Intelligent Transportation Systems Data Warehouses and Their Applications.

INTELLIGENT TRANSPORTATION SYSTEMS DATA WAREHOUSES AND THEIR APPLICATIONS

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Abstract: Archived Data Management Systems (ADMS) offers an opportunity to take full advantage of the data collected by Intelligent Transportation Systems (ITS) devices in improving transportation operations, planning and decision-making at a minimal additional cost. This paper develops an ITS data warehouse, or an ADMS, which can be used to a wide range of applications, such as more effective transportation planning, decision-making and performance measurement, extreme traffic event study, traveller information subscriber system, data support for model development, calibration and validation and so forth. In short, the development of such a data warehouse is going to be beneficial for both traffic management and research purposes.

1 INTRODUCTION

On a worldwide scale, transportation accounts for about 21 percent of CO2 emissions, with surface transportation representing by far the largest source within the transportation sector itself and accounting for more than 90% of the CO2 emissions produced from all transportation modes (Gorham, 2002;EEA, 2003). In the U.S., transportation is responsible for 27 percent of energy consumption, 67 percent of petroleum consumption, and more than one third of the country's CO2 emissions (US Energy Information Administration 2006). With worldwide concerns about energy shortage and global warming, it is no surprise that the transportation profession is leaving no stone unturned in its research for ways to cut down on energy consumption and emissions.

Among the strategies being explored for improving traffic conditions, and hence reducing energy consumption and harmful emissions, are those falling under the umbrella of Intelligent Transportation Systems (ITS) technologies. The basic philosophy behind ITS is to take advantage of recent advances in information technology, communications, and advanced computing to improve efficiency, safety and environmental compatibility. The focus of this paper is on one specific ITS application, namely Archived Data Management Systems (ADMS).

Our data warehouse mainly focuses on the Niagara Frontier Corridor, the border region that encompasses the Niagara River border crossings. In Western New York, it represents a strategic international gateway or corridor of critical importance to trade and tourism flow between the United States and Canada. According to the Canadian Consulate General of Buffalo, approximately 30% of the total Canada-US trade crosses at the Niagara border, along with millions of immigrants and tourists every year. A report by the Ontario Chamber of Commerce (OCC) in 2005 puts the value of the annual land-borne merchandise crossing the Buffalo-Niagara Frontier border at $60.3 billion dollars (OCC, 2005).

An archived data warehouse is an invaluable asset for the transportation systems in Niagara

Frontier corridor, not only for research purposes, but also for traffic management and operation. It supports several applications for improving mobility, sustaining economic development, reducing fuel consumption and minimizing emissions. For example, the data collected could be used to re-time traffic signal systems, which has the potential to reduce vehicle stops by up to 75 percent, with corresponding environmental benefits in terms of fuel consumption and emission reductions. The data could also be used to enhance traveller information systems by providing the added capability of forecasting future condition, especially for the three primary international border crossings in the region. Finally, the Niagara Frontier ITS data warehouse could serve as prototype system for other regions around the State of New York interested in building ITS data warehouse.

Archived Data Management Systems (ADMS) offer an opportunity of take full advantage of the travel-related data collected by Intelligent Transportation Systems (ITS) devices in improving transportation operations, planning and decision-making at a minimal additional cost. ADMS are designed to archive, fuse, organize and analyze ITS data and can therefore support a wide range of multi-layer applications. Examples of such applications include:

(1) Developing more effective operational strategies (e.g. optimizing traffic signal and ramp meters);

(2) Planning for operations and special events (e.g. inclement weather and snow storms);

(3) Enhancing traveller information systems by providing the added capability of forecasting future conditions, e.g. border crossing delay estimation;

(4) Long-term planning and transportation investment decision-making;

(5) Performance measurement benchmarking and reporting.

Given this, an ITS data warehouse is a key component of any integrated corridor management (ICM) approach.

2 LITERATURE REVIEW

The idea of developing ADMS or ITS data warehouse have been officially proposed since 1996 (ADUS Program, 2000; Liu et al, 2002), though the concept itself has been existing for even longer time. Initially, research studies were conducted, aiming at developing standards and guidelines for developing such system. These studies resulted in suggesting best practices for: (1) data archiving and fusion; (2) data screening and imputation techniques; (3) data modelling and mining methods; (4) archived data functions and applications; and (5) data presentation and dissemination techniques, among many other aspects (FHWA, 2009).

Following these research initiatives, several states in the United States took leading roles in implementing ITS data warehouses. For instance, in Maryland, one major objective of the University of Maryland’s Center for Advanced Transportation Technology Laboratory (CATT Lab) is to serve as an AMDS system to meet different data needs from national, state, and local levels (CATT Lab, 2009). In Kentucky, an ADMS has been developed to archive and disseminate the data collected by two ITS deployment, i.e. ARTIMIS and TRIMARC (Chen and Xia, 2007).

Meanwhile, the Portland State Oregon Regional Transportation Archive Listing (PORTAL) system to archive, manage and disseminate real-time loop detector data collected from roadways around the Portland metropolitan area (Bertini, et al, 2005). In addition, Florida and Louisiana are assessing the feasibility of and design the state-wide transportation data warehouses (same concept as ADUS but different name) for the purposes of archiving, modelling, and disseminating ITS data (The Florida Department of Transportation, 2008; Buckles, et al, 2008).

Other examples that have similar concepts but a bit different focus include the California Freeway Performance Measurement Project (PeMS), the data archiving practice in the Minnesota Traffic Management Center, the Archived Data Management System (ADMS) and Cubeview in Virginia, and the Traffic Data Acquisition and Distribution (TDAD) in Washington (ADUS Program, 2000). It is interesting to see that the majority of these systems are housed at research Universities to take advantage of the research resources there.

With respect to the development and applications of ADMS or ITS data warehousing systems, the State of New York has lagged behind other states around the country. Though some studies have been done to identify the needs and the potential resources of ITS-generated data (Lawson, 2003; Hu, et al, 2001), no complete plan has been made to apply the concept of ADMS in New York State.

For example, in the Greater Buffalo-Niagara area, key traffic data such as traffic counts, travel time, accidents, and border crossing delays are separately collected and maintained by different transportation organizations, and no formal data integration and archiving mechanism currently exists due to institutional, technical or budget barriers. This situation hinders the full realization of the utility of ITS data for transportation operations, management and evaluation. With an ITS data warehouse, transportation operators, planners and researchers would be able to make better decisions that can enhance the mobility, safety and sustainability of transportation systems.

3 ITS DATA WAREHOUSE

3.1 Architecture

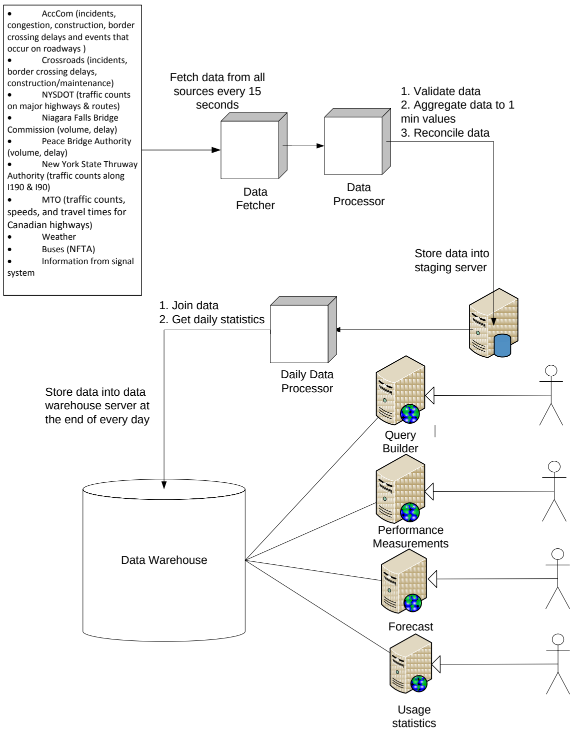


Figure 1: Data warehouse structure

Figure 1 above shows an overview of the ITS data warehouse for the Niagara Frontier Corridor. As can be seen, the data warehouse is envisioned to serve as a data repository for a wide range of useful traffic-related data streams. Those data are transferred, processed and archived in the data warehouse, where the end users are able to perform a one-stop data query to retrieve the data they are interested in. So far, the ITS data warehouse system has archived or is planning to archive the following data and data sources soon:

- Traffic volume on major arterial and freeway with hourly interval (Figure 2);

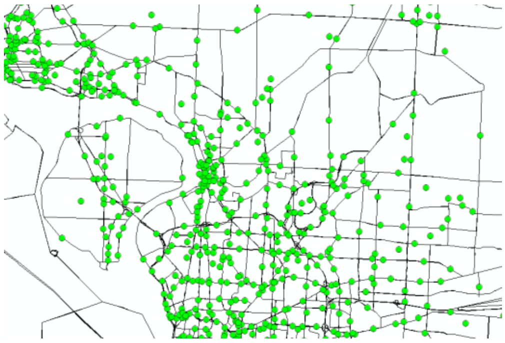


Figure 2: Count Station distribution

- Incident data from two databases maintained by NITTEC, namely the Incident log and the help log which contain information about the incident location, start time, end time and so forth (Figure 3);

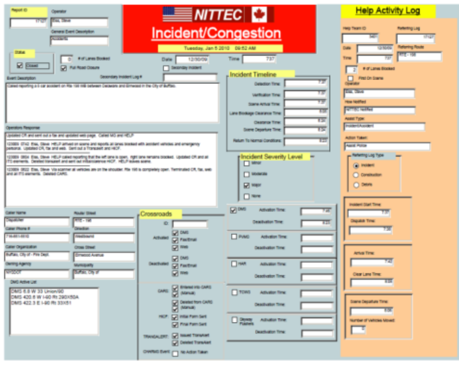


Figure 3: Incident log and help log

- Weather data (e.g. temperature, Hourly precipitation, visibility, etc.);
- Turning movement counts at major intersections;
- Travel Time Data from the TRANSMIT system, which uses roadside readers to identify EZ pass or toll tags (Figure 4); and

Figure 4: TRANSMIT travel time links

- Border crossing delay (delay time of US-Canada border);

3.2 Star and Snowflake Schema

Most of the data are stored as the classic STAR Schema. This is because the primary referencing system used within the data warehouse is link based, which means that most of the data, except some node–based data like intersection turning movements, could be related to a certain link. For instance, when an accident happens, the incident log and help log would record its location and this location is joined to the specific link in the data warehouse as Figure 5 shows.

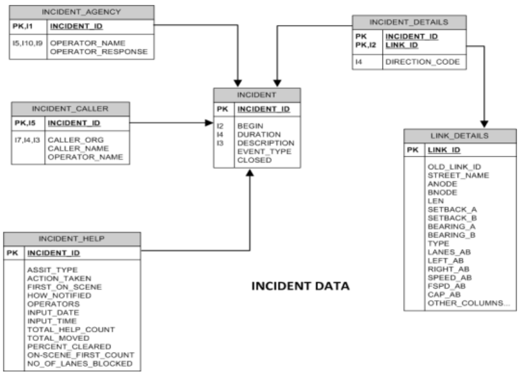


Figure 5: Star Schema for incident log

Another schema which is also utilized within the data warehouse is the snowflake schema, which while similar in many aspects to the STAR scheme, is slightly more complex. In the snowflake schema, dimensions are normalized into multiple related tables (Figure 6).

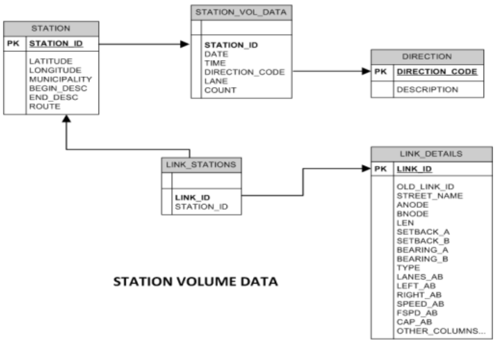


Figure 6: Snowflake Schema for Count Station

3.3 Data Import

Since the data warehouse will be archiving a wide range of data resources, each using a different kind of format (e.g. XML, spreadsheets, text files and so forth), a standard procedure for importing and archiving all of these data streams into the database was needed.

The import process was designed to automatically extract raw data into the archived format on a regular basis. For example, NITTEC would dump the incident XML files onto the server everyday via a scheduled script; our program detects the new files, process them and archive all the information into the data warehouse. All of these processes can be done via the scheduled batch files.

3.4 User Interface

The user interface of the data warehouse connects the database and the end user. So far, a simple web interface, implemented using GeoServer in order to provide for a geographic map for users to select graphically the route segment they are interested in, if provided. The interface supports the following services: historical data query, traffic data on selected roads (Travel times, volume), real-time travel time and incident mapping and so forth. Other functionality will be developed according to the demand of the users. End users could click the query routes they are interested in, and select the specific type of data they are looking for as well as favourite time slot as Figure 7 demonstrates.

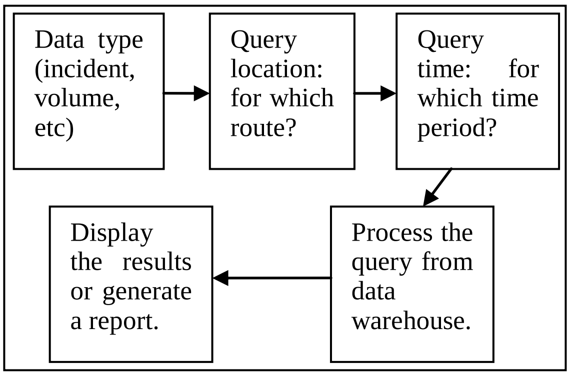


Figure 7: Query procedure of the system

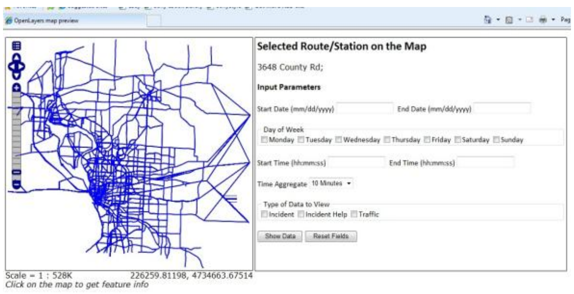


Figure 8: the user interface window

4 APPLICATIONS

4.1 Transportation System Performance Measurement & Management

First of all, a comprehensive network performance measurement system could be developed based on the travel time, border delay and other traffic data archived in the data warehouse. In other words, transportation agencies like NITTEC could use the measurement system to better communicate the "state" of the transportation system to the public and policy makers. Moreover, these performance measures indices can be used to identify potential issues in the current system, and thus help the transportation agencies to develop effective operational and management strategies to improve mobility and reliability of the transportation system.

Secondly, traffic signal optimization could be conducted with the data archived in the systems. Several recent studies of signal optimization and coordination show reductions in the number of vehicle stops, as a result, ranging from 6 to 74%, with the magnitude varying depending upon the congestion level (Sunkari, 2004). Studies also show that reducing the number of vehicle stops could have significant positive environmental impacts.

In addition, the archived data could be mined to gain useful insight into the transportation system performance and its problems. For example, a report could be generated to provide a summary of the frequency and time slots of the incidents on a certain routes, and to study whether there is any common factor among them. Besides, one could study the impact that incidents have on the transportation system performance, and how long it typically takes to clear incidents, and bring operations back to normal.

Other than the applications aforementioned, we are currently performing a research study to develop predictive models for border crossing delays.

4.2 Extreme Traffic Events

The Greater Buffalo Niagara region is well known for its winter weather which is characterized by numerous and sometimes severe 'lake-effect' snow storms. These events result in significant delay and increase the frequency of accidents. The data stored within the data warehouse can provide an opportunity to better understand the impact of such events on the transportation network, and hence can help in devising emergency plans for dealing with such disrupting events.

The Transportation Analysis and Simulation System (TRANSIMS) is an integrated, open-source set of transportation planning models designed to provide a number of capabilities that go beyond the traditional "four-step" modelling process. The TRANSIMS framework has four components: a population synthesizer, an activity generator, a route planner, and a micro-simulator. Also, the area has recently been selected as one among a handful sites nationwide for the test deployment of the TRANSIMS model, focusing on freight border-crossing issues.

On Dec 2nd, 2010, for example, a severe snow storm hit the south Buffalo area, which forced the New York State Thruway Authority to shut down the Thruway (I-90) for several hours (see Figure 9).

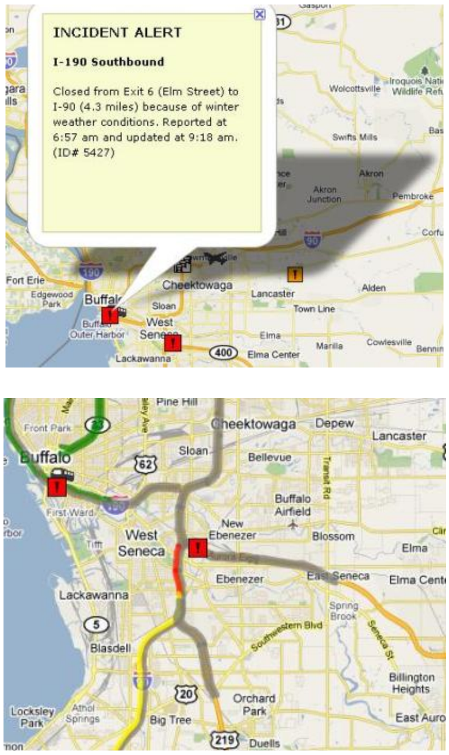


Figure 9: I-190 closure on Dec 2nd, 2010

The data stored can thus be used to study how traffic flow behaviour and patterns change during such events, and then to devise effective management strategies for dealing with such situations. We are currently in the process of correlating the archived weather data to TRANSMIT travel time information to perhaps develop models that show us how travel time or traffic speed changes with the different weather and road conditions

4.3 Traveller Information System

In a related effort, we developed a system called MYNITTEC, which is a personalized subscriber traveller information system that allows users to receive customized real-time traveller information in Western New York and Southern Ontario via text messaging and/or email. Subscribers have the ability to select specific expressways, days of the week and times of day to correspond with your travels.

The way MYNITTEC works is simple. Users choose their favourite routes and time spots as their unique travel profiles. Each travel profile allows the user to receive personalized notifications from the system. The data warehouse could help enhance the traveller information system by providing both predictive information and more detailed route performance measurement. On the other hand, MYNITTEC collects some useful information about travellers in the Western New York region (e.g. their preferred routes, times of travel). This information will also be stored within the data warehouse and can be mined to understand certain aspects of travel behaviour in the region.

Figure 10: MYNITTEC subscriber system

4.4 Model development, calibration & validation

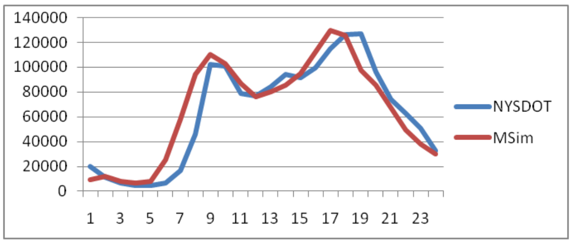
4.4.1 Model development

Aside from the traffic data archived in the data warehouse (i.e. traffic volumes, travel times, accidents, etc.), the data warehouse also includes very useful static information about the attributes of the transportation network. For example, the system has stored very detailed link attributes, like the number of lanes, pocket lane, length of the links and so forth, which provides an opportunity to automate and facilitate the process of developing traffic simulation models to support the different traffic studies in the region.

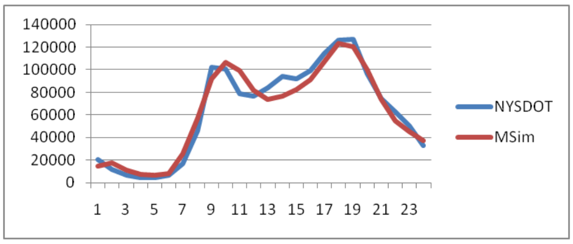
As we know, there are all kinds of simulation models, such as AIMSUN, CORSIM, PARAMICS, VISSIM and so forth. Although some of them are macroscopic model, some are mesoscopic or microscopic model. One thing they have in common is that they all require a network to build the model on, although they all have their own network file format. Therefore, another direct application of data warehouse is the model development based on the network information we've already archived. In other words, if we are able to transfer the network information into the format a simulation software could read, it could make model development a lot easier instead of an extremely time consuming process especially for large-scale networks.

4.4.2 Model Calibration & Validation

After a simulation model is built, large volumes of data are required to calibrate and validate the simulation results. In that regard, the ITS data warehouse plays a significant role as a data provider. We are actually currently doing exactly this in a research project to develop and calibrate a large-scale TRANSIMS model, an agent-based model originally developed by Los Alamos National Lab, of the Buffalo-Niagara region. Within the subarea we are modelling in TRANSIMS Micro-simulator in TRANSIMS, there are 193 count stations. The following example is to just give a simple idea how the data warehouse could benefit us. We summarized the 24-hr trip distribution based on all of those count stations between the model and reality. As the curves in Figure 4.1 shows, they are much closer to each other after the calibration than they used to be.



Before the calibration



After the calibration

Figure 11: Trip Distribution of TRANSIMS model and field counts before and after the calibration

5 CONCLUSIONS

The archived ITS data warehouse for the Niagara Frontier Corridor supports a wide range of applications designed to improve mobility, sustain economic development and reduce fuel consumption and emissions. The benefits associated with the different applications of the data are detailed below:

- The data archived in the system support the development of a comprehensive performance measurement framework for the area, especially for the international border crossings, and their associated delays. The data warehouse could also support signal optimization, which not only improves the transportation system, but also reduces the tail-pipe emission as well as fuel consumed ;
- The data warehouse provides traffic data and weather information to better understand the impact of the extreme events like inclement weather on the traffic and driving behaviour;
- The data can also enhance traveller information systems in the region by adding a predictive component to the traffic data provided;
- The warehouse can also support the development and calibration of traffic simulation models; and The Niagara Frontier ITS data warehouse could serve as a model deployment for other regions around the State of New York, which would benefit from the lessons learnt from this study.

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