ADJACENCY MODELING TOOL FOR CIVIL INFRASTRUCTURE ASSETS

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ABSTRACT

Managing public assets involves a systematic process of operating, maintaining, and upgrading physical assets in a cost-effective manner. In many municipalities and provincial transportation and public works departments, it is common to see rehabilitation work on an asset, say x which often ignores the condition of the adjacent assets (say w, y, z, etc). As one or more of the adjacent assets (w, y, z, etc) deteriorate, the need to carry rehabilitation work on them arises within a short of time, after the completion of the rehabilitation work on asset x. As a result, the subsequent rehabilitation work on adjacent assets w, y, z, etc. often requires partial removal and repair of asset x to allow the completion of this new rehabilitation work. The effects of such subsequent rehabilitation works include premature damage to the recently rehabilitated asset, increased deterioration of such asset, frequent disruptions of service to users and increase in rehabilitation costs.

The adjacency modeling tool provide a context within a GIS and TAMWORTH (Transportation Optimization Software) that assists users to identify and analyze any need to rehabilitate adjacent assets

at the same time. Instead of focusing on any single element for a priority project, the adjacency model seek to organize and analyze all the adjacent assets or facilities into work-zone corridors within the road network to allow a more comprehensive planning and management of undertaking rehabilitation work and develop a process by which rehabilitation work can be scheduled once for a given corridor whenever technically viable and economically justifiable. A case study is presented to show its effectiveness with road and bridge network data in New Brunswick, Canada.

INTRODUCTION

Sustainable economic growth and social development of any country is intimately linked to the reliability and durability of its civil infrastructure systems such as highway and bridges, which are the most critical but vulnerable elements in highway transportation systems. Deteriorating civil infrastructure leads to increased direct and indirect costs for business and users. Therefore, timely and adequate rehabilitation interventions become indispensable to enhance reliability of civil infrastructure. This can substantially increase a country's economic competitiveness. In addition to development of advanced inspection and maintenance technologies, methodologies for cost-effective allocation of limited budgets to maintenance management of aging and deteriorating civil infrastructure over the life-cycle are urgently needed in order to optimally balance the life cycle performance and life-cycle costs while ensuring safety above acceptable levels (Frangopol, 2006).

Infrastructure Assets Management can save a community significant money. Current programs not only analyze and prioritize maintenance needs, they can even create project cost estimates and analyze various funding scenarios. A GIS can add tremendous functionality to Infrastructure Asset Management program not only in graphical output but in analysis, planning, and reporting (Waite and Rocco 2001).

The increasing requirements to maintain acceptable levels of performance in municipal infrastructure systems, combined with budgetary constraints, present significant challenges to municipalities. Sustainable management of municipal infrastructure assets requires the use of sound and reliable modeling systems that address a wide range of technical, economical and environmental issues. Throughout the past two decades, many infrastructure asset management software tools have been developed for a single asset class that lack an integrated and comprehensive view of the whole infrastructure asset management process. This lack of integration and interoperability creates inefficiencies and is a major impediment towards achieving sustainability objectives

In many municipalities and provincial transportation and public works departments, it is common to see rehabilitation work on an asset, say x which often ignores the condition of the adjacent assets (say w, y, z, etc). As one or more of the adjacent assets (w, y, z, etc) deteriorate, the need to carry rehabilitation work on them arises within a short of time, after the completion of the rehabilitation work on asset x. As a result, the subsequent rehabilitation work on adjacent assets w, y, z, etc. often requires partial removal and repair of asset x to allow the completion of this new rehabilitation work. The effects of such subsequent rehabilitation works include premature damage to the recently rehabilitated asset, increased deterioration of such asset, frequent disruptions of service to users and increase in rehabilitation costs.

The adjacency modeling tool provide a context within a GIS and TAMWORTH (Assets Optimization Software) that assists users to identify and analyze any need to rehabilitate adjacent assets at the same time. Instead of focusing on any single element for a priority project, the adjacency model seek to organize and analyze all the adjacent assets or facilities into work-zone corridors within the road network to allow a more comprehensive planning and management of undertaking rehabilitation work and develop a process by which rehabilitation work can be scheduled once for a given corridor whenever technically viable and economically justifiable.

The use of adjacency modeling tool applications can here a significant positive effect on the operational efficiency and maintainability of municipal infrastructure assets and can be a critical tool in achieving sustainability goals.

Research Objective

This paper demonstrates a methodology of implementing adjacency modeling in a GIS-T context to coordinate civil infrastructure works. A case study is used to show that corridor approach to planning and scheduling rehabilitation works can eliminate or reduce unwanted partial removal, damage and repair of adjacent assets due to rehabilitation work on another asset.

LITERATURE REVIEW

Geographic Information System for Transportation (GIS – T)

Sustainable Asset Management of municipal infrastructure assets depends to a large extent on the ability to efficiently share, exchange, and manage life cycle information concerning the assets (Halfawy 2004). It's always easier to manage something knowing what it is, that requires managing. Such is the challenge for today's transportation professionals in government. Today's professionals typically have roads and right-of-ways (ROW's) that are occupied with many types of assets; streetlights, hydrants, sidewalks, signs, furnishings, all having original states of condition and declining rates of condition with age and the environment. Accurate asset records and an understanding of asset behavior are essential for safe and efficient operations and optimal asset management of infrastructure assets. The value of roads and adjacency assets such as sidewalk, underground utilities, culvert, streetlights, signs, etc, can all be calculated over their life span

To improve their operational efficiency, many municipalities want to ensure that their existing asset management systems and any new systems they implement can interoperate and exchange information in an efficient manner (Halfawy 2004). Adopting an adjacency asset model enables municipalities to streamline and coordinate their work processes by integrating workflow from various fields, which would enhance the collaboration among different departments in municipalities.

Modeling is one of the most important parts in a decision making process. Modeling is a way to simplify and abstract data to make the decision process more tractable (Hensher 2000). Transportation problems are becoming more dynamic, consistent with the changes in the complex social, economic, and physical world (Dueker 2000). GIS-T data models are intended to abstract, identify and simplify the relationships and characteristics of the transportation system towards better management and understanding of the existing system (El-Geneidy 2003).

METHODOLOGY

An Overview of the Case Study

The primary function of a municipal asset management system is to maintain the accuracy, consistency, and integrity of the data. A comprehensive municipal asset management system should implement methods to support the efficient modeling, management, integration, exchanging and sharing of data (Halfawy, 2004). Spatial asset data play a key role in the development of an accurate asset inventory and would facilitate the representation and access to other non-spatial data. Therefore, spatial data of the infrastructure asset will serve as a stepping stone in the process of developing a comprehensive and integrated adjacency asset modeling that can meet the aforementioned requirements.

The case study data collected from the city of Fredericton in New Brunswick. The data that are available with spatial references are road network and bridges. For the purpose of this study the road data are divided into four classes and considered as different asset type i.e arterial roads, collector roads, local roads and local named roads. Therefore the total asset type considered are five including bridges.

Study data

In general, the first step was to sort out the various data by asset type (Road type and bridges) and placed them into separate files or tables. Two assets are found with referencing data in New Brunswick ie road network spatial data collected from New Brunswick Department of Transportation (NBDOT) and bridges network spatial data collected from University of New Brunswick. The paper use the available data of assets to develop adjacency modeling tool for transportation asset which can act as a benchmark for the other adjacency assets to be incorporated. The study of the data showed that; each asset data has different referencing system, as bridges uses coordinating system and road network uses linear referencing system.

However, the road network system spatial data are used as a route reference as well as a base layer over other asset data because road networks system covers the whole province network and for the purpose of the study which need to identify adjacency assets along the road network system.

Data Processing

The modeling tool provide a context within a GIS-T that seek to organize all the adjacent assets or facilities into work-zone corridors and use TARMWORTH (software used for transportation optimization) to analyze and develop a process by which rehabilitation work can be scheduled once for a given corridor whenever technically viable and economically justifiable.

Two types of software (Arc GIS and TARMWORTH) were used to analyze the case study data:

Route Reference

The first step is to identify the route identifier for route referencing system as well as base layer where other asset data can be overlaid. The road network acts as a route reference as it covers the whole provinces and can easily be used to identify adjacency assets across it.

Referencing System

Arc GIS requires a common referencing system in order to organize all the adjacent assets or facilities into work-zone corridors. Several groups of assets are overlaid together to produce a set of adjacent assets along the roadway segments (as attributes in a single table). The available assets data tables in different referencing system; That is: bridges and road network use coordinates system and linear referencing system respectively. Linear referencing system was selected as the primary framework for all the assets. The bridge asset data has to be transformed from coordinates system to linear referencing system using Arc GIS software.

Procedure for converting coordinates system to linear reference system:

- Using Arc Map software, the route reference file (road network system) was imported to Arc Map of Arc GIS.
- The bridges data file on Arc Map was added on the same layer of road network system.
- From the Arc Map, the two common reference points represented by both route reference (linear referencing point) and bridges was identified. Two bridges were used to spot their position in the route reference. The linear references of the two bridges were recognized by allocating the exact position in the route reference.
- Using the two common reference points, linear reference points of other bridges were calculated by considering the distance between the two common reference points ("*measure tool*" of Arc Map). The measured distance was then recorded in spreadsheet. Subsequently, the Microsoft excel was used to calculate the linear reference points of all other bridges.

Finally, all the bridges were converted into the same referencing system as the route reference in a single table with other attributes within a spreadsheet.

The new file was saved as bridges linear reference and fig.1; shows the route reference classified by different color representing sixteen counties in New Brunswick province

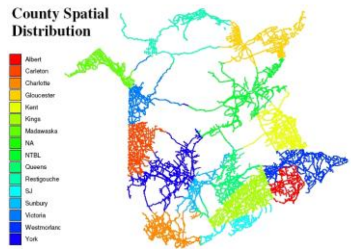

Fig1: A map shows route references of New Brunswick

Once the data is tied to a common referencing system it is easy to use the same data across application as well as to associate diverse data sets previously unavailable for joint analysis.

Data Overlay

In order to arrange all the assets data into one work-zone corridor, the data had to be overlaid into one layer to create a single table that comprises all assets with their attributes.

- In Arc Map software the route reference file (road network system) was imported to Arc Map of Arc GIS.
- Using Arc Map *tool box* / *Overlay Tool* the bridge linear reference file was overlaid into the route reference (by choosing road network system as a *route reference* and roscky as *route identifier key* and measurement as *from measurement - to measurement).*

Finally, all the assets data were incorporated in one single table with their attributes after been exported to a new folder and saved.

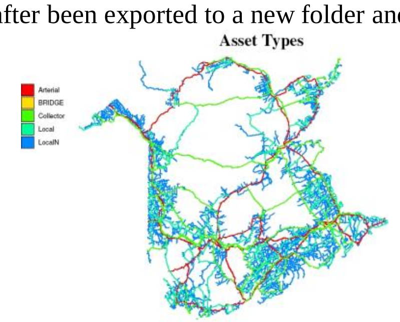

Fig.2: Asset types in color coding

Shapefile Format

Arc Map organize all the adjacent assets into single table (i.e work-zone corridors) and therefore the data has to be exported to transportation optimization software to develop a process by which the timely condition of each assets can be recognized and rehabilitation work can be scheduled once for a given corridor, whenever technically viable and economically justifiable. The data needs to be in a shapefile format in order to enable users to access and query the database visually, and obtain the results displayed directly on a map as a result this functionality can help to eliminate data inconsistency and redundancy, and enable easy data retrieval and update. Moreover, transportation optimization software can recognize and run the data in shapefiles format. Thus, overlaid file has to be transformed into a shapefile format to be recognized and run by optimization software.

TARMWORTH (Transportation Optimization Software)

TARMWORTH is a great and potential software tool in civil infrastructure that can organize and manage multiple assets to ensure maximum benefits. It identifies which and when assets need treatment as well as the cost of each treatment. Most agencies, budget is always limited while the assets continue deteriorating. TARMWORTH helps to process the selection of final set of project, to be funded by transportation agency. It provides decision makers with a set of tool for selecting the subset of projects that optimizes the current resources allocation given that the transportation projects and evaluation criteria are disparate in nature.

The TARMWORTH was run after defining and coding all the information. The projects undergo more critical review by considered number of factors such as assets conditions before and after treatment, treatment cost, time for treatment and type of treatment. It involves assessing and managing tradeoffs between conflicting design objectives. Finally, time and type of treatment for final set of project to be funded were selected.

RESULTS AND DISCUSSION

The use of adjacency modeling tool applications has significantly effect on the operational efficiency and maintainability of municipal infrastructure assets and can be a critical tool in achieving sustainability goals. The Arc GIS software is very useful tool that assist to identify and organize adjacent assets or facilities into work-zone corridors prior to undertake any rehab work. Instead of focusing only on the priority projects, the decision maker will be able to identify condition and the time of rehab for the adjacency assets. Arc GIS prepares a baseline for the TARMWORTH to perform optimization process.

TARMWORTH assists the process of selecting final set of project, to be funded by the transportation agency. This mandates the projects to undergo more critical review, and it is likely that a far larger number of factors need to be considered. However, the software contends financial constraints and high quality of serviceability. It involves assessing and managing tradeoffs between conflicting design objectives and therefore TARMWORTH helps to resolve such conflicts and arrive at a final design. The final output results shows:

Time and space buffer of each asset type
Network Level

The model can show when and where each asset type will require rehabilitation work for the entire network as shown in Figure 3. The color coding shows different years in which a certain asset will undergo rehabilitation work. The information can be used for network planning and managing the infrastructure assets.

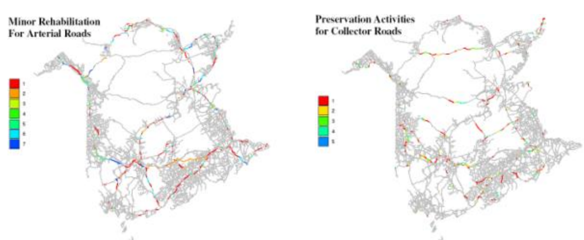

Fig. 3 Types of treatment on different assets for the entire network over period time

Project Level
From the output result, one can find all the assets types in every county that will require a certain type of action in each year over the planned period as shown in Figure 4. The color coding showing different year in which a certain rehabilitation work can be done.

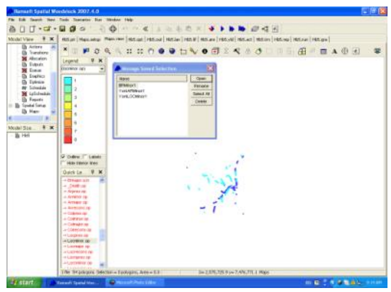

Fig. 4 Location of bridges, arterial, local that will undertake minor rehabilitation in the first year of planning periods at York County (Fredericton).

Therefore by knowing the type of assets, location of assets, type of rehabilitation work and the time at which certain asset will require rehabilitation work, it is easier to plan a work-zone for the adjacent assets to undergo rehabilitation work together whenever it is technically feasible and financially viable.

Cost of rehabilitation on each asset type
The cost of each rehabilitation work has been defined in the output of the software and the results are produced in graph format. We can look at the total cost of each adjacent asset that required at a certain time. This information supports in decision making of budgeting and operation whether to delay or speed up some of rehabilitation work on adjacent asset so as to undertake rehabilitation work together. Fig. 5 and 6 shows a total cost of each asset type that required a certain rehabilitation work in a certain year.

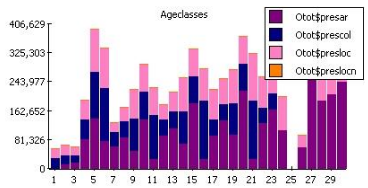

Fig. 5 Total cost of road preservation

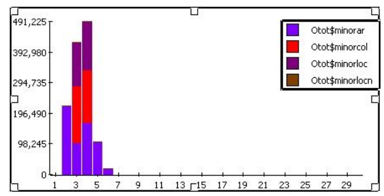

Fig 6 Total cost of road minor rehabilitation

Time buffer condition (life span condition for available budget)

The results output provides the asset type condition over a planning period of 20 years. Agencies had their own way to classify the bridge condition. For the purpose of this paper, I define and coding my condition for bridges to be excellent from (75 – 100) percent. Figure 7 shows the total average bridge condition index over a planning period of twenty years. At first the bridge condition was good then after rehabilitation work of two years, it improves to excellent condition and kept maintained for the overall planning period. Afterwards there is no more rehabilitation work then the bridge condition index starts deteriorating. This helps to understand the overall conditions of assets across the design period.

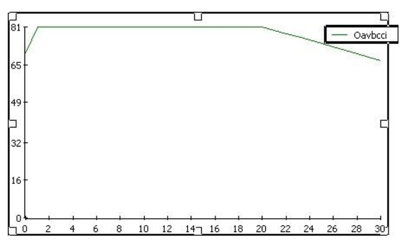

Fig. 7 Average bridge condition index over planning period

The model output can facilitate the task of locating, repairing and updating asset inventories which will minimize cost and time. For example, one could point to one or more assets on the map and identifying adjacent assets, then analyze and schedule inspection / rehabilitation work together, perform the assessment, and update the condition data. This allows a more comprehensive planning and management of undertaking rehabilitation work.

By considering the output results of time and space buffering from York county, one asset type (arterial road) will undertake minor rehabilitation in the first year as well as another adjacent asset type (local road) will need to undertake minor rehabilitation at the same time. These two roads intersect one another and therefore the inspection / maintenance work can be schedule simultaneously.

In addition the model improves work schedule and the overall quality infrastructure, increase quality of service to facility users, and decrease overall rehab costs, including the social and economic impact to road users as it develop a process by which rehabilitation work can be scheduled once for a given corridor, whenever technically viable and economically justifiable.

CONCLUSION

Adjacency asset modeling can plays a crucial role in supporting efficient operations and cost-effective decision-making processes at all levels of municipal asset management. Developing and adopting adjacency asset models of municipal assets is a pre-requisite for enabling the interoperability of municipal asset management systems. This can serve to integrate data across various disciplines, and can facilitate the flow and exchange of information between various parties involved.

Implementing adjacency models for municipal assets can be regarded as a long-term goal that can be realized through a number of incremental steps. Although the initial cost of developing a standard data model is significant, the long-term return on this investment can produce tremendous benefits. The model will improve how schedule of works is currently done and the overall quality infrastructure, increase quality of service to facility users, and decrease overall rehab costs, including the social and economic impact to road users.

The adjacency asset model clearly demonstrates integration of decisions made across all infrastructure assets in order to maximize benefits of a transportation program to its customers (public) and users (employees), based on well defined goals and within available resources (time, man-power, funds, cooperation, knowledge).

However, the adjacent asset model can be used facilitate all other infrastructure asset type which are close to the road network (culvert, water pipelines, sewer pipelines, sidewalk and traffic lights) simultaneously, but due to the data limitation the study use four classification of road and bridges as different asset type for the purpose of demonstrating the usefulness of the model.

Therefore, adjacency modeling tool is the ability to carefully analyze each work-zone corridor within the road network to allow a more comprehensive planning and management of undertaking rehabilitation work. Enabling efficient rehab and management of infrastructure assets plays a key role in supporting the decision-making processes at all levels of municipal asset management: strategic, tactical and operational.

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