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## Knowledge Enabled Tangible Capital Asset Reporting Using Asset Information Integrator System in Infrastructure Management

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**Abstract:** For effective management of the infrastructure systems, municipalities need to efficiently exchange information about these systems (i.e. tangible capital asset information) within different departments of a municipality and between different agencies. This information exchange, referred to as transactions, is presently performed on an *ad hoc* and manual basis in the form of non-standardized reports created in PDF or Word format. Municipal organizations find it very difficult and time-consuming to compile, compare, extract, and analyze the Asset Inventory and Condition Assessment/Tangible Capital Asset information from these reports due to: (i) human interpretational issues; (ii) heterogeneity of the tangible capital asset data format; (iii) inconsistent description of various classes of assets; and (iv) lack of component-based aggregation of assets. There is a need to improve the way Asset Inventory and Condition Assessment Reporting or Tangible Capital Asset Reporting is currently performed by infrastructure agencies.

To address these issues, a Tangible Capital Asset Ontology was developed as part of this research work. The knowledge represented in the ontology was used to define message templates that permit standardized reporting of the asset inventory and condition assessment/tangible capital asset information. Using a four step approach, the formalized message templates were implemented in an Asset Information Integrator System developed as part of this research. The focus of this paper is to introduce the Tangible Capital Asset Kernel Ontology and explain the development and application of the Asset Information Integrator System to demonstrate improved tangible capital asset reporting. The technique employs a case study approach.

**Keywords:** Tangible Capital Assets, Asset Inventory and Condition Assessment Reporting, Infrastructure, Ontology, Tangible Capital Asset Ontology, Asset Information Integrator System, Infrastructure Management

### 1 Introduction

Municipal infrastructure organizations exchange information about their tangible capital assets (TCAs), particularly Asset Inventory and Condition Assessment (AI&CAR) information, in order to efficiently manage their infrastructure systems. These organizations find it difficult to exchange such information due to some issues. The information exchange is typically a manual process—the TCA information is created in PDF or word format and is sent to the receiving partner as an E-mail attachment. The information received in such formats required human interpretation, which is a time-consuming and error-prone process (Zeb and Froese, 2013). According to Felio (2012), the three issues are: heterogeneity of the TCA data format; inconsistency in the TCA class description; and lack of component-based aggregation of the TCA information. As part of a research project to improve the efficiency of computer-based information exchange in the infrastructure industry (El-Diraby, 2004), these issues were addressed by developing a Tangible Capital Asset Ontology (TCA\_Onto) and an Asset Information Integrator System (AIIS) in the domain of infrastructure management.

The basic viewpoint adopted in this research is that computer-to-computer information exchange requires formalized transaction specifications, which is termed as standardized Message Templates (MTs). These MTs were developed based on the knowledge represented in the TCA\_Onto, which was created at two levels of abstraction: Tangible Capital Asset Kernel Ontology (TCA\_Kernel\_Onto) and Tangible Capital Asset Extended Ontology (TCA\_Extended\_Onto). Both the ontologies represent the TCA domain knowledge in a consistent

format to support the design of MTs for the task of Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting. The AI&CAR/TCA Reporting was identified by the authors as one of the transactions that has the greatest potential for information technology (IT) improvement. In this specific type of transaction, the municipal government reports their TCAs information to the provincial government for financial planning and budget allocations. This transaction was identified and selected for IT improvement based on a requirement assessment conducted using an IT survey (Zeb et al. 2012).

The AI&CAR/TCA Reporting transaction was implemented in the proposed AIIS; it uses the formalized MTs developed for the TCA Reporting based on the knowledge represented in the TCA\_Onto. The AIIS enables the users (municipal and provincial governments) to exchange the TCA information in a consistent format that is computer interpretable at the receiving end. The core purpose of this paper is to briefly introduce the TCA\_Kernel\_Onto and then to explain the development and application of the AIIS.

This paper consists of seven sections. Following the introduction of issues in the first section, the second section reviews the relevant literature. The third section explains the approach used to develop the AIIS and the fourth section describes the TCA\_Kernel\_Onto. The fifth and sixth section discusses the development and application of the AIIS respectively. The seventh section describes the conclusions.

## 2 Point of Departure

The work reported in this paper builds upon two primary knowledge areas: the field of ontology development, and the field of information systems for infrastructure management.

*Ontology development*—there are four ontologies in the area of infrastructure management that are of particular interest to this research work. The *Infrastructure Product Ontology, IPD-Onto* (Osman, 2007), represents knowledge related to infrastructure products (i.e. pipe, valve, pump, etc.). The IPD-Onto doesn't represent a complete set of infrastructure products (referred to as tangible capital assets in this research work) to support the design of MTs for the AI&CAR/TCA Reporting. As part of this research, the IPD-Onto was extended to create the proposed TCA\_Onto. In other words, the TCA\_Onto is an expanded version of the IPD-Onto in which detailed taxonomies of the TCAs in the transportation, water, wastewater, and solid waste management sectors were created. The *Infrastructure and Construction Process Ontology, IC-Pro-Onto* (El-Ghohary, 2008), represents the various processes carried out during the life cycle of infrastructure projects. The IC-Pro-Onto categorizes processes into four main categories: core processes, management processes, knowledge integration processes, and support processes. The *Actor Ontology, Actor-Onto* (Zhang and El-Diraby, 2009), represents the range of actors and the roles in a given project context. Specific roles related to the domain of infrastructure management that were missing in the Actor-Onto were included in an actor taxonomy developed as part of this research work. Finally, a *Transaction Domain Ontology, Trans\_Dom\_Onto* (Zeb and Froese, 2012) represents knowledge about information transactions, which supports the design of MTs in the domain of infrastructure management. The Trans\_Dom\_Onto represents the header information (i.e. metadata in a MT such as "from", "to", "e-mail address", etc.) that is required to support the design of the header section of the MTs. The Trans\_Dom\_Onto doesn't completely represent the payload information (i.e. the actual information content that partners need to exchange in a given transaction) to support the design of the payload information section of the MTs for the AI&CAR/TCA Reporting. Hence, there is a need to create the TCA\_Onto to include the TCA information that makes up the payload information section of the AI&CAR/TCA Reporting transaction.

*Infrastructure management information systems*—a set of state-of-the-art applications is currently in use in the domain of municipal infrastructure management to carry out various work processes, including: 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 an IT survey (Zeb et al. 2012), a set of 16 applications was identified that are commonly used in Canada to carry out these six infrastructure management work processes. These applications were: ArcGIS, dTIMS, Road Matrix, Hansen, SAP, MS Excel, Web Works, RIVA, City Works, Microstation, Mapguide, AMS, A2B, MapInfo, VFA, and AutoCAD. The aforementioned software packages work well as standalone applications for carrying out various infrastructure management work processes; however, these applications generally lack the ability to seamlessly exchange the TCA information generated at the municipal level with other infrastructure management agencies. This situation creates a requirement to develop the proposed AIIS system to assist the exchange of the TCA information between the municipal and provincial government.

### 3 Development Approach—Asset Integrator Information System

The AIIS system is a web-based collaboration system that was developed for this research project using the Microsoft SharePoint platform. This platform was selected due to its' robustness. According to Perran *et al.* (2010) and Microsoft (2012), it is a powerful system that enables transaction development personnel to develop and implement web-based collaboration systems without writing any software code. The proposed AIIS was developed following a four-step approach.

Step 1: Create Website and Library—a website for the AIIS was developed on the SharePoint Server using a “4C” approach: Create a virtual directory, Create a collection site, Create subsites, and Create web pages. After developing the AIIS website, a library named “AI&CAR/TCA Message Templates” was created to store all the reports received from different municipalities.

Step 2: Review and Modify Message Template—this part of the research utilized a set of MTs that were previously created in a related research task based on the knowledge represented in the TCA\_Onto (Zeb and Froese, 2013). The defined MTs were reviewed to check that various functionalities and validation rules associated with the MT fields were working properly. The needed modifications were incorporated before implementing the formalized MTs developed for the AI&CAR/TCA Reporting in the proposed AIIS.

Step 3: Design and Configure Workflow—the workflow was modeled in MS VISIO as a SharePoint workflow following the To-be transaction map (which is defined as a set of atomic transactions and their sequence) that was created as part of the transaction specification development. The defined SharePoint workflow was then exported to the SharePoint Designer for configuration where a set of actions and conditions were applied to the workflow. The SharePoint Designer has the capability to design and configure workflows; however, MS VISIO makes the design of the workflow easy to create, understand, modify and to integrate with the SharePoint Designer and SharePoint.

Step 4: Add/Define Functionalities—finally, some functionalities were defined in the proposed web-based AIIS, such as: add reports, edit reports, delete reports, download reports, search reports, navigate through the AIIS system, integrate reports, compare reports, and visualize workflows and reports.

### 4 Tangible Capital Asset Kernel Ontology

According to Gruber (1995), an ontology is “an explicit formal specification of the terms in the domain and the relations among them.” The TCA\_Onto was developed as part of this research work to represent the TCA knowledge in the domain of infrastructure management. The core purpose of the TCA\_Onto development was to capture TCA knowledge to support the design of standardized MTs for the AI&CAR/TCA Reporting. The proposed AIIS implemented these formalized MTs for the reporting of the Asset Inventory and Condition Assessment Information between the municipal and provincial government.

According to Gomer-Perez *et al.* (2005), ontology development follows a layered architecture where each layer represents concepts at different level of abstraction; this involves four types of ontologies. The *upper ontologies* represent the most generic knowledge that is consistent across different industries, (e.g. process, project, actor, etc.) The *domain ontologies* represent knowledge relating to a specific domain of interest that is used to create different applications (software) or application ontologies. The *application ontologies* represent knowledge related to a specific application or software. The *user ontologies* are created at the finest level of granularity where knowledge is captured from a user perspective. The development of the TCA\_Onto used this layered architecture.

The TCA\_Onto was developed at two levels of abstraction: TCA\_Kernel\_Onto and TCA\_Extended\_Onto. The TCA\_Kernel\_Onto represents the TCA knowledge at a higher level of abstraction to: (i) capture a lean knowledge base for better understanding of the TCA knowledge; (ii) better organize the diverse TCA knowledge; and (iii) integrate the TCA knowledge with another kernel ontology used to model information transactions (i.e. the Transaction Domain Ontology, Zeb and Froese, 2012) developed as part of this research work. The TCA\_Kernel\_Onto represents the TCA knowledge in the facility and four infrastructure sectors: transportation, water, wastewater, and solid waste management, all at a very high level of abstraction. The TCA knowledge was organized according to the concept of modality. According to El-Gohary (2008), modality is defined as “a characteristic that describes a thing and denotes its belonging to a particular group or category”. The modality brings multi-dimensional flavor to the knowledge representation while easing categorization, management, and organization of the TCA concepts or knowledge. The TCA\_Kernel\_Onto was further

extended to create taxonomies of the TCAs in the infrastructure sectors based on the notion of modality, to develop the TCA\_Extended\_Onto. At a finer level of detail, the TCA\_Extended\_Onto represents the detailed taxonomies of the TCAs in the four infrastructure sectors and the relationships between various TCA concepts. The detailed development, coding in the Protégé ontology editor (Protégé, 2014) using the ontology web language (OWL), and evaluation of both the TCA\_Kernel\_Onto and TCA\_Extended\_Onto is beyond the scope of this paper; however, a brief introduction of the TCA\_Kernel\_Onto follows. The TCA knowledge in the TCA\_Kernel\_Onto was categorized based on the following four modalities as shown in Figure 1-1.



Figure 1-1 Tangible Capital Asset Kernel Ontology

The *composition asset—modality* categorizes the TCAs based on their level of composition in the overall infrastructure network system: namely, system level, sub-system level or component level. The *sector asset—modality* categorizes TCAs based on the sector to which they belong. Facility assets may be protective services facilities, recreational and cultural facilities, and so on, while infrastructure sector assets include all of the TCAs related to the transportation, water, wastewater, solidwaste, electricity, telecom, and gas sectors. The *function asset—modality* categorizes the TCAs based on the function they perform in the overall infrastructure network system. These functions include control, access, protection, measuring, storage, conveyance, (Osman, 2007) commuting and processing. The *individual asset—modality* classifies the TCAs based on the individual asset type. The PSAB (2009) and TCA (2012) have defined eight individual asset sub-classes: land, land improvement, building, building improvement, infrastructure, machinery and equipment, vehicle and work in progress. The explicit definition of each type of the TCA is presented in Zeb and Froese (2013).

## 5 Asset Integrator Information System Development

A four-step approach was used to develop the proposed AIIS. Before developing the AIIS, a set of pre-development steps were assumed to have already been completed. These steps included the development of the transaction specification, accessing the infrastructure transaction management portal and downloading the formalized transaction specification for the AI&CAR/TCA Reporting, and reviewing and modifying the specification; if any, in order to incorporate location specific requirements.

## 5.1 Step 1—Create Website and Library

As mentioned earlier, the website for the AIIS system was developed using a 4C approach. *Create a virtual directory*—a virtual directory was created on the SharePoint Internal Information Server (IIS). The web-based AIIS was hosted at this location. *Create collection site*—a collection site was created in the virtual directory to house all subsites and web pages. The web page for the collection site is shown in Figure 1-2.

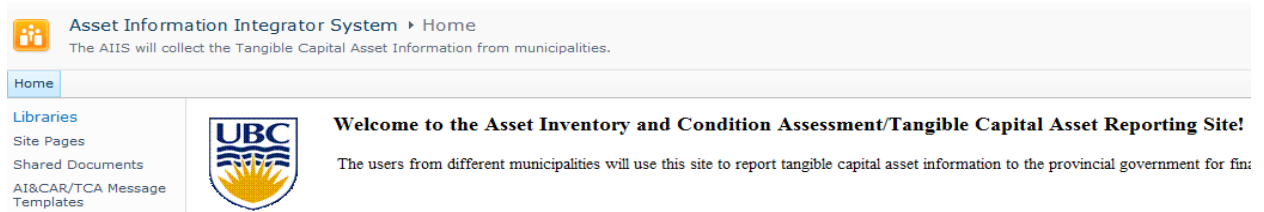


Figure 1-2 Collection Site – Asset Information Integrator System

*Create subsite*—in the collection site, a subsite (library) was created to store the AI&CAR/TCA Reports received from various municipalities. The library and its' attributes are shown in Figure 1-3, which were defined based on the various fields represented in the MTs. Once a report is submitted, it is stored automatically with the attributes as shown in the Figure 1-3. The selection of the attributes depends on the requirements of the user, which can be changed easily at any time as user requirements vary. *Create web pages*—a welcome web page was created for the AIIS system as shown in Figure 1-2 above. The welcome web page briefly introduces the purpose of the AIIS to the users.

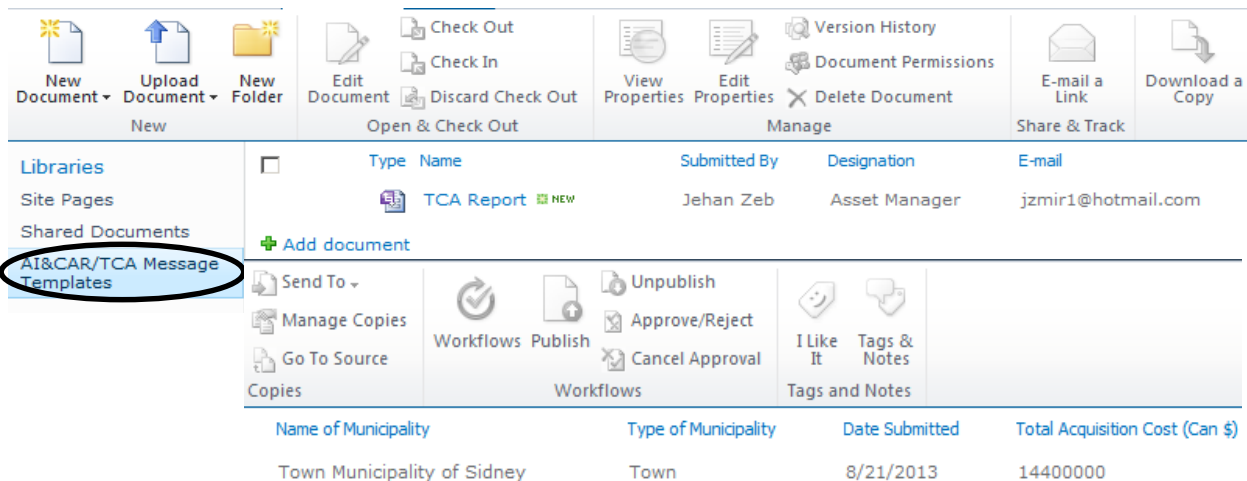


Figure 1-3 Create Library

## 5.2 Step 2—Review and Modify Message Templates

The MTs for each atomic transaction of the AI&CAR/TCA Reporting had previously been designed using the Microsoft InfoPath Designer as part of the transaction specification development for the AI&CAR/TCA Reporting. 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 were working properly before implementing it in the AIIS. While defining the MT for the AI&CAR/TCA Reporting, some validation rules were applied to each field in the header information section and payload information section. Due to space constraints, only the payload information section of the multi-view MT defined for the AI&CAR/TCA Reporting is presented in this paper. The payload information shown in Figure 1-4 representing view 1 of the multi-view MT defined for the AI&CAR/TCA Reporting.

This MT is comprised of eight views, with each view representing the TCA information related to a specific infrastructure sector. The transaction development personnel have the flexibility to switch between the views at any time by clicking on the required view. Navigation between the views was also reviewed and checked to see that the links were defined correctly. The validation rules were used to check that the format of the information was correct and the functionality associated with a specific field was working properly.

Tangible Capital Asset									
Facility Sector									<i>For Disposal Only</i>
Asset Class	Unit Quantity	Acquisition Cost	Net Book Cost	Condition Index	Average Life	Remaining Life	Replacement Cost	Disposed Quantity	Installation Year
<b>1.1 Police Protection</b>									
Land	Sq.m								
Building	Each								
Equipment	Each	59	600000	300000	4	15	8	150000	9
Vehicle	Each								
<b>Sub-Total</b>			600000	300000				150000	
<b>1.2 Fire Protection</b>									
Land	Sq.m								
Building	Each								
Equipment	Each	64	700000	450000	4	15	9	12500	2
Vehicle	Each								
<b>Sub-Total</b>			700000	450000				12500	
<b>TOTAL</b>			1300000	750000				162500	

Figure 1-4 Review and Modify Message Template Payload Information

Accordingly, each field of the payload information section was filled with dummy values as shown in Figure 1-4 to check that various functionalities associated with each data field was working properly and the formatting requirements were complied with the validation rules prescribed for each field. In case of any error; the functionalities; (like sum, product, etc.) were modified according.

### 5.3 Step 3—Design and Configure Workflows

The workflows are repeatable, automated business processes that occur between the collaboration partners within and between organizational boundaries. The workflows are designed based on the To-be transaction map (TM) that was created as part of the transaction specification development. The workflow is an implemented version of the TM. For instance, the TM developed for the AI&CAR/TCA Reporting was implemented as a SharePoint workflow using the SharePoint Workflow Management System. In this research work, the workflow was first designed for the AI&CAR/TCA Reporting in the MS VISIO, which was then exported to the SharePoint Designer for configuration. After configuration, the workflow was attached to the AI&CAR/TCA Message Templates library for execution. The workflow design and configuration are as follows.

#### 5.3.1 Design Workflow

The workflow was designed in the VISIO as a SharePoint workflow and was named as “TCA Reporting”, as shown in Figure 1-5. The SharePoint workflow is commonly composed of a starter, terminator and a number of actions (e.g. send, receive, review, approve, etc.) and conditions (e.g. decision statements—take route A in the workflow for Yes and B for No). Conditions for the TCA reporting workflow were not applied so as to make the workflow simple to understand and implement in the AIIS. In this workflow, three actions were defined in addition to the starter and terminator. These actions were: log TCA information to the history list, review TCA information, and send accept acknowledgement message to the sender. Once the SharePoint workflow diagram was developed, it was then checked for rules validation. The validated workflow diagram was exported as a Visio Workflow Interchange file (vwi) to the MS SharePoint Designer for configuration.

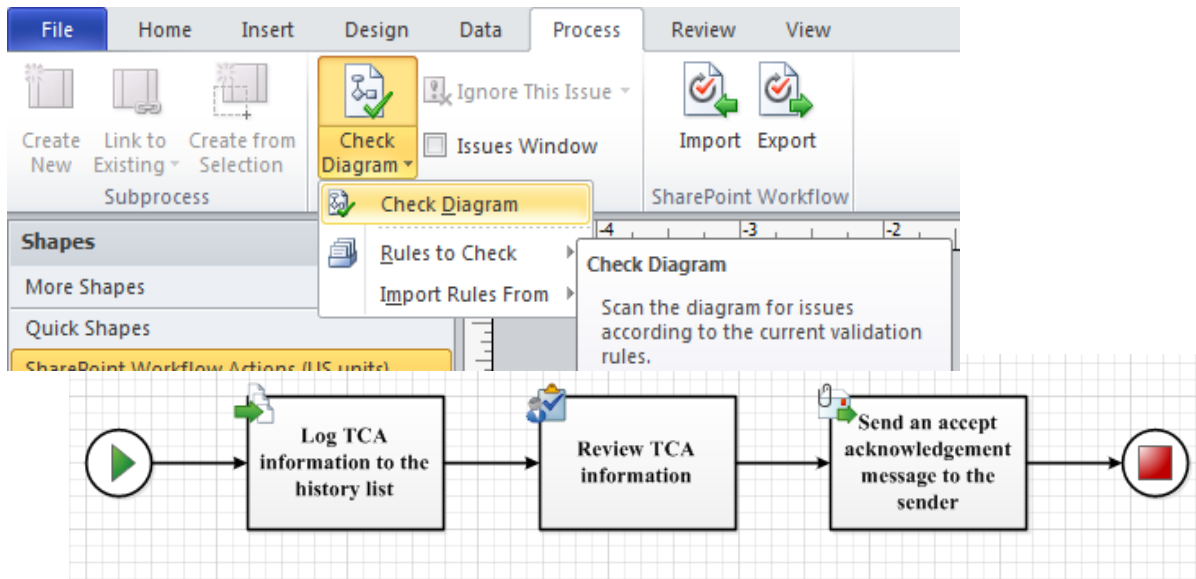


Figure 1-5 SharePoint Workflow Diagram

### 5.3.2 Configure Workflow

In SharePoint Designer, the workflow diagram (i.e. a vwi file) was imported for configuration as shown in Figure 1-6. The term “configuration” means explicitly defining the workflow rules.

Figure 1-6 TCA Reporting Workflow Configuration and Checking for Errors

The TCA workflow diagram (vwi file), when imported to SharePoint Designer, was transformed into a set of statements (i.e. non-configured TCA workflow). Each of the three actions defined in the MS VISIO TCA workflow diagram was converted into two statements as shown in Figure 1-6. The top statement represents the action as-is whereas the lower (bolded) is an automated generated statement that needs to be configured. A set of rules was applied to the underlined words (representing actions) in the lower statements as part of the workflow configuration. The configured workflow for the AI&CAR/TCA Reporting is presented Figure 1-6. The underlined words in the configured workflow (i.e. TCA information, Review TCA information, Richard Hudson,

Finance Manager, jzmir1@gmail.com, and Current item:Created By) were explicitly defined through applying rules as part of the configuration. The TCA workflow configuration was finally checked for errors. As shown in Figure 1-6, there were no errors found in the workflow. The configured was then attached to to the list library—AI&CAR/TCA MTs for execution.

#### 5.4 Step 4—Define/Add Functionalities

Some functionalities (e.g. sum, average, formula, etc.), were defined in the AIIS. These functionalities were used to develop visual representations of the TCA Reports as part of the visual analytics. For instance, the provincial government might wish to see visual representations of the cumulative acquisition, net book value, and replacement costs based on the municipality type (city, town, district, and village). These visual representations can lead to effective and efficient decision making. The screen captures shown in Figure 1-7 shows how the sum and average functionalities were implemented to create fully automated visual representations of the TCA Reports.

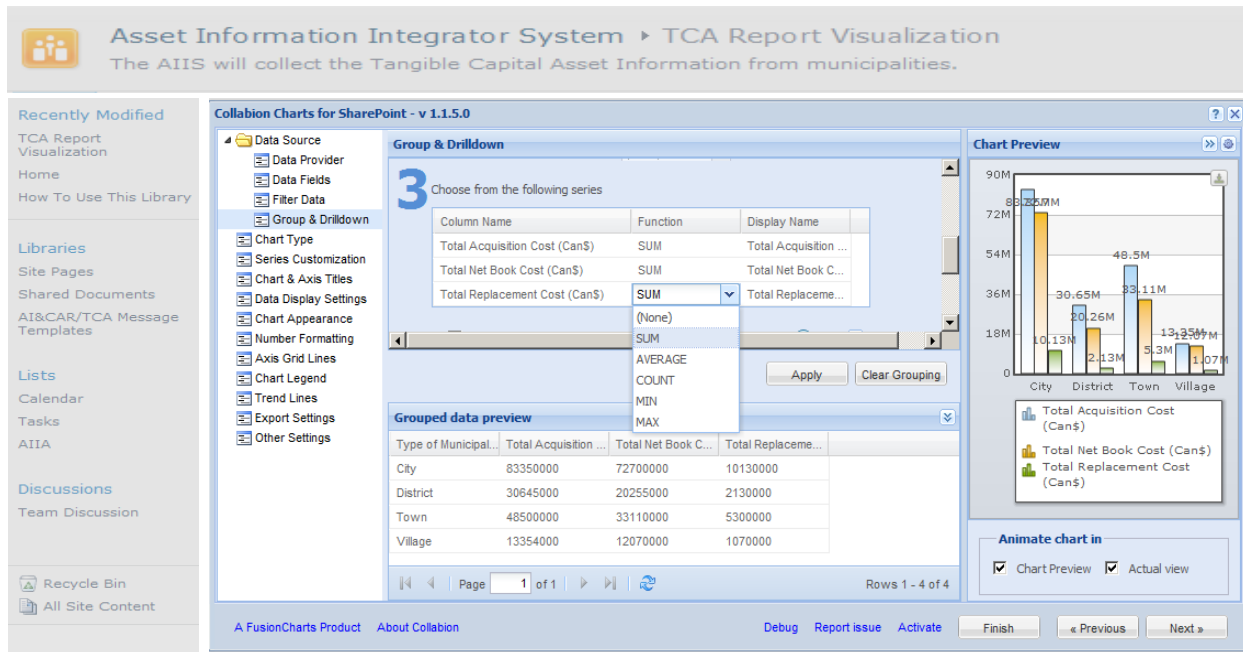


Figure 1-7 Implementing a Sum and an Average Functionality

These graphical representations can be automatically updated in real time when a TCA Report is created or changed in the SharePoint AI&CAR/TCA MTs library. These functionalities were added using an add-in application—Collabion Charts for SharePoint, which is a third party application (Collabion, 2014), developed for creating charts in the SharePoint. Similarly, other functionalities (e.g. add/collect reports, edit reports, delete reports, download reports, search reports, navigate through system, integrate reports, compare reports, and visualize workflows and reports) were also added, which are not presented in this paper due to space constraints.

## 6 The Asset Integrator Information System

The prototype AIIS application represents how the overall information system can work in a practical scenario. This section gives an overall picture of how different components of the prototype information system are interrelated. As shown in Table 1-1, the AIIS is composed of four main components: users, actions, message templates exchanged between the partners, and the use of different software.

The *users* of the AIIS are the municipal and provincial governments who are involved in the exchange of the TCA information. The *actions* represent the most important actions that the municipal and provincial governments have taken to successfully accomplish their AI&CAR/TCA Reporting. Both these types of agencies typically take a total of eight actions to complete the TCA Reporting. The actions related to the municipal government are: complete the MT and forward it the provincial government. The actions pertaining to the provincial government are: receive the MT, upload it, process it, return the acknowledge MT, visualize

data, and analyze the report. The *message templates* are a set of MTs that the municipal and provincial government use to successfully report the AI&CAR/TCA information. For the AI&CAR/TCA Reporting, two message templates (i.e. the AI&CAR/TCA Reporting MT and accept acknowledgement MT) were used in the AIIS system. The municipal government instantiates the AI&CAR/TCA Reporting MT each time they submit their AI&CAR/TCA Report to the provincial government. The *software use* represents applications that were used to accomplish various actions. This component specifies how a specific action is completed in the AIIS through the use of a specific software, e.g. MS InfoPath Filler, MS Outlook, MS SharePoint, MS Excel/SharePoint Excel Services, and MS Exchange.

Table 1-1 Asset Integrator Information Application

Users	Actions	Message Templates	Software
Municipal Government	1. Fill	Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting Message Template	Microsoft InfoPath Filler or SharePoint Form Services
	2. Send		Microsoft Outlook
Provincial Government	3. Receive		Microsoft Outlook
	4. Upload		Microsoft SharePoint
	5. Process		Microsoft SharePoint
	6. Send		Microsoft Exchange or Microsoft Outlook
	7. Visualize		Microsoft SharePoint or SharePoint Excel Services
	8. Analyze		Microsoft Excel or SharePoint Excel Services

The process required to carry out each action is elaborated as part of the AIIS application; however, as an example, the final outcome of action 3—receive or collect the reports from various municipalities is shown in Figure 1-8. A set of 10 TCA reports, three each from a city, town, district, and village municipality were filled with dummy values that were received the prototype AIIS as shown in Figure 1-8.

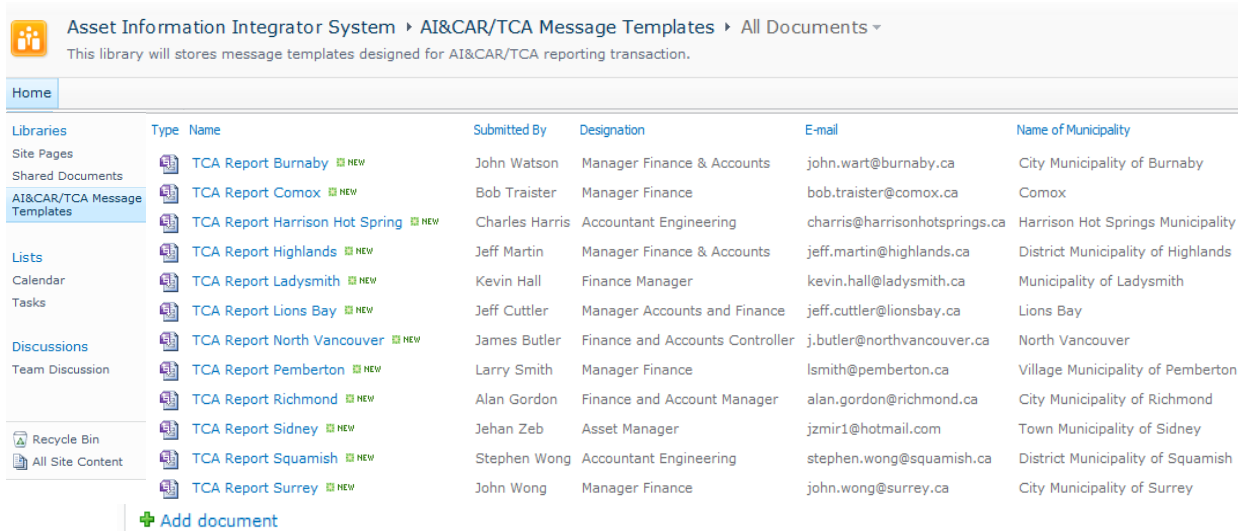


Figure 1-8 Receive or Collect a set of Ten TCA Reports from Various Municipalities

## 7 Conclusions

An effort was made to address the four issues associated with the reporting of the TCA information between the municipal and provincial government. The issues were: (i) human interpretational nature of the As-is TCA reporting; (ii) heterogeneous TCA data format; (iii) inconsistent definitions of the various TCA classes; and (iv) lack of component-based aggregation of the TCA information. These issues were dealt with developing the TCA\_Onto and the proposed AIIS. This paper briefly introduced the TCA\_Kernel\_Onto at a very high level of abstraction, categorizing the TCA knowledge in the facility and four infrastructure sectors: transportation, water,

wastewater, and solidwaste management sectors. The development and representation of the detailed taxonomies (i.e. TCA\_Extended\_Onto) of these infrastructure sectors is beyond the scope of this paper.

The proposed AIIS was developed using the MS SharePoint platform, exploiting a four step approach. *First*, a web site was created for the proposed AIIS in the SharePoint Internal information Server wherein a library with the name, AI&CAR/TCA Reporting MTs, was created to receive or collect the TCA reports submitted by different municipalities. *Second*, the MTs defined for the AI&CAR/TCA Reporting were reviewed for any errors in the functionalities associated with different fields of the MTs and modification were made; if any. *Third*, the TCA reporting workflow was designed using the MS VISIO and configured in the SharePoint Designer. *Fourth*, additional functionalities were added to the proposed AIIS.

The AIIS application was also discussed and the AIIS demonstrated how the proposed system could be used. The AIIS application comprised of fourth components: users, actions, MTs, and software. To accomplish the TCA Reporting successfully, the two users (the municipal and provincial government) typically perform seven different actions (complete, send, receive, upload, process, send acknowledgement MT, visualize, and analyze the AI&CAR/TCA Report) to exchange two MTs (AI&CAR/TCA Reporting MT and accept acknowledgement MT) using a set of software (InfoPath/SharePoint Form Services, Outlook, SharePoint, Exchange, Excel/SharePoint Excel Services).

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