REVIEW OF COMMERCIAL MUNICIPAL INFRASTRUCTURE ASSET MANAGEMENT SYSTEMS

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SUMMARY: *This paper provides a review of municipal infrastructure asset management systems currently available, and discusses the evaluation process of a number of commercial-off-the-shelf (COTS) software systems. The key features, capabilities, and limitations of the evaluated software are presented. The main objective of the paper is to provide infrastructure asset managers with an objective review of existing systems and technologies, and to identify a number of considerations that need to be addressed in the process of selecting asset management systems. The paper also highlights areas where further research and development are needed in order to extend the scope and capabilities of existing systems to better support the sustainable management of infrastructure assets.*

KEYWORDS: *sustainable infrastructure, asset management, software systems.*

1. INTRODUCTION

Significant advances have been made during the last decade in developing municipal infrastructure asset management systems. These solutions are generally used to store and manage asset data, and to support operational and strategic decision making processes. Danylo and Lemer (1998) envisioned the role of an asset management system as “an integrator, a system that can interact with and interpret the output coming from many dissimilar systems.”

Many techniques and software tools have been developed to support activities in various municipal infrastructure domains such as pavement and bridge management, sanitary/storm water sewer management, and water supply management. These tools have supported a wide range of functionality, which include:

- Enable efficient and systematic collection, storage, query, retrieval, management, analysis, and reporting of asset information.
- Integrate and manage various aspects of the asset life cycle by integrating different work processes and their associated datasets.
- Enable the sharing of data across municipalities, and with other organizations (e.g. utility companies).
- Increase operational efficiency by aiding in the planning, execution, and coordination of maintenance operations, and tracking and managing the information related to projects, work orders, inspections, etc.
- Assist in coordinating and optimizing the allocation and distribution of maintenance budgets according to the priority and risk associated with deteriorating components of the assets.

The Municipal Infrastructure Investment Planning (MIIP) project is being carried out by a consortium of researchers from the National Research Council, Canada (NRCC) and ten collaborating municipalities/ organizations from across Canada. One of the objectives of the MIIP Project is the development of a roadmap that identifies areas where further research and development are needed. In accomplishing this objective, it was necessary to evaluate the current state-of-the-art represented by a wide cross section of commercially available software systems. This paper does not rate or rank the packages evaluated herein, but aims primarily to provide asset managers with an objective review of a representative sample of currently available systems, along with some key considerations that need to be addressed in the process of selecting asset management systems. The paper also identifies areas where further research and development are needed.

2. CURRENT STATE-OF-PRACTICE IN SOFTWARE SOLUTIONS FOR MUNICIPAL ASSET MANAGEMENT

A typical municipal asset management system comprises two main components: a relational database containing the asset data, and a set of add-on analysis and decision-support modules. A number of data forms are used for entering, retrieving, and updating asset data stored in the database, and a set of pre-formatted reports can be automatically generated. More modern systems allow interaction with databases through Geographic Information System (GIS) interfaces to graphically represent the asset data in a spatial context. Add-on data analysis and decision-support modules are used to support functions such as assessing current asset condition, predicting future performance, analyzing life cycle costs, and identifying, prioritizing, and selecting feasible renewal plans.

Asset management software can be classified into two broad categories: general-purpose software and asset-specific software. General-purpose systems typically offer generic functionality and need to be customized and adapted for specific data and work processes related to specific classes of assets. Asset-specific software solutions provide a set of built-in data models and processes to support the management of a specific class of municipal assets (e.g. facilities, sewers, roads, bridges, etc.).

The main functionality provided by general-purpose software systems is the management of asset data using a Relational Database Management System (RDBMS). Add-on modules of the underlying RDBMS are developed to support a wide range of additional asset management functionality such as data management, work management and scheduling, and procurement. They also support a range of data import/export options, and the capability to interface with other software (e.g. CAD, GIS, or Enterprise Resource Planning (ERP) systems).

General-purpose software are not currently widely used in municipalities mainly due to the large installation and start up cost, the need for specialized expertise to set up and customize these systems to the processes of specific municipalities, and the high operational and maintenance costs of these systems.

Asset-specific software solutions implement specific data and process management procedures that are required to support the management of certain classes of infrastructure assets. A significant number of asset-specific software systems have been developed during the past decade. These systems are used for managing assets such as pavement, water distribution systems, sanitary and storm water sewers, among others. These applications typically use an RDBMS to support the development and maintenance of the asset inventory database, and may provide built-in GIS capability or support interfacing with other commercial GIS software.

Asset-specific systems typically extend the data management functionality by implementing procedures for estimating and measuring the performance and condition levels of the assets. An example of software in this class includes systems developed for condition assessment and rating of sewers based on Closed Circuit Television (CCTV) inspection, such as Flexidata (www.flexi-data.com) or CIMS (www.cobratech.com).

Another example of asset-specific systems is the family of applications known as Engineered Management Systems (EMS) (www.cecer.army.mil), which supports, in addition to managing the asset data, the evaluation of the asset condition and the use of performance criteria to assess the need for maintenance work, and to aid in the planning and prioritization of the maintenance operations. The EMS applications define fairly detailed data models. Beside the standard data management functionality, these systems adopted a method to estimate and measure the performance level of infrastructure assets. The method involves deriving a Condition Index (CI) from the condition data of the infrastructure structural components. Based on predefined rating criteria, the CI reflects the performance level of the asset components. The CI is used as the basis to select and rank appropriate maintenance work and to allocate financial resources.

Many municipalities may find the functionality offered by commercial asset management systems either too limited or too extensive. To overcome this limitation, many municipalities have developed their own in-house asset management systems, mostly by customizing general-purpose software tools to their specific needs. For example, several commercial DBMS, spreadsheets, CAD, and GIS applications have been used as a platform to support the development of asset inventory and condition databases. Some of these systems have evolved to offer more sophisticated functionality such as work management, procurement, and maintenance planning.

3. THE SOFTWARE REVIEW PROCESS

A representative sample of municipal infrastructure asset management systems has been selected for evaluation. The selected systems cover a wide spectrum of software capabilities and scope, as they are currently available by commercial-off-the-shelf (COTS) software. The rest of this section provides highlights of the review process, focusing on the features, capabilities, and limitation of these systems. The evaluated systems are: Synergen, CityWorks, MIMS, Hansen, RIVA, Infrastructure 2000, and Harfan. The information provided herein is based on trial versions obtained directly from the developer, literature surveys, or demonstration of the software.

3.1 Synergen

Synergen (2205) is a web-based work management and procurement system that is mainly targeted to large organizations with extensive data and process management requirements. According to the taxonomy of asset management systems described in Section 2, Synergen can be classified as a general-purpose system. Synergen defines a set of applications organized in a hierarchy of subsystems and modules. The *subsystems* include: Resources, Maintenance, Purchasing, Inventory, Customer, and Administration (Fig. 1).

The Resource subsystem provides common data management functionality needed by all other subsystems. The Resource data include items such as assets, accounts, inventory, personnel, etc. Each of the five other subsystems represents an area of functionality that is typically supported by a municipal department. The Maintenance subsystem supports work management functions; the Purchasing subsystem supports procurement and contracting processes; the Inventory subsystem supports the tracking, ordering, and receiving of parts and equipment needed for maintenance operations; the Customer subsystem maintains customer data and service requests; and the Administration subsystem manages the set up and customization parameters of the entire software.

A *module* represents a group of functions that can be accessed through a set of "*Views*" or forms to display and edit the data records selected by the user. A module roughly corresponds to a "table" in a relational database, where each View or form displays a subset of the fields in that table. For example, the Asset module in the Resource subsystem would correspond to an Asset table in the database, where each record in the table represents an asset, and each View displays a group of the data fields that are related to a particular aspect of the Asset record, such as Manufacturer data, Cost, Operational data, Work history, Depreciation, etc. Some of the views (such as attachments, or notes) are common to many modules.

In addition, each *module* defines a set of "*Actions*" that represent data manipulation and analysis functions, or a procedure that a user may need to perform while in a particular module. Some actions, such as search for records that satisfy multiple criteria, modify search criteria, and display or save search results, are generic in nature, and therefore, are common to all modules. However, some actions are module-specific, such as the actions for creating or updating work orders in the Work Order Module.

Synergen includes extensive data import/export capabilities, and can interface with external applications such as GIS, email, or Supervisory Control and Automatic Data Acquisition (SCADA) systems. Fig. 1 shows a screen capture that displays the menu items for the six subsystems and the modules of the Maintenance subsystem. It also displays the Work Order default View, and a list of other *Views* and *Actions* in the Work Order module, in the Maintenance Subsystem. The figure also shows a Synergen interface to GIS to display assets selected in the Asset module on the map.

Due to its general-purpose and comprehensive nature, Synergen defines a large number of subsystems and modules that can be customized and configured to manage a wide range of assets. The software allows users to define a subset of the system's components relevant to their areas of responsibility, and to organize these components onto a web portal for easy access. However, the set up and customization process and the investment required in training and maintaining the system may be significant, especially for small to medium size organizations. In the long run, the rewards of using the system may prove to outweigh that investment for smaller municipalities.

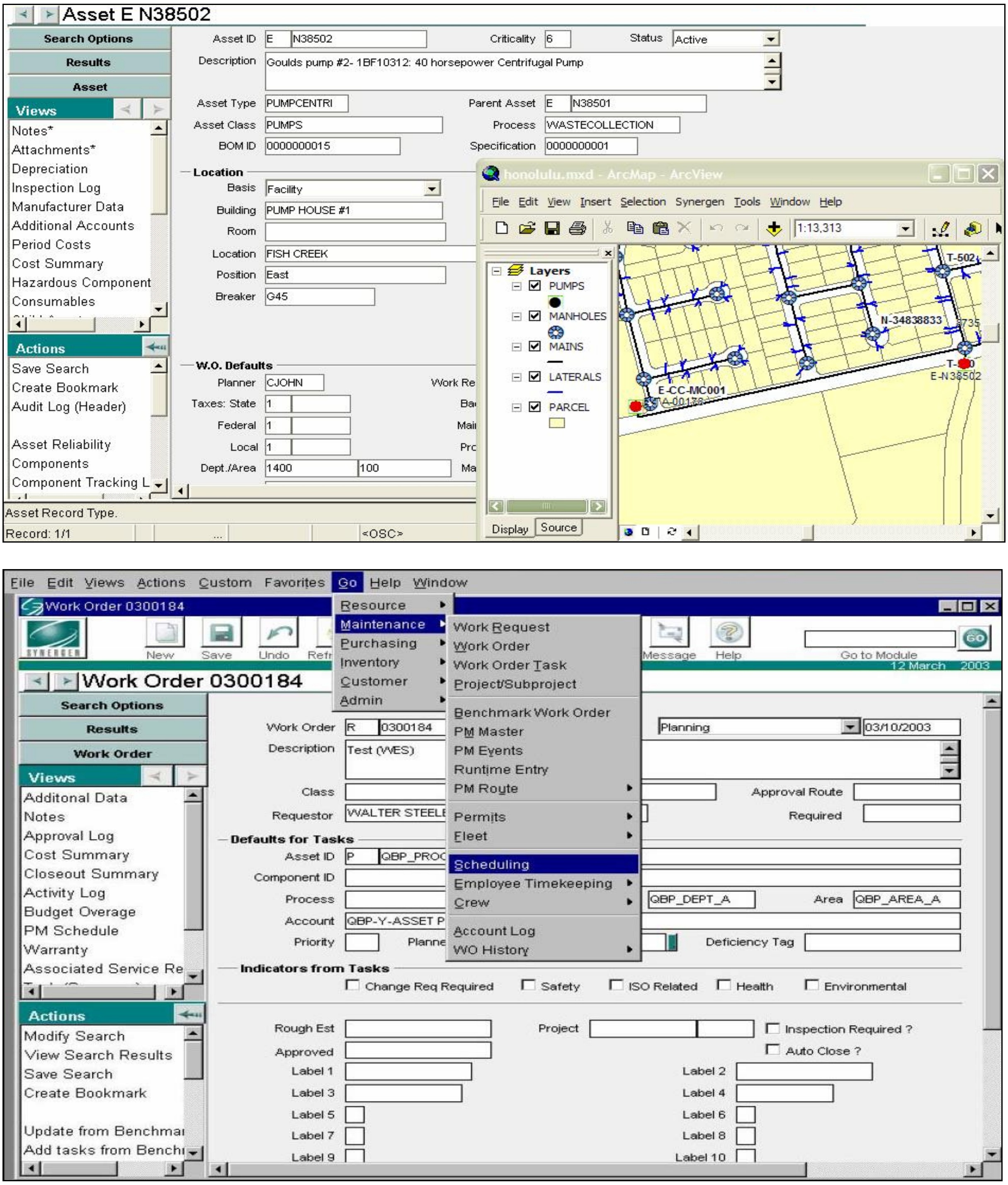

FIG. 1: (Top) Synergen Asset module in the Resource subsystem, and GIS view of selected assets; (Bottom) Web-based interface of Synergen and the menu items showing the six subsystems and the modules of the Maintenance subsystem (Courtesy of SPL).

3.2 CityWorks

CityWorks (2005) is a GIS-based solution for operational and maintenance management of municipal assets. CityWorks supports functions including asset data management, work order management, recording inspection and condition data, and report generation. It also supports logging and tracking of service requests using the add-on “Call Center” module, and supports procurement and inventory management operations, using the “Storeroom” module. CityWorks includes several built-in spatial data models based on the schemas defined by

ESRI (2005). The models support a wide range of municipal assets such as water, wastewater, storm water, and road networks. Users can modify or override the schemas to suit the specific requirements of their organizations.

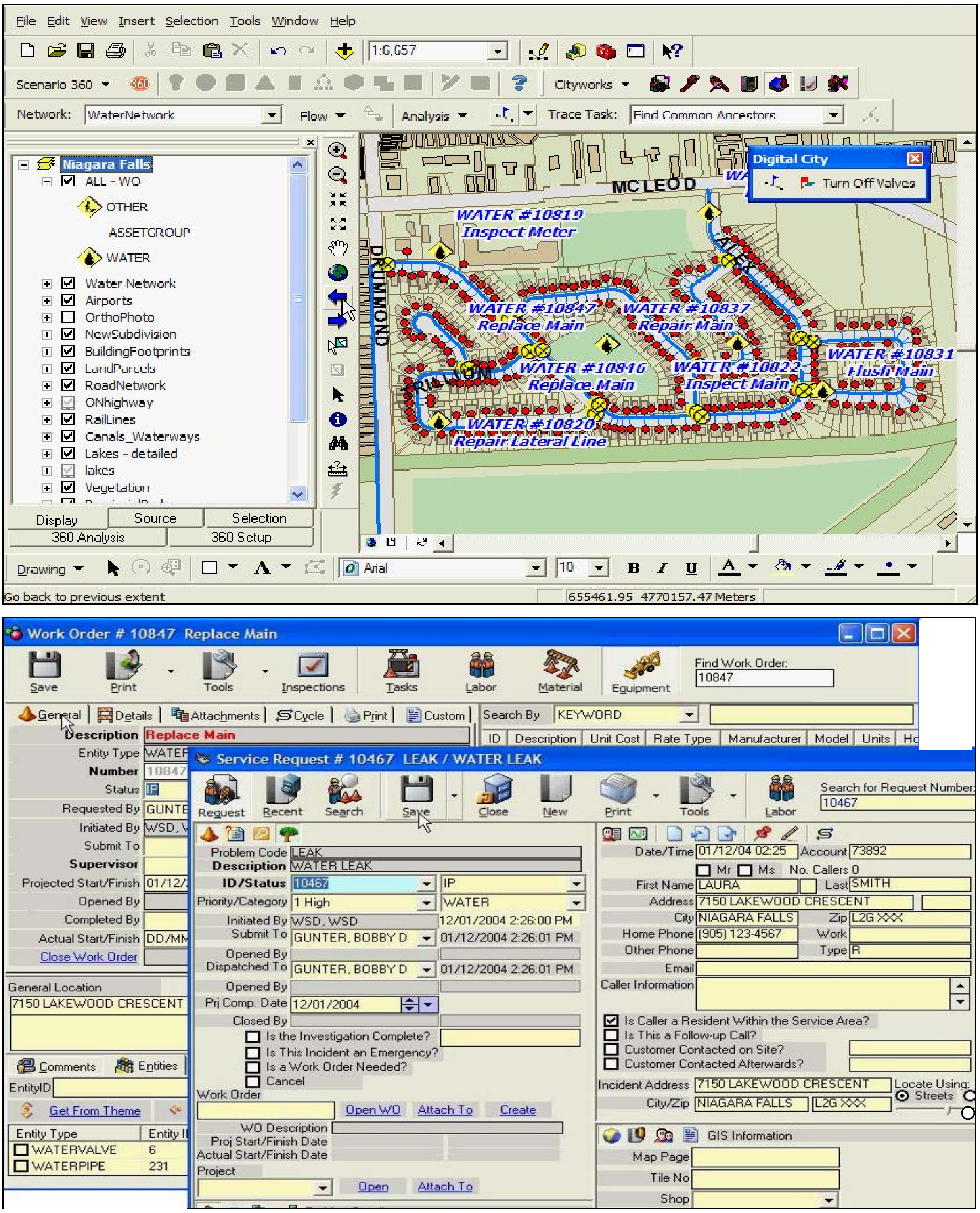

FIG. 2: (Top) CityWorks ArcGIS add-on showing a map of water mains and associated work orders; (Bottom) Forms for Work Order and Service Requests (Courtesy of Azteca).

A distinguishing feature of CityWorks is its tight integration with GIS (Fig. 2 Top). Unlike most of other applications described in this paper, CityWorks uses the GIS database (or geodatabase) to maintain and integrate asset data. This approach of using a single centralized database has the advantage of integrating asset spatial and non-spatial data in one database, ensuring the consistency of asset data, and eliminating the need to duplicate the data in multiple databases or to update different databases to keep the data synchronized.

The CityWorks software can be deployed as an extension to ESRI ArcGIS (as a tool bar) or as a standalone system. The database managed by both software versions have the same geodatabase schema, and therefore, both versions can co-exist and be used by different teams in an organization, depending on whether a GIS interface is required. Fig. 2 shows the ArcGIS add-on showing a map of water mains and associated work orders, and the forms for Work Order and Service Requests.

The CityWorks software also offers the capability to spatially link work orders and service requests to specific assets (e.g. water mains) or to street addresses. The first approach would be useful for municipalities that already maintain a GIS inventory of their assets, while the second approach was designed to enable municipalities with an incomplete asset inventory to link work orders and service requests to addresses. When the complete asset inventory is developed at a later stage, these addresses may be processed (or geo-coded) and associated with the physical assets instead. A useful feature of the software is the link it maintains between the assets and street addresses. This link would facilitate the identification of customers who may be affected by an asset failure or a planned maintenance operation, and serving proper notices to these customers.

Another distinguishing feature of CityWorks is its ability to support field operations by enabling browser-based wireless Internet access (e.g., using a PDA device) to the asset geodatabase, and allowing field staff to access and update work orders and service requests, and to view asset maps. The *DataPump* add-on module enables field staff to run CityWorks in a “disconnected” mode by checking data in and out of the database, and keeping the data synchronized between sessions. Another module, called *Inbox*, routes work orders and service requests assigned to responsible personnel, and enables them to locally or remotely access these work orders.

3.3 Municipal Infrastructure Management Systems (MIMS)

The Municipal Infrastructure Management System (MIMS, 2005) is primarily a data management system for water, wastewater, storm water, and road networks. It also includes modules for managing gas pipelines and municipal buildings. The system is targeted to small and medium size municipalities. MIMS has extensive data import/export and reporting capabilities, and incorporates a wide range of pre-formatted reports. MIMS provides the users with a consistent set of forms and tools for managing different infrastructure assets, and thus enables users to become familiar with the system fairly quickly.

Each class of assets is broken down into its main components, which are in turn subdivided into asset types. Each asset type is represented as a table in the underlying relational DBMS. For example, the water, sanitary and storm water network asset classes are broken down into lines, features, facilities, and equipment components, and the lines component is subdivided into pressure mains, gravity mains, service/leads, and channels asset types. Fig. 3 shows a screen capture of the main form of the four main asset classes, their components, and asset types.

Instead of interfacing with commercial GIS software, MIMS implements its own GIS functionality through the use of ESRI MapObjects COM components. The GIS component provides access to the asset maps and database, and maintains a link between asset IDs and spatial features’ IDs. It also includes a “Data Quality” wizard that allows users to identify missing links between assets and spatial features. Users can navigate through the map using typical GIS viewing functions, and can perform spatial queries to locate assets relative to a user-defined shape or to create thematic maps based on selected asset attributes (e.g. asset condition rating). Users can retrieve an asset record using the “Find” tool, where users can search for assets satisfying multiple criteria, and then access the asset record or view the asset location on the map.

For each asset type, MIMS supports five main functions, which can be accessed from the asset data form. The *Locate* function activates the Map Viewer and zooms to the location of the current asset. The *Costing* function enables users to record cost data related to the asset. The *Functional Adequacy* function allows users to rate the overall performance and the level of service delivered by the asset (good, fair, or poor) for later use in the maintenance planning and prioritization process. The *Condition* function allows users to rate the condition of the asset using a consistent standard for assessing the structural condition of the asset.

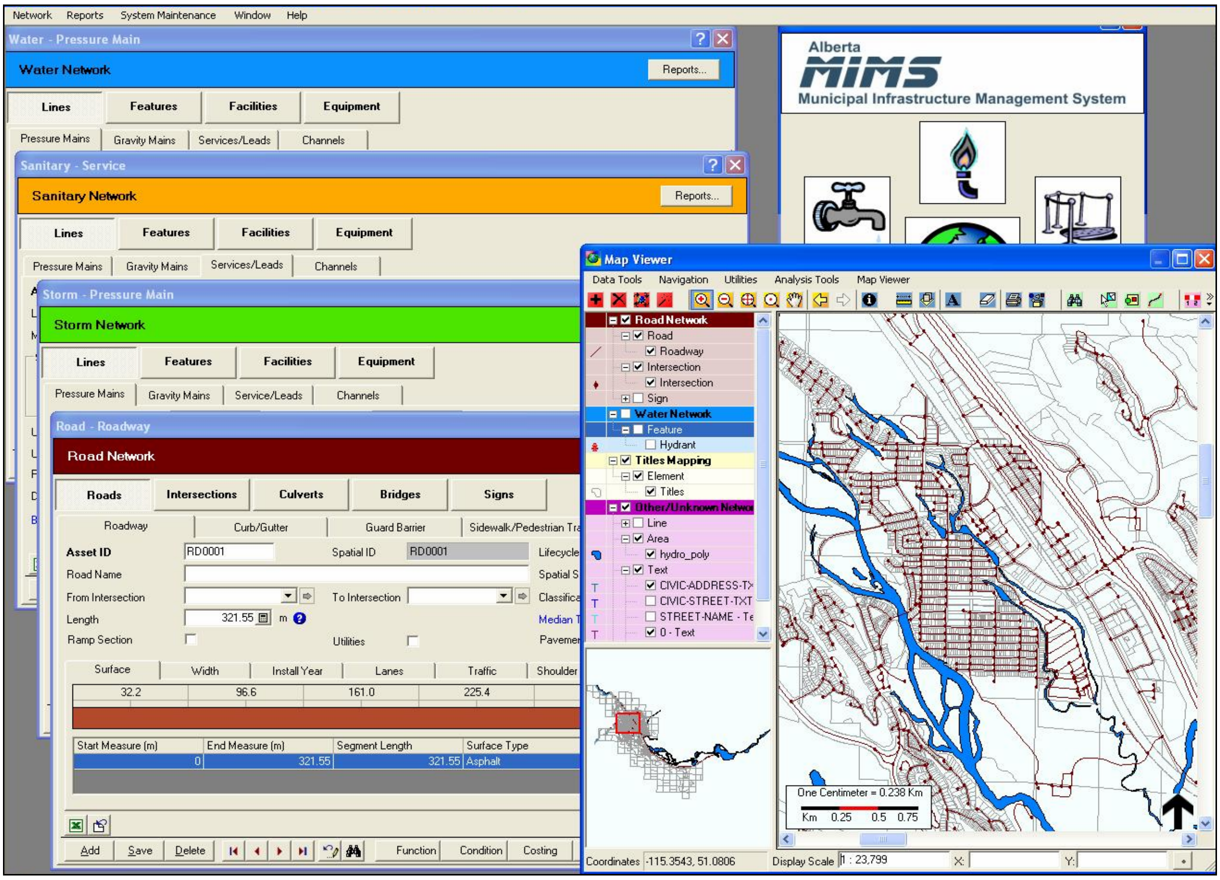

FIG. 3: MIMS main windows for managing water, sanitary, storm water, and road networks, each showing the break down of the network to primary components and asset types. The MapViewer is shown with a sample data (Courtesy of the MIMS Initiative).

3.4 RIVA

RIVA (Real-time Asset Valuation Analysis, 2005), developed by Loki Innovations (www.loki.ca), provides capabilities for long-term asset management planning in a 10 to 200 year planning horizon. RIVA is a web-based client-server application that can interface with most common applications. The data can come from any ODBC-compliant source, so the user can leverage existing data and pull data from other databases, such as Hansen.

RIVA has a modelling capability that can be used for asset valuation, determination of deferred maintenance, condition assessment, estimating remaining service life (RSL), and prioritization of maintenance and rehabilitation (M&R) processes. Deterministic and probabilistic models can be created using the Formula Builder tool. The Formula Builder tool allows users to create, change and test the formulae that drive calculations and models. Models can be trial models, in which the user can vary the model parameters to undertake a comparison of various asset management scenarios, or corporate models. Changes made to the models are automatically reflected in data and model outputs (e.g. deterioration curves, priorities, etc).

The asset inventory and valuation capability within RIVA can retrieve information already in the user's existing databases and permit the user to set up new asset classes. The application can virtually support any number of user-defined asset classes. The hierarchical structure allows the user to specify the level of data detail required for each asset. This enables the user to drill down through the asset from city-level, to street-level, to component. The asset inventory can be viewed both geographically and by asset category for any level of detail. RIVA also has a built-in valuation capability that uses integrated economic factors to calculate asset values. These factors can be amended by the user if desired. RIVA supports both ESRI and Intergraph GIS applications. Fig. 4 shows sample screens that demonstrate the GIS integration capabilities of RIVA and the ability to rollup costs to a network level to demonstrate the long-term impact of stable infrastructure funding on cumulative shortfalls.

FIG. 4: View of RIVA showing GIS integration (Top) and long-term impact of infrastructure funding (Bottom).

The deferred maintenance capability in RIVA is also user defined. The user defines "best practices" and RIVA calculates the level of deferred maintenance based on a set of events triggered by the practice. The application allows modelling to see the impact of various M&R strategies on the size of the maintenance backlog. In modelling the data, the user is able to vary economic factors such as rate of expenditure (% per annum), discount rate, etc. RIVA is not a work order system, but it can import work order data and allow the user to see all of the work done on an asset.

RIVA can import condition assessment data from other sources, and directly link this data to assets at any level of detail. The application allows the user to set up models, based on user-defined parameters or on pre-existing systems (e.g. Water Research Centre-WRc, Road Condition Index-RCI), to determine asset condition. RIVA allows the user to compare condition and shortfall-adjusted condition to show the impact of deferred maintenance and maintenance strategies. Virtually, any condition assessment tool and any scoring metric can be adopted by the user, and the resulting data can be integrated into RIVA for analysis and modelling.

An important part of asset condition is to determine the estimated RSL. RIVA employs user-defined RSL models to calculate RSL, and allows users to vary parameters such as M&R strategies. RIVA also has the capability to set priorities within classes and across all assets. This enables the user to harmonize priorities and generate an event priority list.

RIVA has a "thin client" architecture and does not require desktop installation. The data is typically stored on a server but can be hosted by RIVA for smaller municipalities. The software flexible architecture facilitates adding new features seamlessly. The user configures RIVA to suit their requirements thus, enhancing and complementing the capabilities of existing asset management tools already used by the organization. A useful feature of RIVA is that it implements default models and processes that would allow users to begin implementing all features of the application with minimal starting data.

3.5 Hansen

Hansen (2005) is a major asset management application developed by Hansen Information Technologies to provide capabilities for managing government operations including asset and property management, utility billing, permits, financial and human resources management. The software supports inventory data collection, asset valuation, determination of deferred maintenance, condition assessment, estimating remaining service life, and prioritizing M&R options. The software can interface with two major GIS products: Intergraph's GeoMedia and ESRI ArcGIS. The software also has extensive data import/export capability.

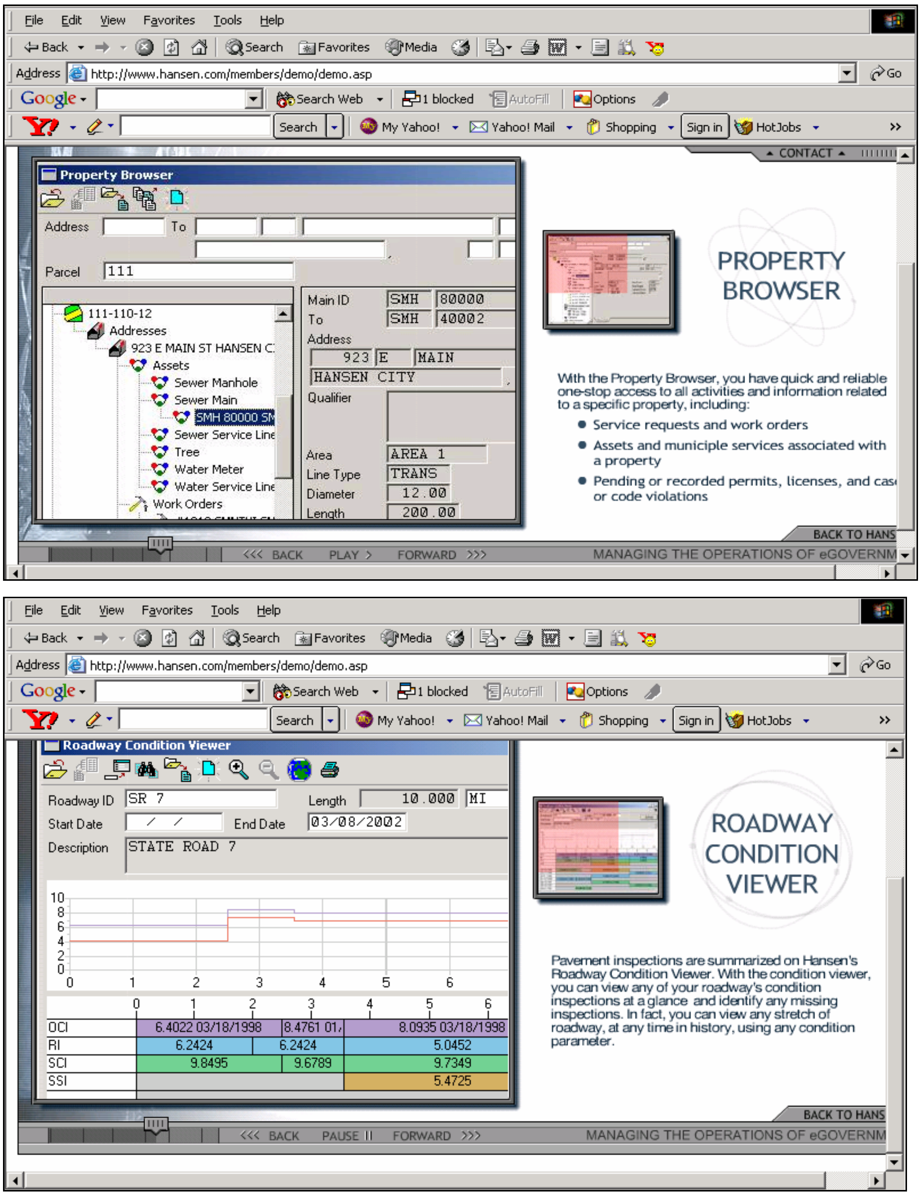

FIG. 5: (Top) View of Hansen demo screen showing Property Browser from Public Works module; (Bottom) view of Hansen demo screen showing Roadway condition viewer from Transportation module.

Hansen applications are typically used by medium to large municipalities or organizations. Hansen is client-server application installed on individual desktops. Future versions of the software will be browser-based, thus eliminating the need for most desktop installation.

Hansen's asset management tools are contained in two major modules: *Public Works* solutions and *Transportation* solutions. Each module is GASB Statement 34 compliant, with an asset-specific infrastructure accounting model. The *Public Works* module contains divisions for: industrial waste management, parks management, plant and fleet management, water and wastewater management, and work management. The *Transportation* module contains: bridge management, facilities and equipment, inventory management, pavement management, property management, railway management, roadway management, sign management, and street management.

Hansen provides a detailed asset inventory and valuation capability using one or more of the following asset data models: hierarchical, directional, pressurized, segmented, point, area, linear and network models. Except for the pavement management module, Hansen does not have a built-in condition assessment capability. The pavement management module incorporates a condition assessment and rating tool, along with deterioration curves to predict future asset conditions. Other condition assessment data are typically integrated into the database through interfaces to compliant applications. Examples of such applications include Flexidata and CIMS, which are used for condition assessment of sewer assets. The user can define rating criteria to obtain asset condition ratings.

Activity based costing, and budgeting and planning capabilities within the *Transportation* module allows the prioritization of M&R activities. To address the strategic asset management gap, Hansen has recently teamed up with RIVA to extend Hansen's operational management functionality with RIVA's long-term asset management capabilities. Fig. 5 shows sample screens of elements of Hansen's public works and transportation modules.

3.6 Infrastructure2000

Infrastructure2000 (2005), developed by Vanasse Hangen Brustlin, Inc. (VHB), provides capabilities for asset management planning, and is targeted at small to medium size organizations. Infrastructure2000 is client-server application installed on individual desktops. It supports inventory data collection, asset valuation, determination of deferred maintenance, condition assessment, estimating remaining service life, and prioritizing maintenance and rehabilitation (M&R) options. The software can be integrated with popular GIS applications such as ESRI's ArcGIS. Other software interfaces and custom applications can be created by VHB for their clients to convert data to a format compatible with Infrastructure2000.

Infrastructure2000 consists of RoadManager2000, with five asset management modules, and three work management tools: WorkManager2000, EquipmentManager2000, and PermitManager2000. The five RoadManager2000 modules include: Pavement, Sidewalk, Traffic Control, Drainage/Utility, and Budget Analysis. The Pavement, Sidewalk and Drainage/Utility modules all provide a detailed asset inventory and valuation capability. The pavement module is the most comprehensive of the five. It also provides a condition assessment capability using the standard rider comfort index (RCI) or the pavement condition index (PCI) protocols as a measure of pavement condition. The 0–100 index score is mapped to a condition score where "1" (one) is defined as a "do nothing" intervention and "5" (five) is defined as a "reconstruct" intervention. This module also includes a GASB 34 notebook. The remaining modules are not based on established condition assessment protocols. Other asset classes such as bridges, channels, pipes, and street lights are included in the Drainage/Utility module. The Sidewalk module includes trees, pedestrian ramps, and curbs.

The Budget Analysis module provides the capability to define repair alternatives, create and compare funding scenarios, and define and view deterioration models. Currently, this can only be accomplished for pavement assets. For other types of assets, the user has to define the appropriate models and scenarios. Fig. 6 shows sample screens from RoadManager2000, demonstrating the Pavement module notebook, table options, pavement assessment, as well as deterioration curves from the Budget Analysis module.

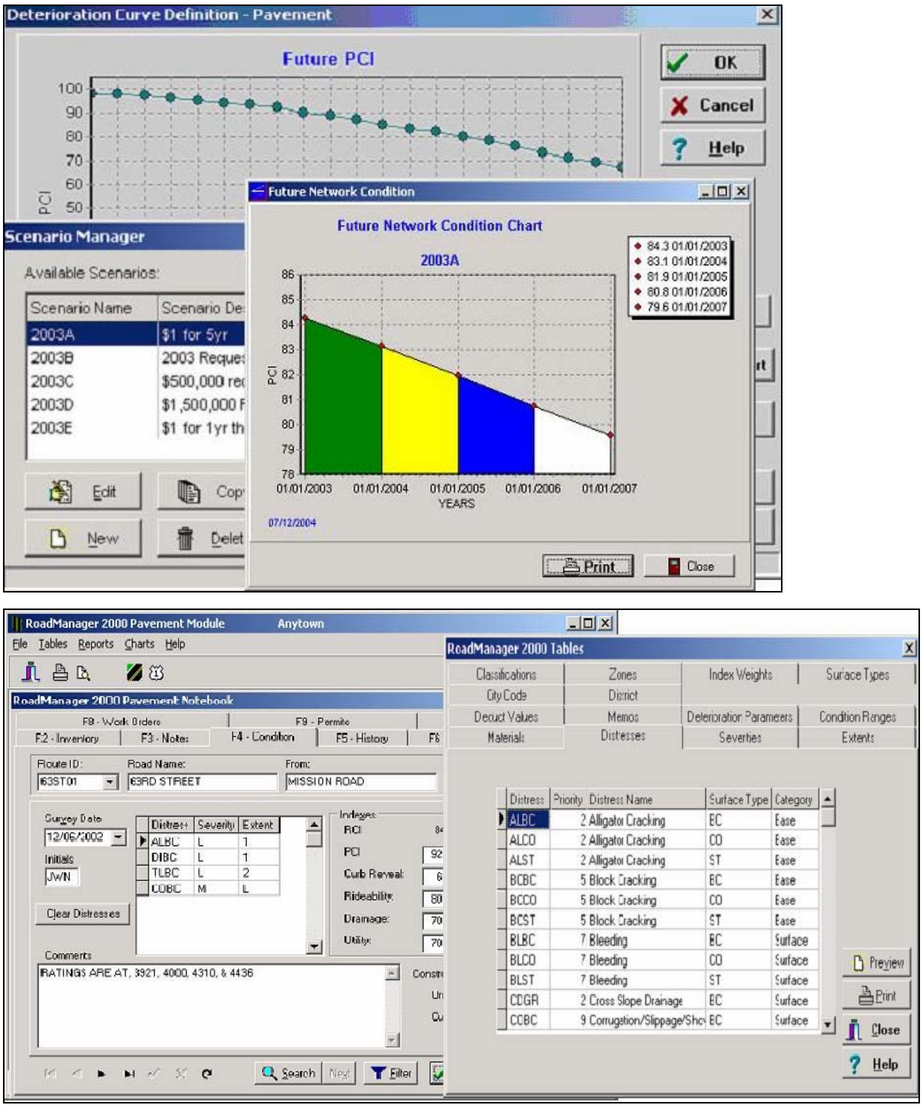

FIG. 6: Sample screens from RoadManager2000 showing the Pavement module notebook and table options, pavement assessment, and deterioration curves from the Budget Analysis module.

3.7 Harfan

Harfan's (2005) method is geared to be a generic solution for long-term management of municipal assets. It attempts to be flexible in its design, so that it can be adapted to support: (1) extending the asset service life, and (2) optimizing the long-term investments. The software can be applied to diverse areas such as: water and sewer networks, roads, gas and telecommunications networks, electricity networks, street lighting, buildings, marine assets, airports, and rail systems. Harfan uses an Oracle RDBMS, and allows one-way integration with the most popular GIS systems (e.g., Autodesk MapGuide and ESRI ArcGIS).

Harfan philosophically recommends a five-step methodology that includes addressing typical asset management issues such as: what do you own, what is it worth, what is the condition, what is the remaining service life, how much you should invest to ensure sustainability, and what needs to be done and when. As a result, the software modules are designed to produce answers to these questions.

The inventory module serves as the data warehouse, and provides the functionality to define customized input forms for data entry, and the search and retrieval of asset data. The condition assessment module allows users to select an existing assessment protocol or to define their own protocols. For example, a weighted factor method can be used to assign weights to a variety of assessment metrics to produce a physical, functional, sustainability and global index. Typically, infrastructure assets with similar physical and functional properties can be grouped together as “families of behaviour” for the purpose of harmonizing their future condition.

The service life prediction module uses deterministic curves, selected by the user, to calculate the remaining service life. An interactive program to build user-defined rule-based “decision trees” to be used for suggesting the most appropriate asset renewal strategy, given asset condition, remaining service life, maintenance strategy, and available funding levels. Fig. 7 shows a screen capture of integrated capital plan and the resulting Global Condition 10 years into the future, after having applied a scenario of roughly $22.4 million of rehabilitation and reconstruction works.

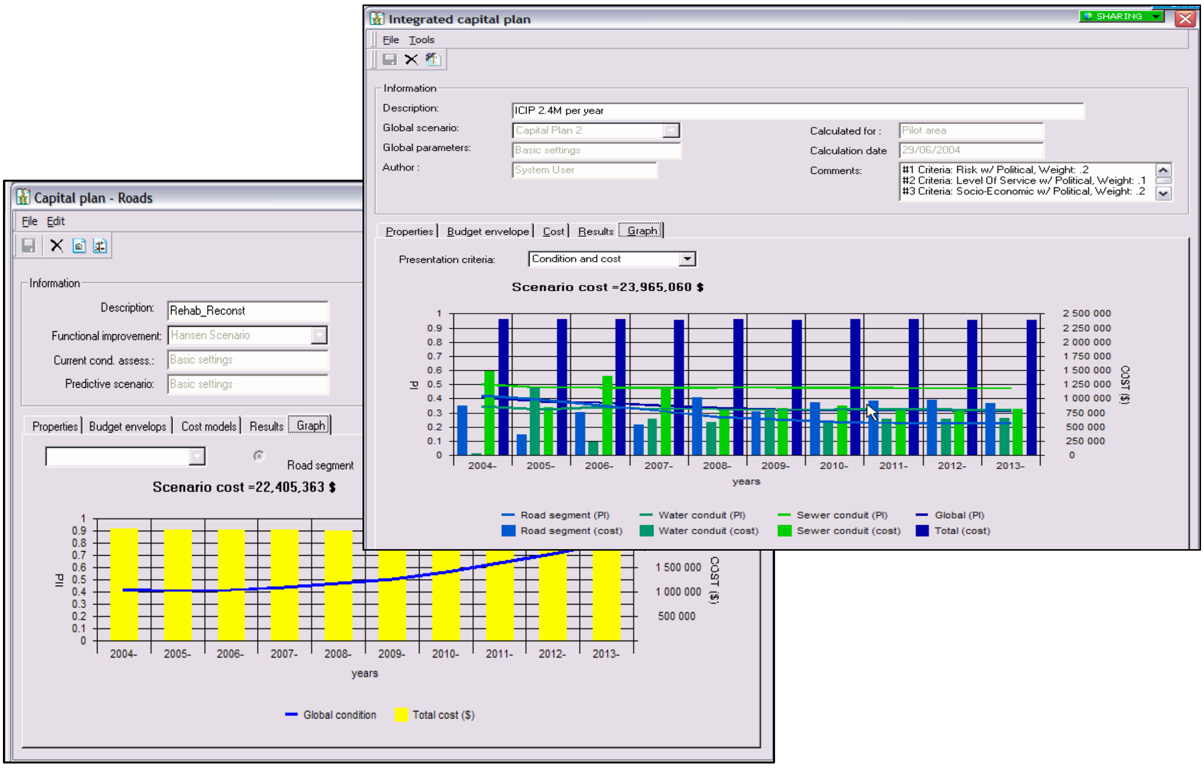

FIG. 7: (Top) View of Integrated Capital Plan for integrated right-of-way and the associated costs and global condition of the contributing asset classes; (Bottom) View of Global Condition (PII left axis) 10 years into the future, after having applied a scenario of roughly $22.4 million of rehabilitation and reconstruction works.

Harfan’s maintenance prioritization module can produce multi-year capital improvement plans based on analysis of asset data. Techniques such as weighted factor method are used to prioritize the infrastructure projects. The software also permits the user to select overall renewal options and compare the renewal alternatives (i.e. rehabilitation vs. reconstruction).

4. DISCUSSION

Asset management is essentially a set of data-intensive decision-making processes. Therefore, the development of asset management systems typically starts by developing a database to store and manage asset data. However, fewer systems implement data analysis and decision-support modules that would automate some aspects of the decision processes. Furthermore, the vast majority of existing asset management software still focus on the operational management aspect (e.g., work orders, service requests), with little or no functionality to support long-term renewal planning decisions (e.g., deterioration modelling, risk assessment, life cycle cost analysis, asset prioritization). From the reviewed systems, RIVA, Harfan, and Infrastructure2000 implemented some level of support for long-term renewal planning of particular assets, mainly pavement. The other four systems included condition assessment and rating modules.

Clearly, modern asset management systems can play an integral role in supporting efficient operations and long-term renewal planning of municipal infrastructure assets. However, selecting and implementing an asset management system that best suits the requirements of a particular municipality is a challenging endeavour that will have important implications on an organization both in the short and long tem. Short-term implications are mainly financial commitments, while long-term implications involve the requirements for maintenance, staffing, and the return on investment. To make a cost-effective selection decision, asset managers need to address a number of considerations and selection criteria. In light of the review process, a number of these considerations can be identified.

The distinction between general-purpose and asset-specific software systems is significant in guiding asset managers in the process of selecting the software best suited to the requirements of their respective municipalities. Asset-specific software systems may be more suitable to small to medium organizations, while general-purpose systems may be more suited for medium to large organizations. The investment required to set-up, customize, and maintain general-purpose software may not be affordable to many of the smaller municipalities.

Another important consideration for selecting software systems is the level of integration and interoperability with other legacy systems already being used in an organization. Of particular importance is the integration with GIS and Enterprise Resource Planning (ERP). The majority of existing COTS asset management systems implement some form of GIS support. This support ranged from sending simple queries from the asset management software to identify the selected assets on the map, to more tightly coupled integration of the asset database and the GIS spatial database. Synergen and MIMS, among others, represented the former, while CityWorks represented the latter. Selection between these two approaches may depend on the level of completeness of GIS implementation in a municipality and the level of in-house IT support. A single database that includes both spatial and non-spatial data will have the advantage of eliminating the need to duplicate the data or to maintain the consistency of the data across different databases. However, developing such a database will require the municipality to develop a comprehensive GIS-based asset inventory, and to ensure that the data schema will be able to accommodate various forms of non-spatial data. On the other hand, maintaining a dual database system to store spatial and non-spatial data only requires the use of a consistent scheme to identify the assets across the databases (i.e. use of a common key). Given the fact that spatial data are generally static and do not need to be frequently updated, keeping the spatial data separated from the more dynamic and changing asset data (condition and operational data) would facilitate the maintenance of asset data. In this case, only the changing part of the data will need to be frequently backed up and audited to ensure the integrity and consistency of the data.

Although the majority of COTS asset management systems supported interfacing with GIS, very few systems could support integration with ERP or financial software systems. Many asset management decisions and policy-making depend on the availability of accurate up-to-date financial data. Historically, ERP systems have been the main source of financial and personnel data, and the need to link asset management systems to these data sources is a critical step towards supporting integrated long-term asset management strategies. Some systems, such as Synergen, provided support to some ERP functionality; however, re-implementing the entire scope of ERP functionality in asset management systems, or a GIS system for that matter, seems to be an unfeasible option.

5. CONCLUSION

This paper presented a review of number of COTS municipal infrastructure asset management systems. The main features, capabilities, and limitations of the evaluated software were briefly discussed. Compared to software systems developed in other sectors in the construction industry, the systems developed for asset management are relatively limited in number and scope, and are generally less mature. The software review discussed in this paper was limited to seven well-known systems available in North America that are commonly used by municipalities, and that constitute a representative sample of the currently available asset management systems in terms of functionality, features, and limitations.

In light of the software review results, some directions for future research can be identified. Of particular interest is the development of methods and tools for long-term renewal planning of infrastructure assets. The vast majority of the existing systems focus primarily on supporting the operational day-to-day management activities, and an extremely small number of software tools implemented limited support for long-term renewal planning. Also, many fundamental asset management functions, such as performance modeling, and maintenance prioritization, are not supported by most of these applications. Part of this scarcity can be attributed to the complexity of the long-term planning problem, and the lack of a clear and systematic approach to tackle this problem.

Developing industry-wide standard integrated data models for infrastructure systems is another critical area for future research. The data models supported by existing software are mostly proprietary, which impedes the ability of software systems to interoperate and share asset data. Standardizing the underlying data models would further enhance the role that the systems can play to enable better integration and coordination of the infrastructure management activities, and the interoperability between various software applications.

Asset management systems typically support the management of different classes of municipal assets (e.g. roads, water, and sewer networks), with little or no consideration to their inter-dependencies. This lack of integration of asset management activities has created significant inefficiencies in maintenance coordination and asset planning. Optimally, renewal plans for assets at a particular site should be coordinated to span multiple infrastructure assets as much as possible, thus minimizing the disruption, cost, and risks associated with maintenance operations. Integrated asset management is becoming a critical area that future systems will need to support.

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