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An ontology-supported asset information integrator system in infrastructure management

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Abstract

Purpose – The purpose of this paper is to develop and apply an ontology-supported asset information integrator system (AIIS) in the domain of infrastructure management. The two objectives are: first, to describe how different ontologies developed as part of this research support the design of message templates (MTs) that were implemented in the AIIS; and second, to explain the development and application of the prototype system for tangible capital asset (TCA) reporting.

Design/methodology/approach – The proposed system was developed in the MS SharePoint platform using a four-step methodology: create a web site and library; review and modify MTs; design and configure workflows; and add functionalities.

Findings – First, the architecture, methodology, and evaluation of the two ontologies: Transaction Domain Ontology and Tangible Capital Asset Ontology, developed as part of this research work were briefly introduced to describe how both the ontologies supported the design of MTs that were implemented in the AIIS. Second, the AIIS was successfully developed and applied in the domain of infrastructure management for the Asset Inventory and Condition Assessment Reporting.

Practical implications – The development of the AIIS would enable industry experts to exchange the tangible capital information. The built-in search engine and history services would help the experts to search a transaction and track the transaction history. The real-time visualisation of the data would help in decision making.

Originality/value – Infrastructure agencies use diversified information systems to manage infrastructure systems. Due to propriety nature of the information systems, the TCA data generated is heterogeneous and inconsistent, which make it difficult to exchange with other organisations. Also, the existing applications focus on processing and managing the TCA data for a variety of tasks; however, lack to support data exchange with other organisations. This emphasises the gap that requires the development of an ontology-supported collaboration system in the domain of infrastructure asset management.

Keywords Asset management, Information system, Asset information integrator system, Asset inventory and condition assessment reporting, Infrastructure asset management, Infrastructure management, Tangible capital asset, Tangible capital asset ontology, Tangible capital asset reporting, Transaction domain ontology

Paper type Research paper

Introduction

Infrastructure agencies own, operate, and manage various infrastructure systems. To efficiently manage these systems, various private, para-governmental (e.g. Crown corporations), and public agencies (e.g. municipal, regional, provincial, and federal governments) use diversified information systems that support proprietary data models. Different agencies 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

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that was traditionally exchanged through human-to-human communications can now be exchanged electronically through computer-to-computer data exchange (referred to as a transaction). This allows for more extensive, rapid, and error-free exchange of information, but it requires more formal specifications and agreements to govern these data exchanges or transactions. Example of information exchange between infrastructure organisations include communications during disaster response (Is power available in this area? Who is responsible for this section of roadway? When will water be restored to this area?). A set of issues is associated with these transactions that hamper the development of the transaction specifications are: lack of a systematic procedure for transaction formalisation; and according to (Felio, 2012) heterogeneity of the infrastructure data; lack of uniformity in class descriptions; and lack of component-based aggregation of the infrastructure data.

The first issue addressed through the development of the ontology-supported Transaction Formalism Protocol (TFP) in the domain of infrastructure management. The TFP is an eight-step procedure developed to formalise transactions and create transaction specifications. The remaining three issues were addressed in this research through the development of ontologies: Transaction Domain Ontology (Trans_Dom_Onto), and 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, and implementation of transaction specifications. On the other hand, the TCA_Onto represents the Tangible Capital Assets (TCAs) to support the design of message templates (MTs) in a consistent and neutral data format to address message-based interoperability between information systems of the infrastructure organisations. 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 development of the protocol and ontologies are the main contributions of the overall research work, which is beyond the scope of this paper.

The proposed protocol and the two ontologies were used to develop a transaction specification for the Asset Inventory (PSAB, 2009) and Condition Assessment (SORP, 2008) Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting, which was identified as one of the potential transactions for IT improvement (Zeb *et al.*, 2012). In this transaction, municipalities exchange their TCA data with the provincial government (in this case, British Columbia) for financial planning and budget allocations. Presently, the TCA information is exchanged in the form of electronic TCA reports created in PDF or MS Word formats, which require manual interpretation at the receiving end; thus making the whole communication process time-consuming and error-prone.

The formalised transaction specification developed for the AI&CAR/TCA Reporting was implemented in a prototype asset information integrator system (AIIS). The prototype system collects, stores, visualises, and analyses the asset inventory and condition assessment information to help the provincial government to: understand long-term financial needs of municipalities for infrastructure management and develop a consistent approach for funds allocation. The proposed AIIS can help industry experts to exchange the TCA information and transform the way the TCA information is currently exchanged between the municipal and provincial governments.

The purpose of this paper is to introduce the two ontologies and explain the development and application of the prototype AIIS. This paper is divided into six sections. The first section describes the research background. The second section reviews the literature to identify gaps. The third section discusses the architecture, methodology, and evaluation of ontologies. The fourth section briefly describes the development of the AIIS. The fifth section explains the application of the proposed AIIS while conclusions are discussed in the sixth section.

Literature review

This research work builds on two primary knowledge domains: ontology development and information systems in the area of infrastructure management.

Ontology development

Ontologies in non-Architecture, Engineering, Construction and Facilities Management (AEC/FM) domains – some of the most relevant ontologies in the non- (AEC/FM) are as follows. The Open-electronic Data Interchange Transaction Ontology, Open-edi Onto (ISO, 2006) represents transaction domain knowledge to support the design of commercial transactions (i.e. buying/selling transactions) in the area of business development. The Open-edi Onto was developed based on the Resource-Event-Agent Ontology (Allen and March, 2006), which evolved from an accounting model Resource-Event-Actor (McCarthy, 1982). The three core concepts of these ontologies are: resources, events, and agents. The Open-edi Onto represents transaction knowledge based on three main categories: financial (exchanging something of value), commercial (business markets), and industrial (diversified industries in various geographic locations). These ontologies represent knowledge to support the design of commercial transactions in the business development domain, whereas this research work focuses on information transactions in infrastructure management. This emphasises the need to develop an ontology to support the design and management (i.e. archival) of information transactions. In response to this need, a Trans_Dom_Onto (Zeb and Froese, 2012) was developed.

The Trans_Dom_Onto represents the transaction domain knowledge that was organised according to core concepts (transaction, message, actor/actor role, and information) and support concepts (mechanism, modality, attribute, axiom, constraint, and relationship). The core concepts represent the main entities that are required for the design, management, and implementation of transactions. Detailed taxonomies of each of the core and support concepts were developed based on the concept of modality. El-Gohary (2008) defines modality, "is a characteristic that describes a thing and denotes it's belonging to a particular group or category". A brief description of some of the abstract modalities of the core concepts is discussed here; however, details can be seen in Zeb and Froese (2012, 2013). The transaction was categorised based on two abstract modalities. The communication transaction-modality classifies transactions based on the way these are communicated between collaboration partners. The domain transaction-modality categorises transactions based on the infrastructure sector to which these belong. The message was classified based on the following four abstract modalities: message function-modality (classifies transactions based on the function they perform); message formulation-modality (represents how messages are created, i.e. written or verbal); representation message-modality (i.e. how information is represented in a MT); and message intelligent-modality (the level to which these are computer interpretable). The actor role was classified based on the function role-modality, which means the function an actor role performs in a given transaction.

Moreover, the information was classified based on header information-modality (representing meta information about a transaction or message) and payload information-modality (representing actual information content that the collaborating parties require to exchange in a given transaction. The header information-modality classifies the header information as preamble, delivery, and service header information, whereas the payload information-modality classifies the payload information based on the message-placement, formulation, and delivery method of the payload information. On the other hand, the following support concepts enrich the knowledge representation and assist in modelling the core concepts: mechanisms (representing communication channels), relationships between entities, constraints in knowledge representation, axioms (representing the explicit and formal description of entities), and attributes (representing the characteristics of concepts). Some of these concepts were used to define the To-be TM and the header of the MTs formalised for the AI&CAR/TCA Reporting, which was implemented in the AIIS.

Ontologies in the AEC/FM domain – the three relevant ontologies are: the Infrastructure Product Ontology (IPD-Onto) (Osman, 2007), the Infrastructure and Construction Process Ontology (IC-Pro-Onto) (El-Gohary, 2008), and the Actor Ontology (Actor-Onto) (Zhang and El-Diraby, 2009). The IPD-Onto represents infrastructure products (e.g. pipe, pump, manhole, etc.) in the five infrastructure sectors: water, wastewater, electricity, telephone, and gas sector. This ontology does not completely represent all knowledge related to the TCAs that are owned and operated by the municipal organisations to support the design of MTs for the AI&CAR/TCA Reporting. Therefore, the IPD-Onto was further specialised to include TCA knowledge in the area of municipal infrastructure management. This emphasises a gap in the existing knowledge representation that led to the development of the TCA_Onto (Zeb and Froese, 2013). The TCA_Onto classifies the TCAs based on the following four modalities. The individual asset-modality classifies the TCAs based on an individual asset type. According to PSAB (2009), there are eight types of the individual assets: land, land improvement, building, building improvement, infrastructure, machinery and equipment, vehicle, and work in progress. The function asset-modality categorises the TCAs based on the function they perform in an infrastructure system. Osman (2007) has identified six types of assets: conveyance, control, access, protection, measuring, and storage. Two additional types were identified in this research work: processing and commuting. The composition asset-modality classifies the TCAs based on their composition in an infrastructure system. Osman (2007) identified and defined three types of function-based assets: systems, sub-system, and component level. The sector asset-modality classifies the TCAs based on the sector to which they belong. This modality has the following two types. Facility sector modality – classifies the TCAs based on the different types of facilities in the construction industry. Infrastructure sector modality – classifies the TCAs based on the infrastructure sector to which they belong, which includes: transportation, water, wastewater, and solid waste management. Detailed taxonomies of the TCAs in these four sectors were created to support the design of MTs for the AI&CAR/TCA Reporting.

According to El-Gohary (2008), the IC-Pro-Onto represents diversified processes over the life cycle of projects; however, it lacks to represent a complete set of communication processes or transactions in infrastructure management. Similarly, the Actor-Onto represents different actors and their roles in a project context; but lacks to represent a complete set of roles in infrastructure management.

Some building and construction ontologies include the following. Lee *et al.* (2014) developed an ontology-based process for automatic searching of construction work items to help experts to find work items efficiently for cost estimation. The approach focuses on improving the accuracy of Building Information Modelling (BIM)-based quantity take-off. Karshenas and Niknam (2013) developed an ontological approach to BIM to facilitate information exchange among diversified applications. Park *et al.* (2013) built an ontology of construction knowledge to develop a knowledge retrieval system to improve the search process in terms of precision and recall rate. Nepal *et al.* (2013) developed a feature ontology for automatic extraction of features from BIM to help practitioners quickly extract the required feature information for quantity take-off and cost estimation. The building and construction ontologies focus on improving person-to-computer transactions whereas the main focus of this research work is on computer-to-computer transactions between diversified partners in the construction industry. The knowledge represented in these ontologies lack the transaction domain knowledge to support the design of information transactions in infrastructure management. These shortcomings in the existing knowledge representation emphasise the need to develop the Trans_Dom_Onto and TCA_Onto to support the design, management, and implementation of transactions and MTs in infrastructure management.

Information systems

Infrastructure organisations currently use a set of information systems to manage their infrastructure systems. These information systems range from very basic to advanced applications used to carry out diversified work processes: asset inventory management, asset condition assessment, asset service life analysis, asset life cycle cost analysis, asset risk analysis, and decision-making analysis (Vanier and Rahman, 2004). According to the results of a recent ICT survey (Zeb *et al.* 2012), a set of applications is currently in use in the area infrastructure management to carry out these work processes. These applications include: dTIMs, Hansen, ArcGIS, Road Matrix, Web Works, RIVA, SAP, MS Excel, City Works, AMS, Mapguide, A2B, Microstation, VFA, AutoCAD, and MapInfo. These are propriety applications, which work well as stand-alone applications for carrying out specific tasks; however, these applications are unable to exchange the TCA data with other organisations due to the heterogeneity and inconsistency of the underlying TCA data format. These issues were dealt with developing two ontologies: Trans_Dom_Onto and TCA_Onto. The ontology-based solution was proposed to: represent knowledge in a neutral format so that it can be implemented in a variety of applications including the AIIS; fill the gap in the current knowledge representation in infrastructure management; and integrate the knowledge with other ontologies in the domain of infrastructure management. This highlights the need to develop collaboration systems that experts in the area of municipal infrastructure management can use to exchange the TCA information.

Development of ontologies

The proposed AIIS implements the transaction specification developed for the AI&CAR/TCA Reporting. One of the main elements of the transaction specification is the MT defined for the AI&CAR/TCA Reporting. These MTs were defined based on the knowledge represented in the two ontologies: Trans_Dom_Onto (representing 420 classes and 1,726 axioms) and TCA_Onto (representing 345 classes and 1,517 axioms), developed as part of this research work. This paper briefly discusses the architecture, methodology, and evaluation of these ontologies.

Ontology architecture – according to Gomez-Perez *et al.* (2005), ontologies are constructed in a layered architecture; therefore, the ontologies were developed using the same approach. Both the ontologies were created at two levels of abstraction. The two levels of the Trans_Dom_Onto are: Transaction Domain Kernel Ontology (Trans_Dom_Kernel_Onto) and Transaction Domain Extended Ontology (Trans_Dom_Extende_Onto). Similarly, the two levels of the TCA_Onto are: Tangible Capital Asset Kernel Ontology (TCA_Kernel_Onto) and Tangible Capital Asset Extended Ontology (TCA_Extended_Onto). The kernel ontologies represent the knowledge at a higher level of abstraction to: capture a lean knowledge base for better understanding; organise the diverse knowledge efficiently; and integrate the knowledge with other kernel ontologies used to model information transactions. The extended ontologies were developed at a finer level of abstraction to represent detailed taxonomies of all concepts. The knowledge in both the ontologies was organised based on the concept of modality as discussed in the literature review section.

Ontology development methodology – to develop both the Trans_Dom_Onto and TCA_Onto, a ten-step methodology was devised, which is a hybrid version of the methodologies developed by: Gruninger and Fox (1995); Uschold and Gruninger (1996); Fernandez-Lopez *et al.* (1997) – the Methontology; and Noy and McGuinness (2001):

- Step 1 – define ontology coverage: the purpose, usability, and scope of the ontology were defined.
- Step 2 – capture competency questions: according to Gruninger and Fox (1995), competency questions represent a set of requirements that the ontology should be able to answer. Examples of competency questions are: Are transactions defined based on the means of transmission? Are transactions defined based on the sector or application area? Does the ontology specify water system assets?, etc.
- Step 3 – create taxonomy: the required concepts were identified, which were then compared to avoid duplication and delete synonymous concepts. A preliminary categorisation of concepts was made, which led to the development of detailed taxonomies.
- Step 4 – reuse and merge existing ontologies: where possible, relevant existing ontologies were used. In this research, the existing IPD-Onto was used and extended to create the TCA_Onto.
- Step 5 – develop kernel ontologies: a kernel ontology was developed first to represent the transaction knowledge and TCA knowledge at a very abstract level.
- Step 6 – extend kernel ontologies: the knowledge represented in kernel ontologies were extended to develop detailed taxonomies.
- Step 7 – capture ontology: involves the development of axioms. The axioms describe a concept unambiguously and constraints on its interpretation (Gruninger and Fox, 1995).
- Step 8 – code ontology: both the ontologies were formally coded using the web ontology language for its richness and robustness. Coding was done in Protégé ontology editor.

- Step 9 – evaluate ontology: both the ontologies were verified and validated as part of the evaluation.
- Step 10 – document ontology: finally, both the ontologies were documented for future use.

Ontology evaluation – ontology evaluation is judging the content of the ontology with respect to a frame of reference characterised by a set of requirements (Gómez-Pérez, 2001). Ontology verification involves checking the content of the ontology with respect to a set of modelling requirements, whereas ontology validation involves judging the content with respect to a real-world model through domain experts. The ontology verification and validation for both the Trans_Dom_Onto and TCA_Onto is complete; however, details can be seen in Zeb and Froese (2012, 2013).

AIIS development

The proposed AIIS is a web-based prototype system developed using the SharePoint platform following the four-step methodology reflected in Microsoft (2012) and Perran *et al.* (2010). This platform was adopted due to its robustness and ease of use.

Step 1 – create a web site and library

A web site for the proposed AIIS was developed first using a 4C approach. Create a virtual directory – a virtual directory was created on the Internal Information Server (IIS) of the SharePoint. All information, transaction instances, and documents being exchanged through the AIIS are stored at this location. Create collection web site – a collection web site was created in the virtual directory to store all subsites and web pages. Create web sites – a set of web sites in the form of libraries, lists, and discussions was created. To store the TCA reports received from various municipalities, a library with the name AI&CAR/TCA Reporting was created as shown in Figure 1(a).

Depending upon the requirements of the users, some attributes (e.g. name of TCA report, submitted by, name of the municipality, etc.) as columns were defined for this library. These attributes were the various fields represented in the MT defined for the AI&CAR/TCA Reporting. Once a TCA report is submitted, it is stored with the these attributes as shown in Figure 1(b). The benefits of defining fields from the MTs to the library are: searching – the documents or MTs added to the library can be searched using column headings; sorting – the users can sort different MTs added to the library based on column heading; filtering – similarly the added MTs can be filtered using column heading; and creating different views. Create web pages – to introduce the AIIS to the user, a welcome web page was created as shown in Figure 1(a).

Step 2 – review and modify MTs

The second step relates to reviewing and modifying MTs. It was assumed that the MTs to be implemented in the proposed AIIS had previously been developed based on the knowledge represented in the Trans_Dom_Onto and TCA_Onto. In this research work, the MTs for each atomic transaction of the AI&CAR/TCA Reporting was designed using the Microsoft InfoPath Designer. In case the MTs were not defined, then an additional step of "create MTs" would be required before the "review and modify MTs" step. The MTs were opened and reviewed in the Microsoft InfoPath Designer to check that various functionalities (e.g. sum, product, formula, etc.) associated with each field was working properly before implementing it in the AIIS. Validation rules were used to check that the format of information was correct and the functionality associated with a specific field was working properly.

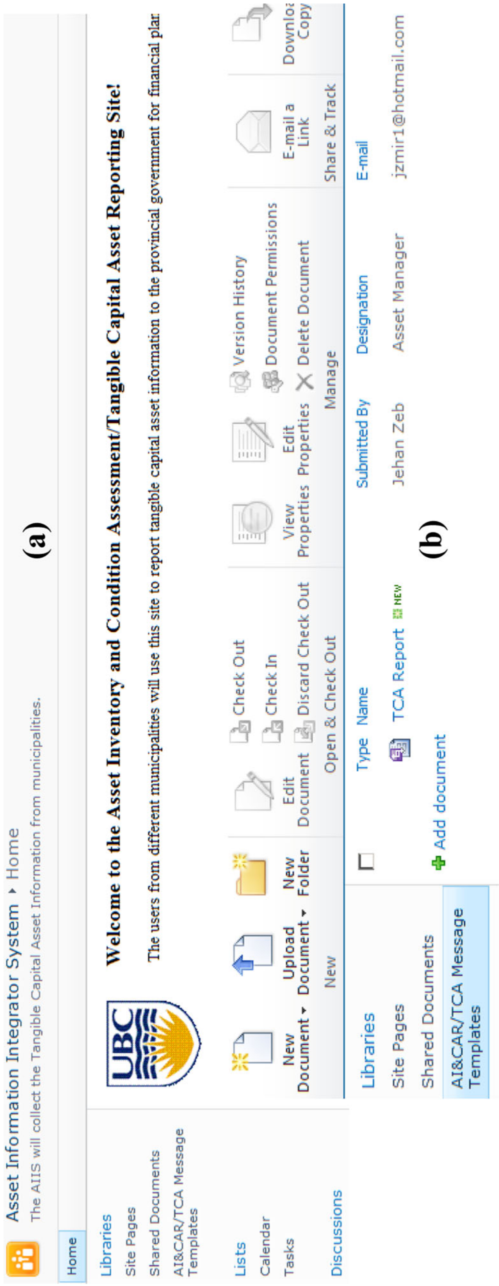


Figure 1.
(a) Create AIIS web site and a library and; (b) library attributes

Step 3 – design and configure workflows

Design workflow. The workflow was designed in VISIO as a SharePoint workflow and was named "TCA Reporting" as shown in Figure 2(a). The SharePoint workflow is generally composed of a starter, a terminator and a set of actions (e.g. send, receive, review, approve, etc.) and conditions (e.g. decision statements, such as "if the result is yes, follow route A, otherwise, follow route B"). For the TCA Reporting workflow, as a simple demonstration transaction, included no conditions and three actions: log the TCA information to the history list, review the TCA information, and send an accept acknowledgement message to the sender. The first action is to log all the actions to the history list that achieves all TCA information exchanged through the AIIS. The second action is to send the TCA information to an expert within the provincial government for review, and the third action is to send an accept acknowledgement message to the sender of the TCA information. All of these actions were fully automated. The TCA Reporting workflow diagram was checked for rules validation and a validated workflow diagram was then exported as a Visio Workflow Interchange file (vwi) to the SharePoint Designer for configuration.

Configure workflow. In the SharePoint Designer, the TCA Reporting workflow diagram was imported as vwi file for configuration (means explicitly defining workflow rules). Upon import to the SharePoint Designer, the TCA workflow diagram transformed into a set of statements (non-configured TCA workflow), as shown in Figure 2(b). Each action defined in the TCA Reporting workflow diagram was converted into two statements. The top statement written in grey represents the action as-is, whereas the lower (bolded) statement is an automated generated statement that needs to be configured. Each of the underlined words were configured by applying rules. The term "ID3" was changed to represent the name of the workflow – TCA Reporting and all action statements were defined as shown in Figure 2(c). The statement "this message" was explicitly defined as "TCA information". The action statement "a to-do item" was assigned to the "Review TCA information" action, and the "these users" role was directed to a specific user to whom the TCA report was to be directed. The final "these users" role in the last line represents the sender of the TCA information to whom an accept acknowledgement message was to be sent. During the configuration, the review action message and accept acknowledgement message was automatically generated that was used during the TCA Reporting.

Step 4 – define/add functionalities

Some functionalities (e.g. sum, average, formula, etc.) were defined in the prototype AIIS. These functionalities were used to develop visual representations of the TCA reports, which lead to better decision making. The sum and average functionalities were added to create fully automated real-time visual representations of these reports. In addition, other functionalities (e.g. collect reports, edit reports, delete reports, download reports, search reports, navigate through system, integrate reports, compare reports, and visualise workflows and reports), were also defined.

AIIS application

The proposed AIIS was developed for reporting the AI&CAR/TCA information between the municipal and provincial government. Presently, municipal organisations 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

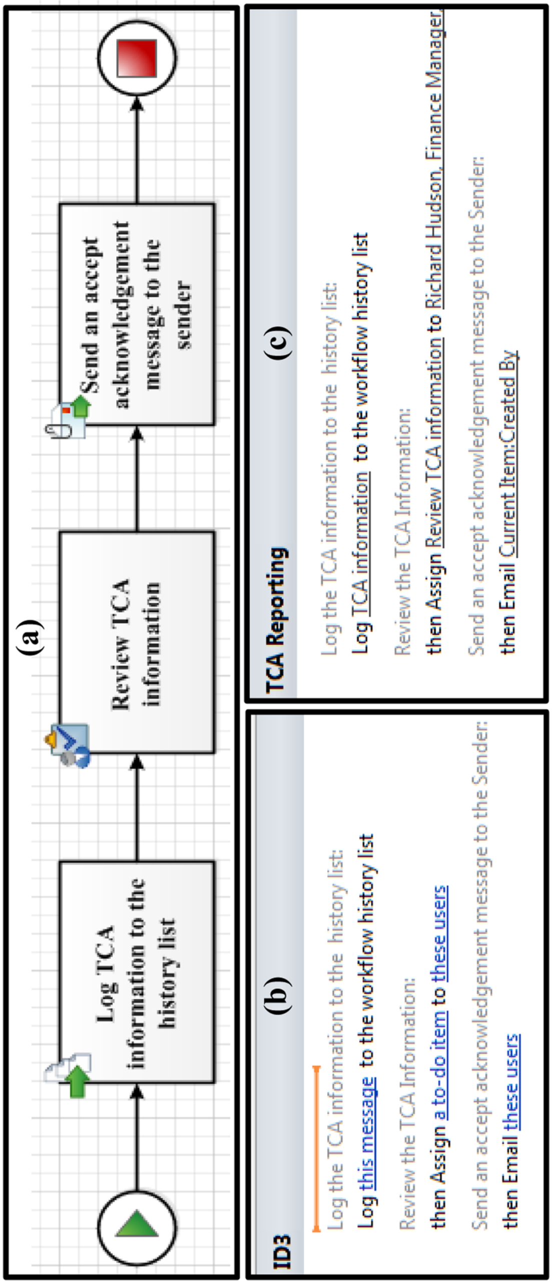


Figure 2.
(a) Validated sharepoint workflow diagram; (b) non-configured TCA reporting workflow; and (c) configured TCA reporting workflow

computer-based exchange of the TCA information, the AIIS implemented standardised MTs that were defined based on the knowledge represented in the two ontologies. The AIIS collects the TCA reports received from various municipalities and integrate them with back end applications (MS Excel, Excel Services within SharePoint, SharePoint Reporting Services, etc.) for further processing and analysis.

The AIIS application demonstrates how the industry experts could use the proposed system. It gives an overall picture of how different components of the prototype AIIS are interrelated. As shown in Figure 3, the AIIS is composed of four main components: users, actions, MTs exchanged, and software used.

Users – the municipal and provincial government are the two main users of the AIIS. Actions – the most important actions are fill, send, receive, etc., which the municipal and provincial governments use to accomplish the AI&CAR/TCA Reporting. Message templates – the MTs defined as part of the AI&CAR/TCA Reporting specification development include two MTs: the AI&CAR/TCA Reporting MT and accept acknowledgement MT. Software – a diverse range of software applications are used to accomplish various actions. These applications are: MS InfoPath Filler, MS Outlook, MS SharePoint, MS Excel/SharePoint Excel Services, and MS Exchange. The following discussion of the AIIS application is organised according to the sequence of actions presented in Figure 3.

Action 1 – fill the MTs

Once the municipal government has compiled all the TCA information, the next step is to report it to the provincial government for fund allocations through the MT defined for AI&CAR/TCA Reporting. The municipalities have a range of options for working

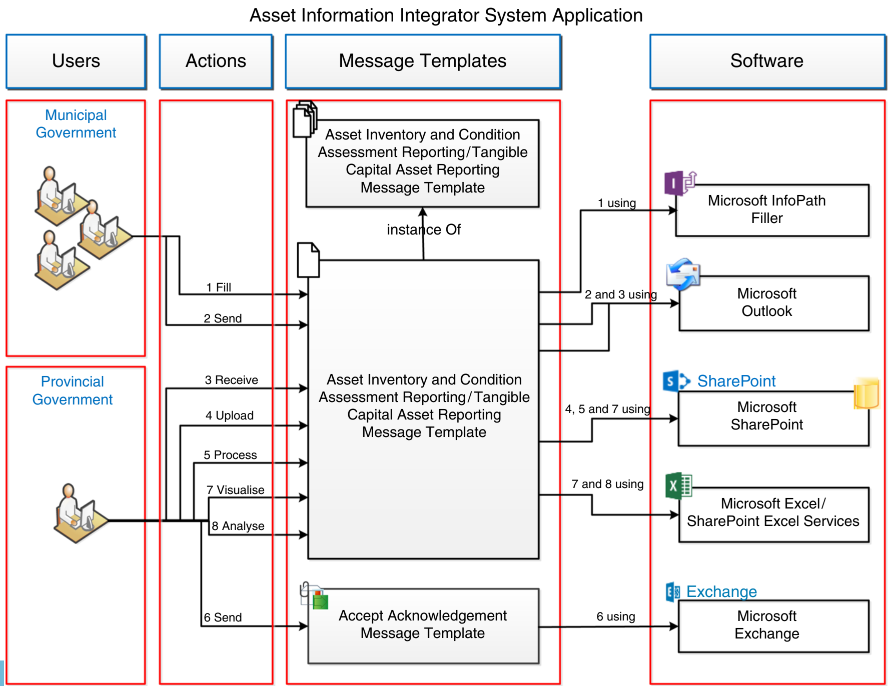


Figure 3.
AIIS application

with this MT, including Microsoft InfoPath Filler or SharePoint Form Services. The choice of applications depends upon the type of the municipality, affordability, and availability of the human resources. Small village municipalities may choose to use MS InfoPath Filler for filling the MT due to low cost and easy availability. The MT includes buttons to save, next, back, and submit actions, which makes the form filling process simple for the users.

Action 2 – send the TCA information

If a MT is filled in using MS InfoPath Filler, it can be sent to the provincial government via e-mail using the submit functionality. The e-mail account configuration enables municipalities to send the AI&CAR/TCA MT directly from the their client application (i.e. InfoPath filler) to the provincial government as an XML file attachment. The AI&CAR/TCA MT was filled and sent to the provincial government successfully, which represents a simple and accessible mechanism for submitting the MT, but a wide range of more advanced alternatives is also possible.

Action 3 – receive the TCA information

In this example, the provincial government receives the filled AI&CAR/TCA MT (i.e. the TCA Report) as an e-mail file attachment in the Outlook. The TCA Report (i.e. filled MT) was received as an XML file attachment, which also shows the e-mail body information. The TCA Report was downloaded in XML format for further uploading to the web-based AIIS.

Action 4 – upload the TCA information as a list item

The AI&CAR/TCA Reports received from different municipalities were uploaded and stored as a list item in the library (AI&CAR/TCA MTs) previously created in the AIIS. A set of column headings (representing the TCA Report attributes) was defined in the library that were linked to the fields in the MT. Each time a report was uploaded to the library, the information in the columns were automatically retrieved from the MT and updated accordingly. The AI&CAR/TCA Report was successfully uploaded to the library using the upload document icon in the ribbon.

Action 5 – process the TCA information

During the development phase, the configured workflow was attached to the AI&CAR/TCA MTs library in the AIIS, which was kicked off when a TCA Report was uploaded. The status (i.e. in-progress, or complete) of the TCA report processing can be seen visually at any given point in time. When a task is completed, its status changes from in-progress to complete.

Action 6 – send accept acknowledgement message

After the TCA review task was completed, an accept acknowledgement message was sent to the respective municipality using the MS Exchange. All the three workflow tasks were completed successfully.

Action 7 – visualise the TCA information

A set of ten TCA Reports, three each from city, town, district, and village municipalities, were filled with dummy values and were uploaded to the prototype AIIS as shown in Figure 4. For each TCA report, the workflow attached to the library was

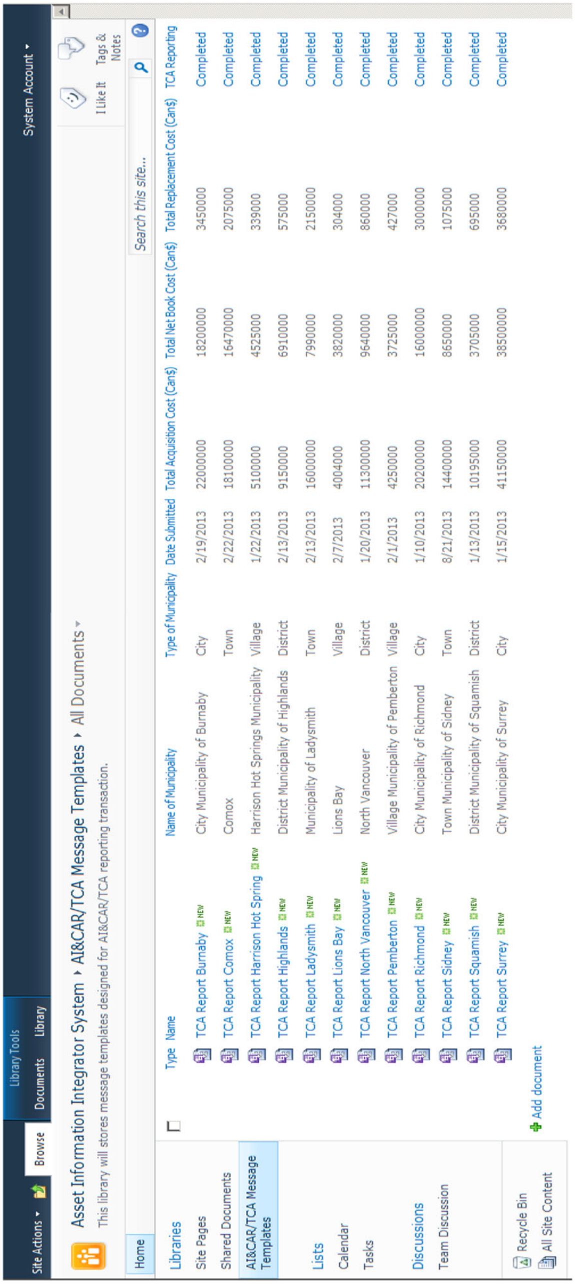


Figure 4.
A set of ten TCA Reports

run to complete all the three workflow tasks discussed above. The last column "TCA Reporting" shows that workflow tasks are now completed. The information in all other columns was automatically updated when a TCA report was uploaded to the AIIS.

For a quick review of the TCA Reports, the list information was transformed into a real-time graphical representation within the SharePoint environment. For the list items (TCA reports) shown in Figure 4, two types of graphs were developed as shown in Figure 5.

The upper chart – municipality type vs TCA costs was created between different types of municipalities and accumulated costs (M $). This chart shows the total acquisition, net book value, and replacement costs against each type of municipality: city, town, district, and village. The acquisition, net book, and replacement costs shown in the chart are the average of all the respective costs for a specific type of municipality. This chart gives an overall idea at a very abstract level about the replacement cost requirements in each type of municipality. Decision makers can allocate funds based these requirements without going into the detail analysis. Similarly, the lower chart – municipality vs cost was created to represent the name of the municipality on the *x*-axis and the cost (M/K $) on the *y*-axis. This chart shows the three types of costs against each municipality. These graphs are automated and each time a TCA report is added or

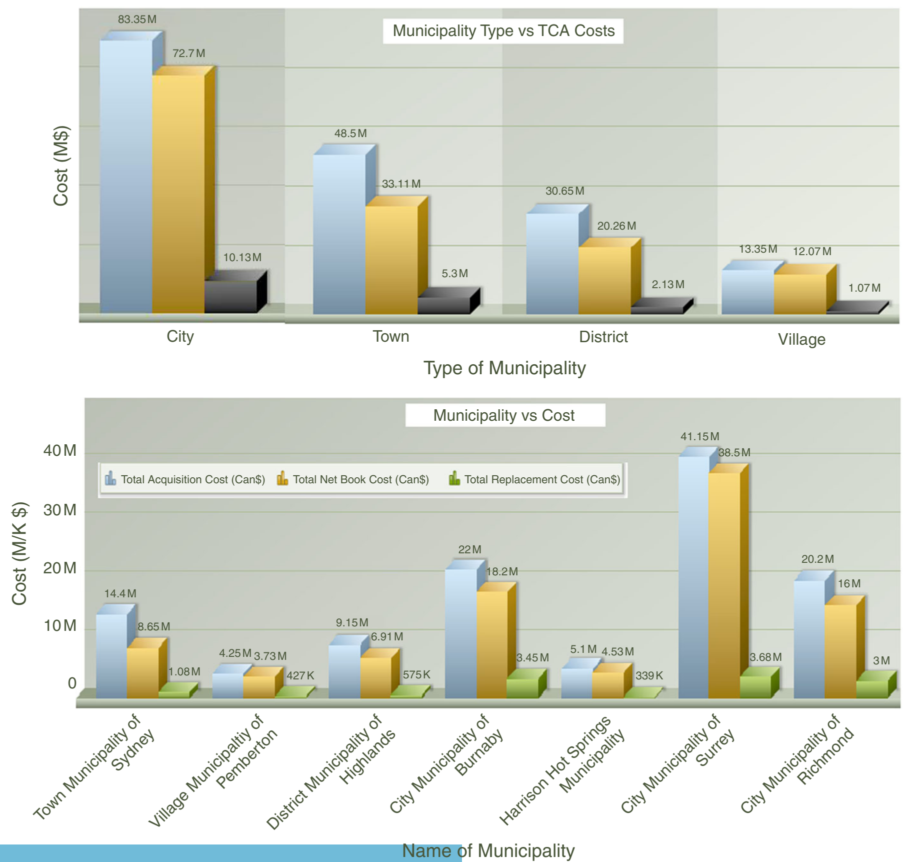


Figure 5.
Real-time charts development for the TCA list

deleted, these charts are updated accordingly in real time. The interactive nature of these charts makes it easy to change the shape, colour, and format any time a user needs. The chart can be exported or imported in a variety of formats any time a requirement warrants.

Action 8 – analyse the TCA information

The set of TCA reports received from city, town, district, town, and village municipalities can be analysed using the MS Excel or Excel Services within the SharePoint Environment. All the list items that need to be analysed were exported to Excel using "Export to Excel" functionality. All the list items in AI&CAR/TCA MTs library were selected and exported as MS Excel Web Query File. The file with "iqy" extension was saved on the local machine and was opened using the MS Excel for further analysis. A simple export that lists the items in Excel is shown in Figure 6.

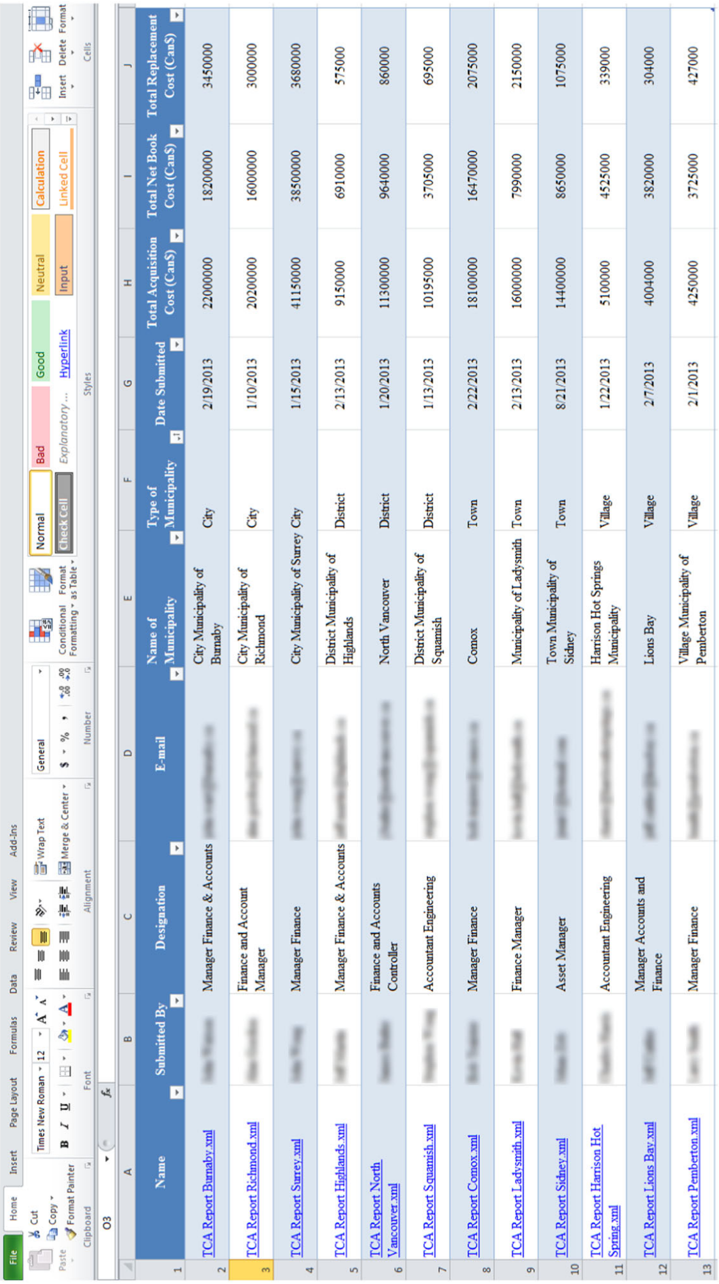
Conclusions

Infrastructure organisations find it difficult to exchange the TCA data with other organisations due to: heterogeneity of data format; inconsistent class description of data, and lack of component-based categorisation of data. An ontology-supported web-based AIIS was developed to address these issues. The prototype AIIS implemented two main outcomes (i.e. formalised TM, and MTs) of a transaction specification developed for the AI&CAR/TCA Reporting. The proposed system was developed using a four-step methodology, which was applied in the domain of infrastructure management to demonstrate how experts from different municipalities will use the system while exchanging the TCA data with the provincial government. The AIIS consisted of four components: users, actions, MTs, and software applications. The whole idea was to explicitly demonstrate how users will use the proposed AIIS.

The theoretical implications of this research are as follows. First, the development of the Trans_Dom_Onto is the major contribution of this research work that represents the transaction domain knowledge in infrastructure management. Second, to support the design of MTs in the area of infrastructure management, a TCA_Onto was developed to represent the TCA knowledge in the transportation, water, wastewater, and solid waste sectors. Third, the development of a transaction specification for the AI&CAR/TCA Reporting is another contribution, which is an important communication in the area of infrastructure management. Fourth, the development of the AIIS is a significant contribution to the body of knowledge as the experts from different municipalities will use this system for the exchange of the TCA information.

The practical implications of developing ontologies and the AIIS are as follows. Ontologies development – the knowledge represented in the Trans_Dom_Onto can be used to develop software applications and define header part of the MTs designed for the AI&CAR/TCA Reporting. On the other hand, the knowledge represented in the TCA can be used to define payload information part of the MTs for any potential transaction in infrastructure management. AIIS development – the proposed AIIS would enable experts from different municipalities to exchange the TCA information with other organisations. The real-time visualisation of the data would help in decision making.

The future research work in the area of ontology development and AIIS development is as follows. The Trans_Dom_Onto needs to be extended to incorporate a complete set of collaboration-based transactions in infrastructure management. The TCA_Onto needs to be extended to incorporate the TCA knowledge related to the electricity, gas, and the



Name	Submitted By	Designation	E-mail	Name of Municipality	Type of Municipality	Date Submitted	Total Acquisition Cost (Can$)	Total Net Book Cost (Can$)	Total Replacement Cost (Can$)
TCA Report Burnaby.xml	[illegible]	Manager Finance & Accounts	[illegible]	City Municipality of Burnaby	City	2/19/2013	22000000	18200000	3450000
TCA Report Richmond.xml	[illegible]	Finance and Account Manager	[illegible]	City Municipality of Richmond	City	1/10/2013	20200000	16000000	3000000
TCA Report Surrey.xml	[illegible]	Manager Finance	[illegible]	City Municipality of Surrey	City	1/15/2013	41150000	38500000	3680000
TCA Report Highlands.xml	[illegible]	Manager Finance & Accounts	[illegible]	District Municipality of Highlands	District	2/13/2013	9150000	6910000	575000
TCA Report North Vancouver.xml	[illegible]	Finance and Accounts Controller	[illegible]	North Vancouver	District	1/20/2013	11300000	9640000	860000
TCA Report Squamish.xml	[illegible]	Accountant Engineering	[illegible]	District Municipality of Squamish	District	1/13/2013	10195000	3705000	695000
TCA Report Comox.xml	[illegible]	Manager Finance	[illegible]	Comox	Town	2/22/2013	18100000	16470000	2075000
TCA Report Ladysmith.xml	[illegible]	Finance Manager	[illegible]	Municipality of Ladysmith	Town	2/13/2013	16000000	7990000	2150000
TCA Report Sidney.xml	[illegible]	Asset Manager	[illegible]	Town Municipality of Sidney	Town	8/21/2013	14400000	8650000	1075000
TCA Report Harrison Hot Spring.xml	[illegible]	Accountant Engineering	[illegible]	Harrison Hot Springs Municipality	Village	1/22/2013	5100000	4525000	339000
TCA Report Lions Bay.xml	[illegible]	Manager Accounts and Finance	[illegible]	Lions Bay	Village	2/7/2013	4004000	3820000	304000
TCA Report Pemberton.xml	[illegible]	Manager Finance	[illegible]	Village Municipality of Pemberton	Village	2/1/2013	4250000	3725000	427000

Figure 6.
Excel web query file is exported and opened in MS Excel

telephone infrastructure sector. The transaction specification for the AI&CAR/TCA Reporting needs to be implemented in a full fledge web-based collaboration system in order to integrate the provincial and municipal governments. A TCA information dashboard should be added in the AIIS to automatically generate different types of graphs and reports that the provincial government needs for the analysis of the TCA information. The proposed AIIS needs to be validated to assess its benefits objectively with evidence.

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