation, water, wastewater and solid waste management sector assets were further specialized and extended to develop detailed taxonomies as presented in Zeb and Froese (2014). Development of the detailed taxonomies of the gas, electricity, and telecom sector assets was omitted as these assets are generally not owned and operated by municipal infrastructure organizations and was covered in other existing ontologies. The TCA\_Onto represents 345 classes of various TCAs in the facility and four infrastructure sectors. In addition, 1517 axioms were developed to explicitly describe TCAs in the domain of infrastructure management.

#### 4.2 Development of the Transaction Formalism Protocol

The proposed TFP protocol is an eight-step procedure developed to define transactions in the domain of infrastructure management effectively and efficiently. The protocol was developed from two perspectives; TFP Specification and TFP Tool. The *TFP Specification* was developed from a conceptual perspective where each step of the protocol was modeled as a distinct function for which inputs, controls, mechanisms, tools/techniques, and outputs were defined. The TFP Specification was developed using the IDEF0 modeling technique. The TFP Specification provides the formal “instruction set” for creating transaction specifications as presented in Zeb and Froese (2013). On the other hand, the proposed TFP Tool includes a set of Excel-based forms and some guidance that the transaction development personnel can use to define transaction specifications. These steps are: assess needs—step 1, define As-is transaction map (TM)—step 2, develop To-be TM—step 3, collect information—step 4, design message template (MT)—step 5, review TM and MT—step 6, adopt and implement TM and MT—step 7, and monitor transaction specification—step 8. The forms for the Tool were developed in step 1, 2, 3, 4, 6, and 8. The forms were developed to capture information easily, accurately, and consistently while defining transactions. For step 5 and 7, only guidance was provided on how to perform these steps because no data is required to be captured in these steps. A brief description of these steps is as follows.

- *Step 1*—a comprehensive needs assessment is conducted to identify and select among a set of transactions that has the greatest potential for IT improvement. The assessment criteria include: manual/paper based transaction, criticality, frequency, importance, likelihood of the management, cost of the transaction, and contractual and regulatory requirements.
- *Step 2*—a preliminary As-is TM is developed based on the needs assessment.

- *Step 3*—a To-be TM is developed that is an improved version of the As-is TM incorporating process, information, and mode improvements.
- *Step 4*—required header and payload information is collected in this step.
- *Step 5*—based on the collected information, MTs are defined.
- *Step 6*—the designed TMs and MTs are reviewed for errors; if any, and make changes before implementation.
- *Step 7*—the designed TMs and MTs are implemented in the Asset Information Integrator System.
- *Step 8*—the implemented transaction specifications are monitored for continuous improvements.

## 5 APPLICATION AREA AND ASSET INFORMATION INTEGRATOR SYSTEM

The proposed TFP Tool was applied to one of the transactions identified through an IT survey (Zeb and Froese, 2012) conducted as part of this research work—AI&CAR/TCA Reporting. The municipal experts completed the needs assessment form using the above-mentioned criteria. The AI&CAR/TCA Reporting transaction was selected because it scored high against the assessment criterion. Despite the fact that the frequency of this transaction is not high, the municipal experts identified it as one of the potential transactions due to three reasons. *Compliance with regulatory requirements*—newly imposed regulatory requirements require municipalities to report asset inventory information in compliance with the Public Sector Accounting Board reporting requirements-3150 (PSAB, 2008) and condition assessment in compliance with the Statement of Recommended Practices, SORP reporting requirements (SORP, 2008). *Manual/paper based transaction*—currently, this transaction is manual as human interpretation of the information is required and organizations find it difficult and time consuming to compile, extract, and compare the TCA information. *Costly*—this transaction is costly in terms of time spent in extracting and comparing information.

The AI&CAR/TCA Reporting is a communication process in which different municipalities report their AI&CAR/TCA information to the provincial government for financial planning and funds allocation. The provincial government collects and analyzes this information to: (i) understand the long-term funding needs of different municipalities for infrastructure management; (ii) develop a consistent and planned approach to fund allocation; and (iii) to present the case to the federal government for additional funding, if required. This reporting also helps municipalities to update asset data on a regular basis, resulting in better management of their infrastructure systems. The AI&CAR/TCA Reporting case study transaction was used in two ways. *First*, the TFP Tool was applied to formalize this transaction to develop the transaction specification for the application area. *Second*, the transaction specification for AI&CAR/TCA Reporting was implemented to develop the prototype system—the AIIS.

The proposed AIIS was developed for the reporting of the AI&CAR/TCA information between the municipal and provincial government. Presently, the municipal organizations exchange this information in a manual and *ad hoc* way in the form of a PDF or Word file due to heterogeneous and inconsistent data formats. To transform to a more computer-based exchange of the TCA information, the AIIS implemented standardized MTs that were defined based on the knowledge represented in the two ontologies developed as part of this research work.

The proposed AIIS is a web-based prototype system that was implemented using the SharePoint platform. This platform was adopted due to its robustness and ease of use (Microsoft, 2012). The proposed AIIS collects the TCA reports received from various municipalities via standardized MTs, as shown in Figure 1, and integrate them with back-end applications (MS Excel, Excel Services within SharePoint, SharePoint Reporting Services, etc.) for further processing and analysis.

Asset Information Integrator System > AIR/CAR/TCA Message Templates > All Documents >

This library will store message templates designed for AIR/CAR/TCA reporting transaction.

Home Search this site...

Libraries	Type	Name	Name of Municipality	Type of Municipality	Date Submitted	Total Acquisition Cost (Can\$)	Total Net Book Cost (Can\$)	Total Replacement Cost (Can\$)	ICA Reporting
Site Pages		TCA Report Burnaby	City Municipality of Burnaby	City	2/19/2013	22000000	18200000	3450000	Completed
Shared Documents		TCA Report Comox	Comox	Town	2/22/2013	18100000	16470000	2075000	Completed
AIR/CAR/TCA Message Templates		TCA Report Harrison Hot Spring	Harrison Hot Springs Municipality	Village	1/22/2013	5100000	4525000	3390000	Completed
Lists		TCA Report Highlands	District Municipality of Highlands	District	2/13/2013	9150000	6910000	5750000	Completed
Calendar		TCA Report Ladysmith	Municipality of Ladysmith	Town	2/13/2013	16000000	7990000	2150000	Completed
Tasks		TCA Report Lions Day	Lions Day	Village	2/7/2013	4004000	3020000	304000	Completed
Discussions		TCA Report North Vancouver	North Vancouver	District	1/20/2013	11300000	9640000	860000	Completed
Team Discussion		TCA Report Pemberton	Village Municipality of Pemberton	Village	2/1/2013	4250000	3725000	427000	Completed
		TCA Report Richmond	City Municipality of Richmond	City	1/10/2013	20200000	16000000	3000000	Completed
		TCA Report Sidney	Town Municipality of Sidney	Town	8/21/2013	14400000	8650000	1075000	Completed
		TCA Report Squamish	District Municipality of Squamish	District	1/13/2013	10195000	3705000	695000	Completed
		TCA Report Surrey	City Municipality of Surrey	City	1/15/2013	41150000	38500000	3680000	Completed

Figure 1: Asset information integrator system

## 6 EVALUATION

The ontology-supported TFP is composed of two parts and; therefore, the evaluation was separately conducted for each part: ontology and protocol.

*Ontology evaluation*—both the Trans\_Dom\_Onto and TCA\_Onto were evaluated through industry experts using a criteria-based approach (Gomez-Perez, 2001). The criteria used to validate both the ontologies include: completeness (Gomez-Perez, 1996), correctness (Guarino, 1998), and clarity (Gruber, 1995 and Yu *et al.*, 2007). *Clarity* judges the level to which a knowledge representation is clear and understandable. The class description communication error was used measure clarity of these ontologies. *Completeness* judges the level to which a knowledge representation is incomplete. Completeness is measured in terms of incompleteness. *Correctness* measure accuracy of the knowledge representation from a real-world perspective. The identity error was used to measure the correctness of both the ontologies. 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 the data or information modeling and the process of communication formalization. Similarly, the TCA\_Onto was validated through three experts. Each of the experts had more than 15 years of experience in managing different types of infrastructure systems. They were extremely familiar with different infrastructure systems being owned, operated, or managed by municipalities. They were moderately familiar with data or information modeling and TCA reporting under PSAB-3150 reporting requirements. Two separate structured questionnaires were presented to the 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 respondents' responses in the columns. The respondents were asked to rate a given concept on a scale of 1 (strongly disagree) to 5 (strongly agree) under each of the three assessment criteria. The responses were recorded for each concept reflected in the tables developed for clarity, completeness, and correctness, and an average score was calculated. In both ontologies, the average score ranged from 4 (agree) to 5 (strongly agree), which indicates that all the respondents were in universal agreement on the clarity, completeness, and correctness of the knowledge represented in the Trans\_Dom\_Onto and TCA\_Onto.

*Protocol evaluation*—the proposed TFP Tool was validated through experts using a criteria based approach. Adesola and Baines (2005) identified three criteria: feasibility, usability, and usefulness to validate an improvement methodology, which were adopted with modifications to validate the proposed TFP Tool. An additional criterion—generalizability—was also identified, defined, and used to validate the TFP Tool. *Feasibility* assesses the appropriateness of the TFP Tool in terms of completeness, correctness, and reasonableness. *Usability* assesses the ability to learn and work with the TFP Tool, which was evaluated using three measures: understandability, applicability, and guidance/supportability.

*Usefulness* assesses the utility and value of the tool in terms of five measures: effectiveness, efficiency, consistency, changeability/adaptability/customizability, and reusability. Finally, *generalizability* assesses the applicability of the Tool across a wide variety of communications within AEC/FM and non-AEC/FM industries, using a single measure of generality. A set of questions was framed under each criteria. The experts answers were recorded on an agreement continuum rating system: unable to rate (0), strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), and strongly agree (5). Answers were recorded for each question given under feasibility, usability, usefulness and generalizability and average scores were calculated. The resulting average scores ranged from 4 (agree) to 4.8~5 (strongly agree), indicating that the proposed TFP Tool was feasible, usable, useful, and generic.

## 7 CONCLUSIONS

Presently, data exchange in the domain of infrastructure is performed on a manual and *ad hoc* basis. The growing trend is to transform this manual data exchange to a more formalized computer-to-computer based exchange of information. To accomplish the paradigm shift, an ontology-supported TFP was developed. The proposed protocol consisted of two parts: ontologies and protocol. To support the design, implementation, and management of transactions in the domain of infrastructure management, two ontologies were developed: the Trans\_Dom\_Onto and TCA\_Onto. Also, the protocol—an eight-step procedure was developed at two levels of abstraction: TFP Specification and TFP Tool. The TFP Specification is a conceptual model that makes a foundation for the TFP Tool. On the other hand, the TFP Tool includes a set of forms and guidance developed for specific steps of the protocol. The TFP Tool was applied in the domain of infrastructure management to develop transaction specifications for the AI&CAR/TCA Reporting, which was implemented in an AIIIS. Both the ontologies and protocol were validated through industry experts using criteria based approach. The evaluation results indicate that the transaction development personnel (i.e. transaction analyst, process modellers, software developers, industry experts, and users) can use the protocol effectively and efficiently.

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