

Municipal Infrastructure Asset Management Systems: State-of-the-Art Review

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ABSTRACT: Significant advances have been made during the last decade in developing infrastructure asset management systems. However, there is an obvious need to extend the scope and capabilities of these systems to better support the sustainable development and management of infrastructure assets. This paper provides a state-of-the-art 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 main features, capabilities, and limitations of the evaluated software are presented. The main objective of the paper is to provide asset management organizations with an objective review of these systems, and to identify areas where further research and development are needed.

1 INTRODUCTION

A municipal asset management system is used to store and manage asset data, and to support operational and strategic decision making processes. Municipal infrastructure asset management systems are used for land and property management, facilities and infrastructure management, and utility management. 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 new techniques and software solutions have been developed during the last decade in an attempt to improve the infrastructure asset management process. Significant advances have been made in developing software tools to support activities in various domains such as pavement and bridge management, sanitary/storm water sewer management, and water supply management.

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. The goal of the MIIP project is to develop and formalize a generic framework and decision support tools for collecting and storing information and knowledge related to prominent issues in sustainable infrastructure asset management.

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 solutions. This paper does not rate or rank the packages evaluated herein, but aims primarily to provide asset managers with an objective review of systems, and to identify areas where further research and development are needed.

2 GENERAL-PURPOSE VS. ASSET-SPECIFIC SYSTEMS

Asset management software can be classified into two broad categories: general-purpose software and asset-specific software. General-purpose systems typically offer generic functionality that 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 data 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 procurement. They also support a range of data import/export options, and the capability to interface with other software (e.g. CAD or GIS 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. Examples of these systems include pavement management systems, bridge management systems, sewer management systems, and facilities management systems. A number of asset-specific systems are also available as Commercial-Off-The-Shelf (COTS) products for managing buildings, water distribution systems, sanitary and storm water sewers, pavement, among others. These applications typically use an RDBMS to support the development and maintenance of the asset inventory database. Many applications provide built-in GIS capability or support interfacing with other commercial GIS software.

Asset-specific software solutions extend the data management functionality by implementing procedures for estimating and measuring the performance level of a particular infrastructure asset based on the physical and condition data. 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).

3 THE SOFTWARE REVIEW PROCESS

A representative sample of infrastructure management software systems has been selected for detailed evaluation. The selected systems cover a wide spectrum of software capabilities and scope, as they are currently available by COTS software. Due to space limitations, this paper only provides highlights of the evaluation process, focusing on the features, capabilities, and limitation of these systems. A more detailed description can be found in (Vanier et al 2005). The systems presented in this paper are: Synergen; CityWorks; MIMS; Hansen; RIVA; Infrastructure 2000; and Harfan. The information provided herein is based on trial versions obtained directly from the developer and represents the most current version of the software, or they are based on literature surveys and demonstration of the software.

3.1 Synergen

Synergen is a web-based work management and procurement system that is mainly targeted to large or-

ganizations 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. 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 Depreciation, Manufacturer data, Cost, Operational data, Work history, etc.

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. Figure 1 shows a screen capture that displays the Asset default View, and a list of other Views and Actions in the Asset module, in the Resource Subsystem. The figure also shows Synergen GIS interface.

Due to its general-purpose nature, Synergen can be customized and configured to manage assets in virtually any organization. However, the set up and customization process and the investment required may be significant, especially for small to medium



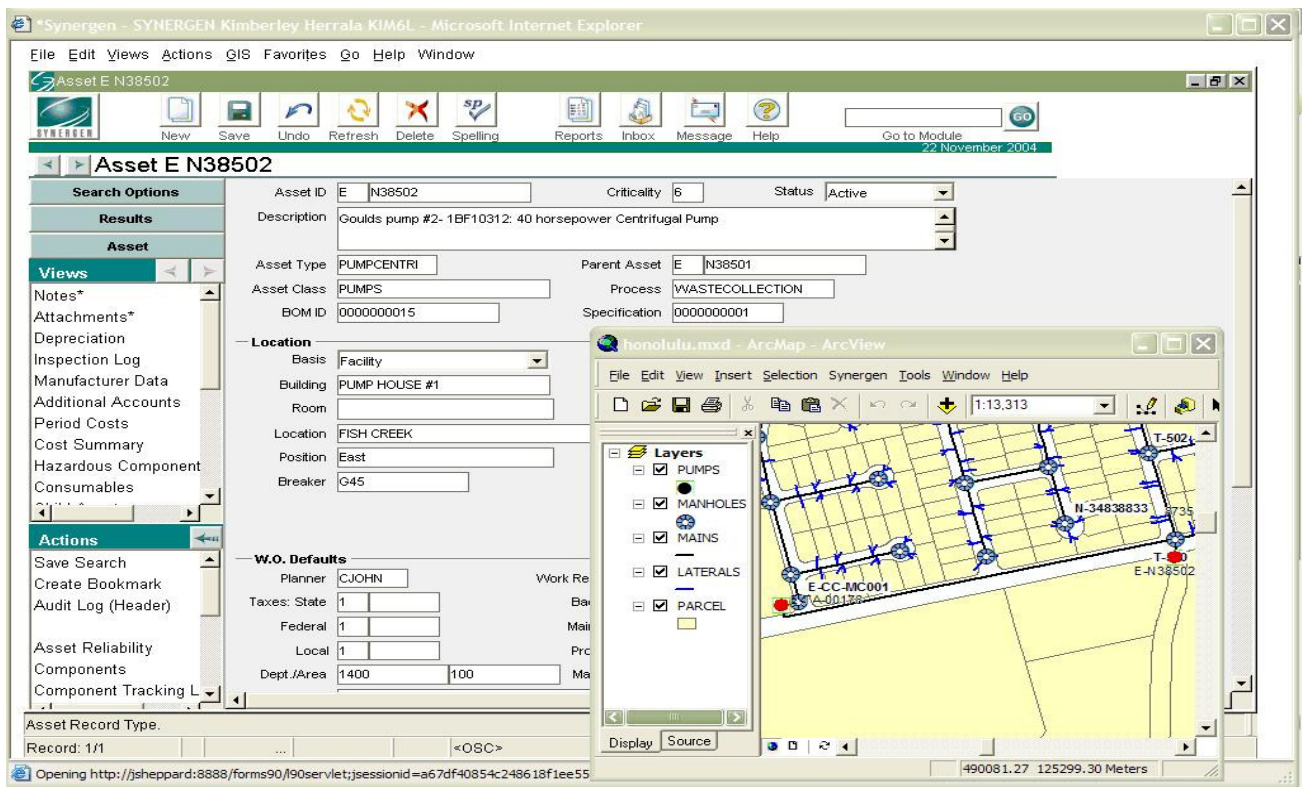


Figure 1. Synergen Asset module in the Resource subsystem, and GIS view of selected assets (Courtesy of Synergen).

size organizations. On the long run, the rewards of using the system may prove to outweigh that investment for smaller municipalities.

3.2 CityWorks

CityWorks is a GIS-based solution for operational and maintenance management of municipal assets. CityWorks supported 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 (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. Figure 2 shows the ArcGIS add-on showing a map of water mains and associated work orders.

A distinguishing feature of the software is its tight integration with GIS. Unlike most of other applications, 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 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.

CityWorks can be deployed as an extension to ESRI ArcGIS or as a standalone system. The data-

base managed by both 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. CityWorks also offers the capability to spatially link work orders and service requests to specific assets or to street addresses. The first approach would be useful for municipalities that already maintain a GIS asset inventory, while the second approach was designed for municipalities with 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 can be processed 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.

A distinguishing feature of CityWorks is its ability to support field operations by enabling browser-based wireless access (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 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.



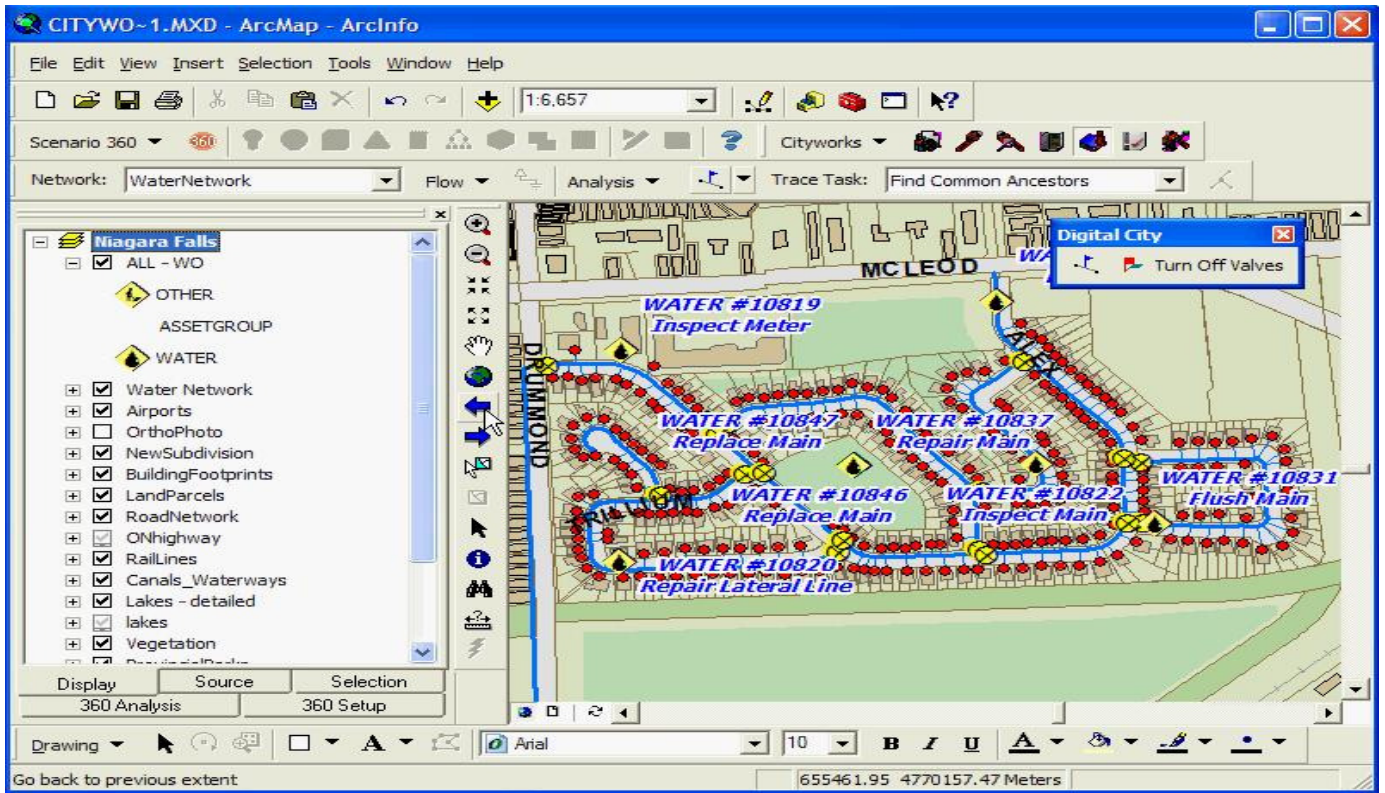


Figure 2. CityWorks ArcGIS add-on showing a map of water mains and associated work orders (Courtesy of Azteca).

3.3 Municipal Infrastructure Management System (MIMS)

The Municipal Infrastructure Management System (MIMS) 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.

Each class of assets is broken down into its main components, which are in turn subdivided into asset types. Each asset type is roughly 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. Figure 3 shows a screen capture that displays the main form of the four main asset classes.

MIMS implements its own GIS functionality through the use of ESRI MapObjects. 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. Users 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 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.

3.4 Hansen

Hansen is a major 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. It includes inventory collection, valuation, determination of deferred maintenance, condition assessment, estimating remaining service life and prioritizing maintenance and rehabilitation (M&R) options.



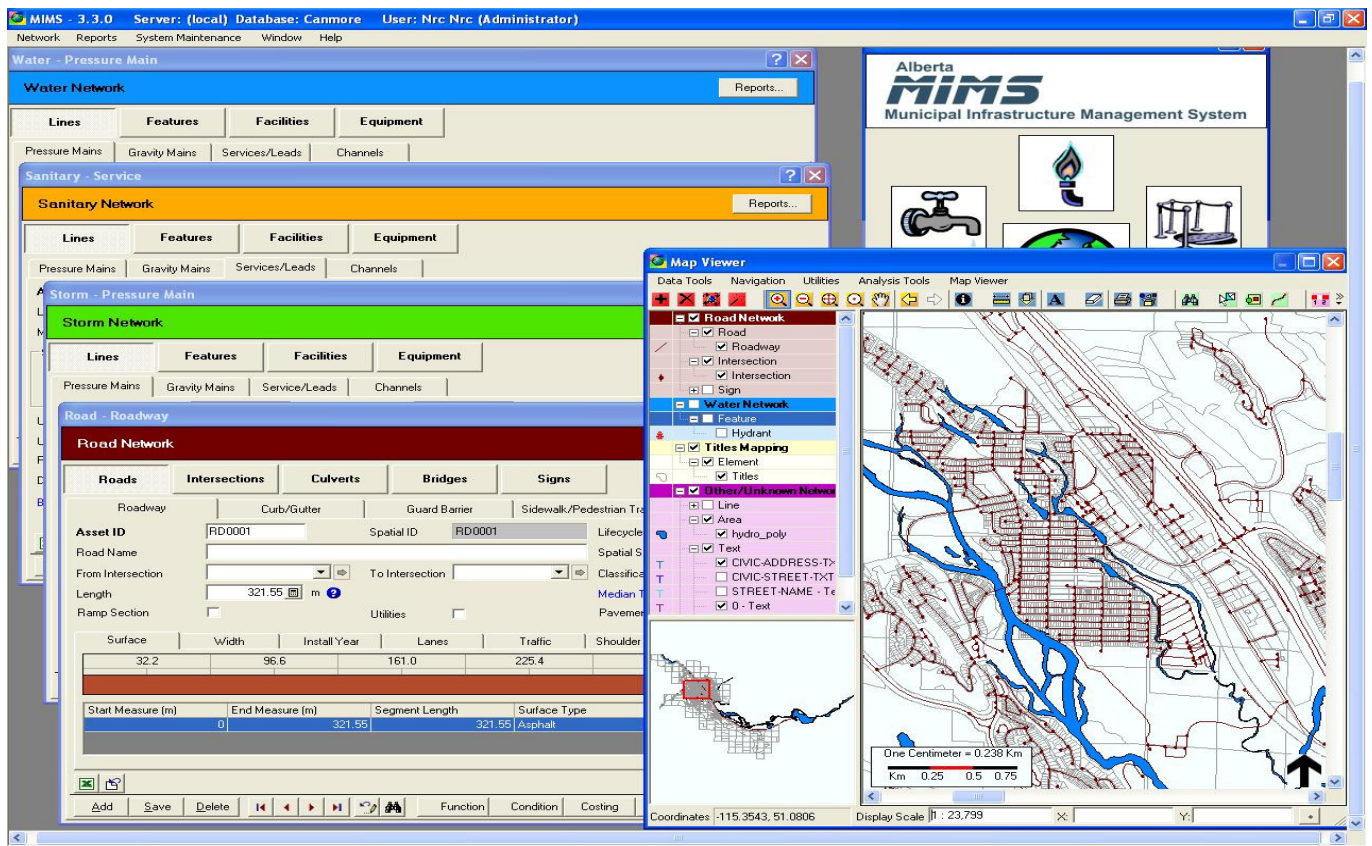


Figure 3. MIMS MapViewer and forms for managing water, sanitary, storm water, and roads networks (Courtesy of MIMS).

Hansen is client-server application installed on individual desktops. Interfaces written by Hansen to allow data import/export include the GeoMedia-Hansen Interface and Integrated Map Viewer, which allow a GIS link to Intergraph and ESRI applications. Other software interfaces include those for Flexidata and CIMS sewer condition assessment software. The next version of the product, will be web-based thus, eliminating the need for most interfaces and desktop installation. Hansen applications are typically used by medium to large organizations.

Hansen's asset management tools include two main 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, street management, water and wastewater management, and works management. The Transportation module contains: bridge management, facilities and equipment, inventory management, pavement management system, property management, railway management, roadway management, sign management, street management, and work 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. Hansen does not have an extensive condition assessment capability. Only the pavement management

system sub-module has integral condition assessment tools including deterioration curves and decision models. Other condition assessment data are fed into the Hansen database through compliant applications such as Flexidata and CIMS. The user can define condition rating criteria within Hansen and obtain asset conditions. Activity based costing, and budgeting and planning capabilities in the Transportation module appear to allow for prioritization of M&R activities. It was not clear from the product literature if this capability extended to multi-year asset management. Hansen has recently teamed up with RIVA (See Section 3.5) to use RIVA's long-term asset management capabilities to extend Hansen's operational management functionality. Figure 4 shows sample screens displaying elements of the public works and transportation modules.

3.5 RIVA

RIVA (Real-time Asset Valuation Analysis), developed by Loki Innovations (www.loki.ca), provides capabilities for long-term asset planning in a 10 to 200 years planning horizon. RIVA is a web-based application that can interface with most common applications. The data can come from any ODBC-compliant source so the user can pull data from other databases, such as Hansen. It supports inventory data collection, valuation, determination of deferred maintenance, condition assessment, estimating remaining service life (RSL) and asset prioritization.



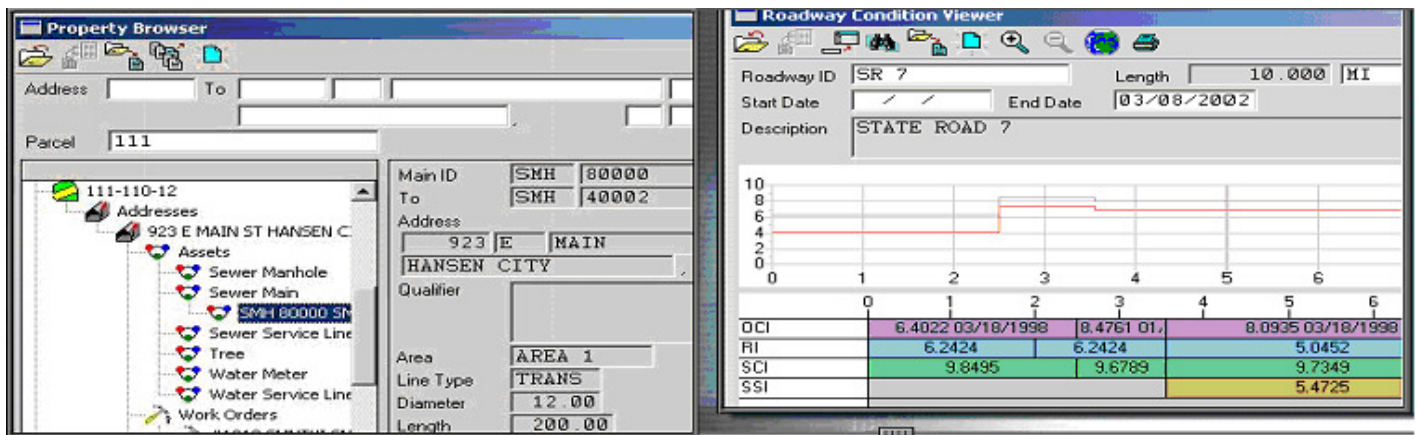


Figure 4. View of Hansen demo screen showing Property Browser from Public Works and Transportation modules.

RIVA has a modeling capability that can be used for valuation, determination of deferred maintenance, condition assessment, estimating remaining service life and prioritizing M&R. Deterministic and probabilistic models can be created using formulae set up by the user or with help from Loki. The Formula Builder allows the user 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. This allows the user to begin using the application almost immediately. The application is limitless in the number of asset classes it can contain. 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 to component. The asset inventory can be viewed both geographically and by asset "silos" for any level of detail. RIVA has a built-in valuation capability that uses integrated economic factors to value assets. These factors can be amended by the user if desired. RIVA supports both ESRI and Intergraph GIS applications. Figure 5 shows the GIS integration capabilities of RIVA and the ability to rollup costs to a network level to demonstrate the long-term impact of infrastructure funding on cumulative shortfalls.

The deferred maintenance capability within RIVA is also user defined. The user defines "best practices" and RIVA calculates the level of deferred maintenance based on set of events triggered by the practice. The application allows modeling to see the impact of various M&R strategies on the size of the maintenance backlog. In modeling the data, the user is able to vary economic factors such as rate of ex-

penditure (% per annum), discount rate, etc. RIVA is not a work order system but it can import work order data and allow the user to access these data.

RIVA can import condition assessment data from other sources and directly link them 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), to determined asset condition. RIVA allows the user to compare condition and shortfall adjusted condition to show the impact of deferred maintenance and maintenance strategies. Any condition assessment tool and any scoring metric can be used, and can have the resulting data incorporated into RIVA for analysis and modeling. An important part of asset condition is to know the estimated RSL. In RIVA, user defined RSL models allow users to vary parameters such as M&R strategies to estimate RSL. RIVA has the capability to set priorities within classes and across all assets, which enables users to harmonize priorities and generate an event priority list. RIVA's "thin client" architecture means that new features can be added seamlessly.

3.6 Infrastructure2000

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

Infrastructure2000 consists of RoadManager, with five modules, and the following work management tools: WorkManager, EquipmentManager, and PermitManager.



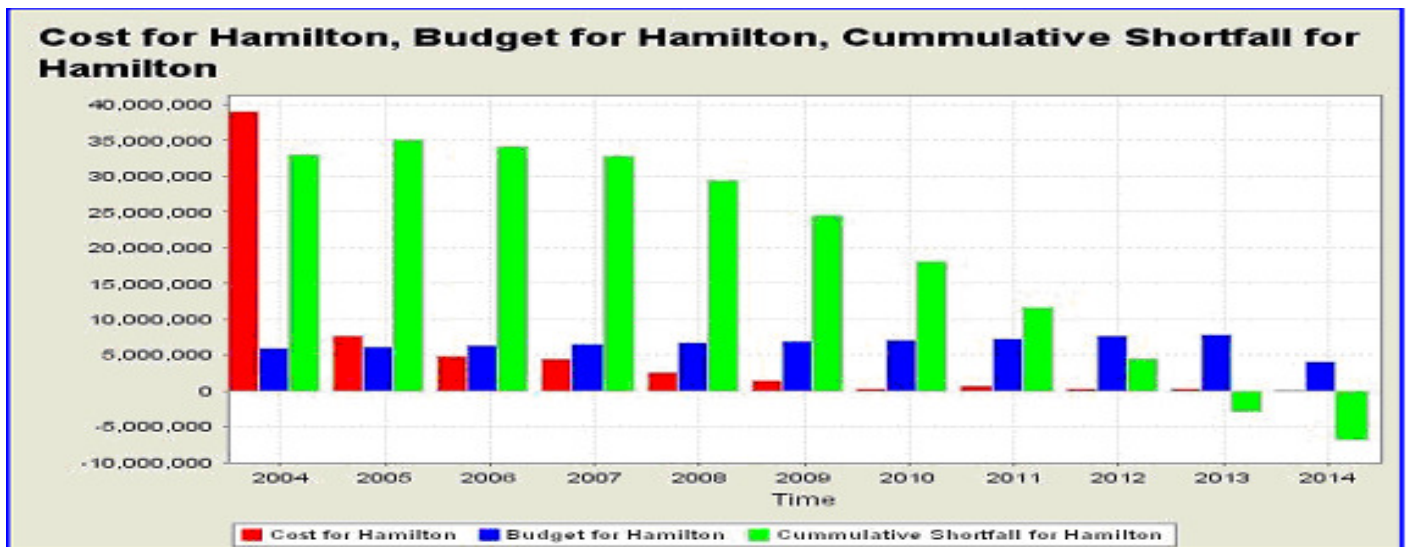


Figure 5. View of RIVA showing long-term impact of infrastructure funding.

The RoadManager modules are: Pavement, Sidewalk, Traffic Control, Drainage/Utility, and Budget Analysis. The Pavement, Sidewalk and Drainage/Utility modules provide a detailed inventory and valuation capability. The pavement module provides a condition assessment capability using the standard rider comfort index (RCI) or the pavement condition index (PCI). The 0–100 index score is mapped to a condition score where “one” is defined as a “do nothing” intervention and “five” is defined as a “re-construct” 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, structures, channels, and pipes are included in the Drainage/Utility module. The Budget Analysis module provides the capability to define repair alternatives, create and compare funding scenarios, define and view deterioration models. This can only be accomplished for pavement assets, however. Figure 6 shows a sample screen demonstrating the pavement module notebook and table options.

3.7 Harfan

Harfan’s method and software is geared to be a generic solution to municipalities. 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 areas such as: water and sewer networks, roads, gas and telecommunications networks, electricity networks, street lighting, buildings, marine assets, airports, and rail systems. It is possible at the upper levels of the data structure to drill down to the basic level of inventory data and search for information. Harfan uses an Oracle RDBMS and allows one-way integration with popular GIS systems (e.g. ArcGIS and MapGuide).

Harfan philosophically recommends a five-step methodology that addresses 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 is the data warehouse that permits both the design of the input forms for the data storage, and the entry and retrieval of relevant 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 lumped together as “families of behavior” for the purpose of harmonizing future condition.

The service life prediction module uses deterministic curves selected by the user to calculate the remaining service life. An interactive program to develop “decision trees” is available to the user; this rule-based decision tree can then be used to suggest the most appropriate renewal strategy given condition, service life, maintenance strategy, funding levels, etc. The maintenance prioritization module can produce multi-year capital improvement plans based on analysis of existing data. Techniques such as weighted factor method are used to prioritize the infrastructure projects; however, other decision prioritization methods are currently under consideration. The software permits the user to select and compare different renewal options. Figure 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.



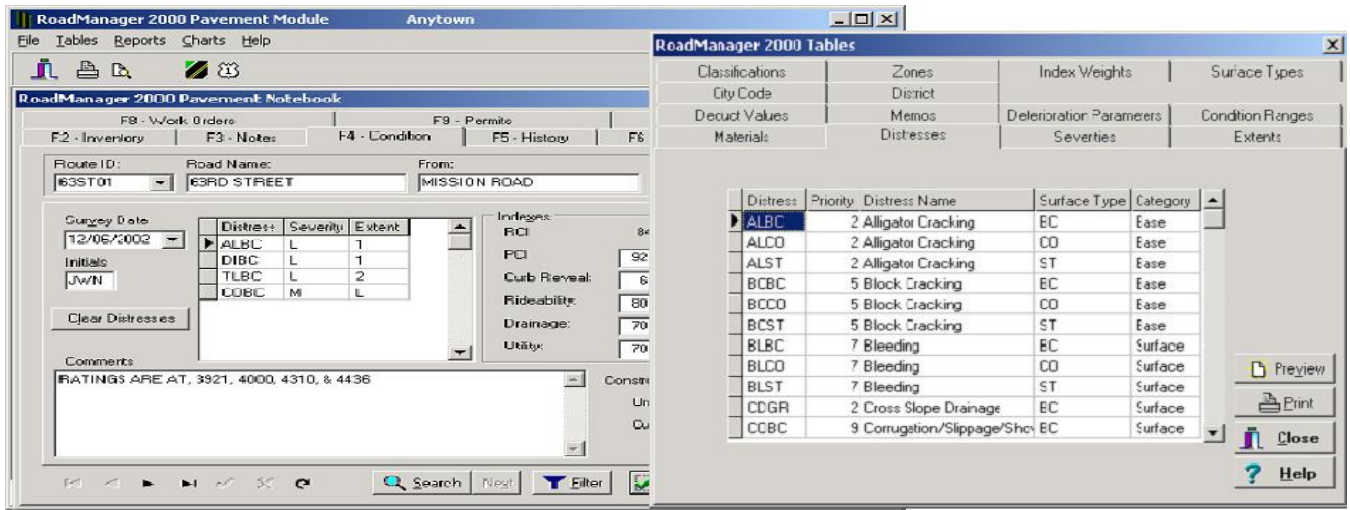


Figure 6. Sample screens from RoadManager showing the Pavement module notebook and table options.

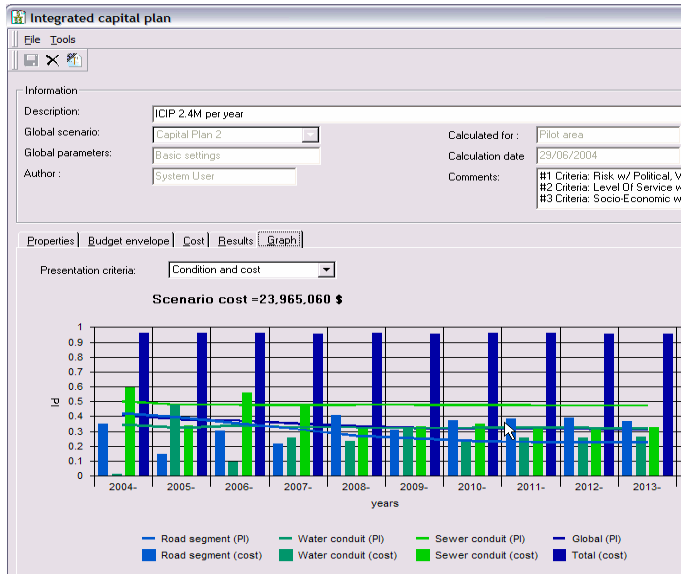


Figure 7. Harfan Integrated right-of-way 10-year Capital Plan.

4 CONCLUSIONS

This paper presented a review of a number of COTS municipal infrastructure asset management systems. The main features, capabilities, and limitations of the evaluated software were briefly discussed. The evaluated software comprised seven well-known systems available in North America that are commonly used by municipalities, and that constituted a representative sample of the available systems.

Although the majority of asset management systems supported interfacing with GIS, very few systems could support integration with Enterprise Resource Planning (ERP) or financial software systems. 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 long-term asset management strategies.

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.

Developing industry wide standard 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 to share and exchange asset data. Standardizing the data models would enhance the role that the systems can play to enable better integration of the management processes, and the interoperability between various software applications.

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