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ArcPad Applications Development

Mobile GIS Applications for Municipal Pavement and Sidewalk Asset Collection and Management

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ABSTRACT

The City of Toronto Transportation Services Division needs field data collection applications that can be used to collect field data related to Transportation assets such as pavements and sidewalks. ESRI ArcPad 6.0.3 was customized to design the field data collection tools using ESRI ArcPad Application Builder 6.0.1. ESRI ArcGIS 9.0 was used to manipulate the supporting spatial dataset.

The Municipal Pavement Management Application (MPMA) is a third party application developed by Stantec Consulting Limited. The MPMA provides required standardized attributes and historical data related to the City's transportation assets that are exported to the customized ArcPad application. The customized ArcPad tools are then used to select and identify segment information by the surveyor for verification and to collect new condition records including visually observed pavement and sidewalk defects. Pavement and sidewalk condition index calculators are built into the ArcPad customized application thereby allowing the surveyor the ability to verify overall conditions based on City and industry accepted procedures. Standalone DBF tables are the output from the ArcPad application.

The MPMA is used to import DBF tables for database inventorying and further analysis. The condition index data and individual distresses can be used to determine the priorities and to provide recommendations for pavement and sidewalk rehabilitation and maintenance strategies. In addition, ArcGIS can be used to manipulate the collected field data.

INTRODUCTION

Background

On January 1, 1998, the new City of Toronto along with 2.6 million people covering 620 square kilometers came into existence by the amalgamation of seven municipal governments. The new City's Transportation Infrastructure serves the needs of residents, businesses and thousands of visitors annually.

Amalgamation brought with it the need to harmonize numerous activities, processes, and services within the City, not the least of which was the management of the Transportation Infrastructure by the Transportation Services Division (Transportation).

From 2001 to 2002, Transportation retained Stantec Consulting Limited (Stantec) to provide engineering services to database existing City data within and customize their Municipal Pavement Management Application (MPMA) computerized information system to suit the City's needs. The MPMA stores a vast quantity of pavement related data in a fashion that can be easily retrieved for purposes of editing, reporting and analysis of pavement data. During the original MPMA project, the City developed customized modules to store information for other hard surface assets, referred to as peripherals, such as sidewalks, curbs and boulevards, to name a few. Since 2002, the City has continued to work with Stantec on additional customized tools such as an embedded ArcExplorer module and import/export tools related to field surveys.

Street segments within the MPMA, identified as MPMA Sections, are based on pavement characteristics such as work history, geometry, and road classification. For each street segment

record, additional peripheral data is appended as illustrated in Figure-1. The City's MPMA database contains in excess of 27,300 street segments that represent about 5,450 kilometres of roads. Associated with the street segments is an inventory of about 7,100 kilometres of sidewalks.

Figure-1: Example of the MPMA detailed view/edit interface.

Field Data Collection

Field surface distress data collection surveys for pavement management applications such as the MPMA may be conducted using either the windshield method or by data collection equipment (typically provided through third party vendors). The windshield survey method consists of identifying the Severity [EN1] and Extent [EN2] of observed pavement or sidewalk surface distresses within the specified segment.

Surveys using data collection equipment allows for the detailed collection of data but typically requires significant post-collection data reduction to determine specific distress types, severities, and quantities and can be costly. For the purpose of network level data collection, the City employs trained staff to complete windshield surveys. The applicability and use of detailed data collection at the network level is limited within the City.

SURVEY METHODS AND CHALLENGES

When the City amalgamated the use of then-existing methods and systems was suspended as staff investigated opportunities for their harmonization. In some cases, significant backwards steps were taken in order to start from some common ground.

The various pre-amalgamation cities had employed manual, semi-automated or fully automated survey methods for field data collection. However, no agreement could be made to employ one of the existing systems to the newly amalgamated City. Ultimately, the City retained Stantec to provide and customize the MPMA. However, in the interim, day-to-day work continued and the evolution of the field surveys was initiated by staff searching for methods to complete this work in a cost-effective and reliable manner. The following paragraphs describe the systems and methods that led to the development of the new and all-encompassing ArcPad/Stantec MPMA collaboration and the selection of ArcPad customized applications for field data collection.

The manual method of survey consisted of pen and paper with manual data entry required in the office following the field survey. The surveyor would record details of the pavement or sidewalk location, type, width, and length and then identify the severity and extent of any observed distresses. The necessary information was recorded on a survey form accompanied with the location sketch as illustrated in Figure-2.

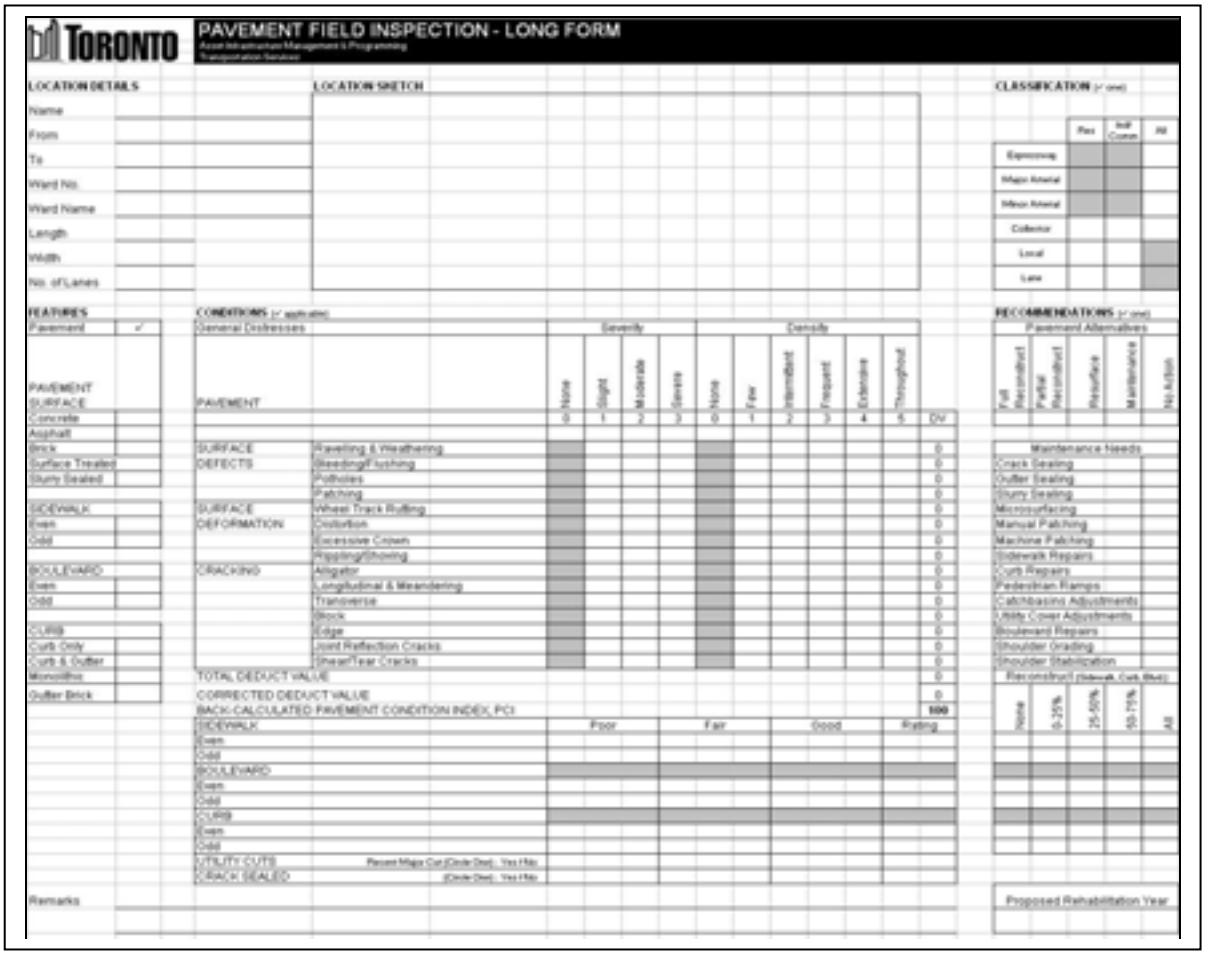

Figure-2: Traditional pen and paper survey form, October 2000

With the introduction of ArcView 3, City staff developed forms whereby the segment locations could be identified and mapped and then field observations could be recoded in a table embedded with the map layout as depicted in Figure-3.

Figure-3: ArcView 3 map and data collection table, 2002-2004

The main drawback of using paper surveys, as illustrated in Figures 2 and 3, is the significant amount of time required to set up the field survey forms in advance, record data, and then reduce the data. The collected data must be manually updated into the MPMA database and the condition rating values must be calculated. This process is very time-consuming when there are numerous paper surveys.

To overcome the use of paper based survey forms, staff reviewed previously employed semi-automated or fully-automated computer programs that were used prior to amalgamation. These types of systems were only available for pavement management systems. At the time, sidewalk management systems did not exist nor were they considered as critical an asset as pavements to manage. An example of a fully-automated pavement management application field form, previously used by the Municipality of Metropolitan Toronto, is illustrated in Figure-4.

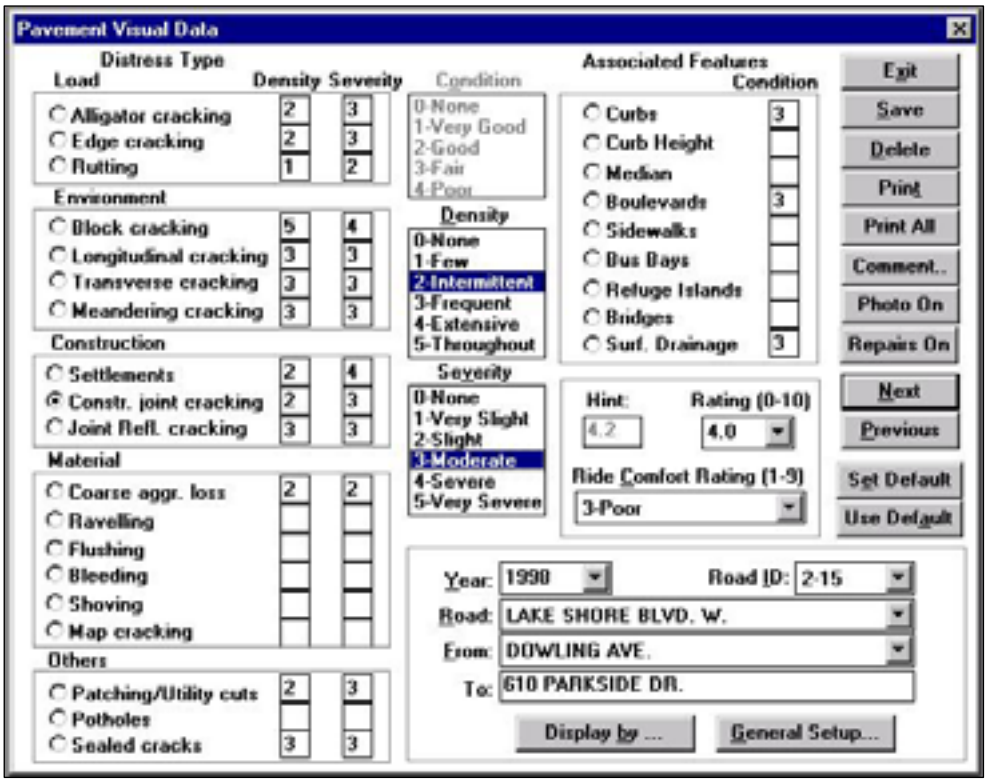

Figure-4: Field pavement survey form from the former Municipality of Metropolitan Toronto, 1994

City staff then created Microsoft Excel Spreadsheet forms for field data collection that could be used across the entire city. These forms allowed for automated data collection, but required setup in the office prior to surveys (although significantly less time consuming than previous paper-based surveys), maps to be followed in the field, post-survey data validation, and back-loading data into the MPMA.

This post-survey work was time consuming, required significant data validation and resulted in a time void in the updated data within the MPMA for up to one year based on the timing of backloads. Examples of the Excel based data collection tools are illustrated in Figure 5A and 5B for pavements and sidewalks, respectively.

Figure-5A: Microsoft Excel based pavement survey input screen

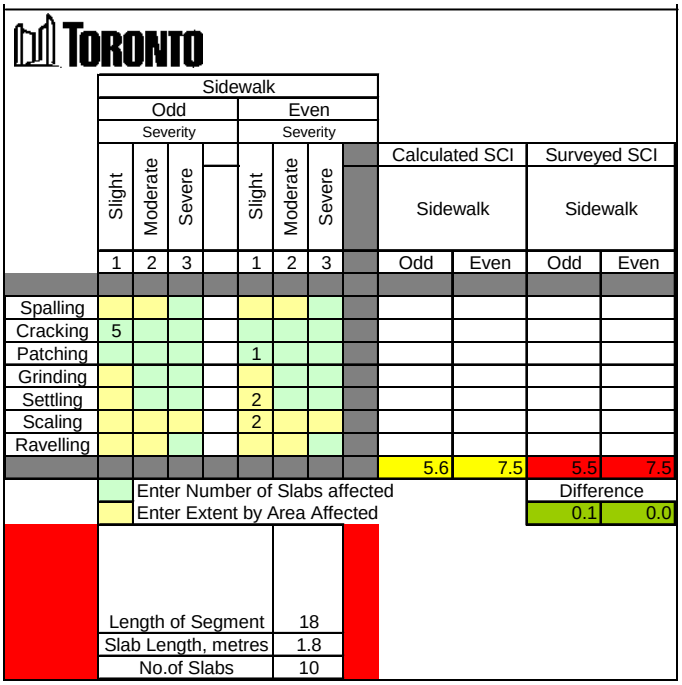

Figure-5B: Microsoft Excel based sidewalk survey input screen

It should also be noted that staff developed survey guidelines for sidewalks that included methods to calculate condition indexes based on commonly observed sidewalk surface distresses. These sidewalk methods are the same as those used for pavements, however, modified and calibrated to reflect sidewalk characteristics within the City [COT].

In the interim, the Geographic Information System (GIS) was becoming a more and more common tool for Transportation. It was being used in all facets of operations, from creating the City's Road Classification System to identifying snow plowing routes and setting levels of service across the City. Within the pavement management and capital programming areas, staff were creating maps to be used for field surveys (as shown in Figure-3) and mapping capital works programs for the City and utility projects.

To overcome the main drawbacks of the existing situation, consisting of the time-consuming pre-survey set up, post-survey data reductions, and back loading data, a full functioning field data collection module using GIS was contemplated for the MPMA system by customising ESRI ArcPad 6.0.3 Software.

In addition, a relationship needed to be developed between the sectional road segments within the MPMA database and the linear features of existing City of Toronto Centreline (TCL) fabric for the road network. This work included relating the 27,300 MPMA segments to 44,500 TCL arcs. The project to develop the relationship took a period of three years (2003-2005). At this time, more than 98% of the systems are related with only limited data verification and ongoing regular maintenance required. It is anticipated that annual geo-coding maintenance of 500–1000 arcs is required to reflect changes to the roadway network that continuously occur in a city the size of Toronto.

When Transportation decided to investigate and implement a GIS based data collection tool, staff recognized that in-house expertise and resources were available to undertake the work with Stantec. The City approached Stantec to work jointly on a project to further customize the MPMA to be able to export appropriate fields of data and then import the field survey data back into the MPMA for a seamless operation. Ultimately, the MPMA system and the Customized ArcPad Applications (GIS Component for MPMA) stand as two separate systems. Both systems exchange/share the data in database file format (.dbf file format) that is compatible for both systems.

ARCPAD APPLICATIONS (GIS COMPONENT) FOR MPMA

ESRI ArcPad™ software has designed as a low-cost solution for Mobile GIS Technology for field mapping and field data collection applications. ArcPad enhances portable touch screen computers with intuitive mapping, GIS and Global Positioning System (GPS) functionality. ArcPad provides database access, mapping, GIS and GPS integration to field users via handheld devices (e.g.: Pocket PCs, Palm Pilots, etc.) and mobile devices (e.g.: Tablet PCs, Laptops, etc.). Data collection with ArcPad is fast, easy, efficient, and significantly improved with immediate field-based data validation and availability [ESRI].

On a request made by Transportation, the City's Data Integration Services (DIS) designed and developed Customized ArcPad Applications for the MPMA by creating Customized Tools,

Electronic Data Collection Forms, and Sidewalk and Pavement Visual Condition Index (VCI) Calculators using ESRI ArcPad Application Builder (Studio) 6.0.1.

The tools are implemented in ArcPad as a customized applet to the software. Stantec MPMA Design Specifications and Guidelines [SC2] were used to design the two standalone databases that are used to save the collected field data. The application deploys on TabletPCs or Laptops with the corporate datasets required for the field surveys. Figure-6 illustrates the conceptual diagram of the "System" designed to enhance the MPMA.

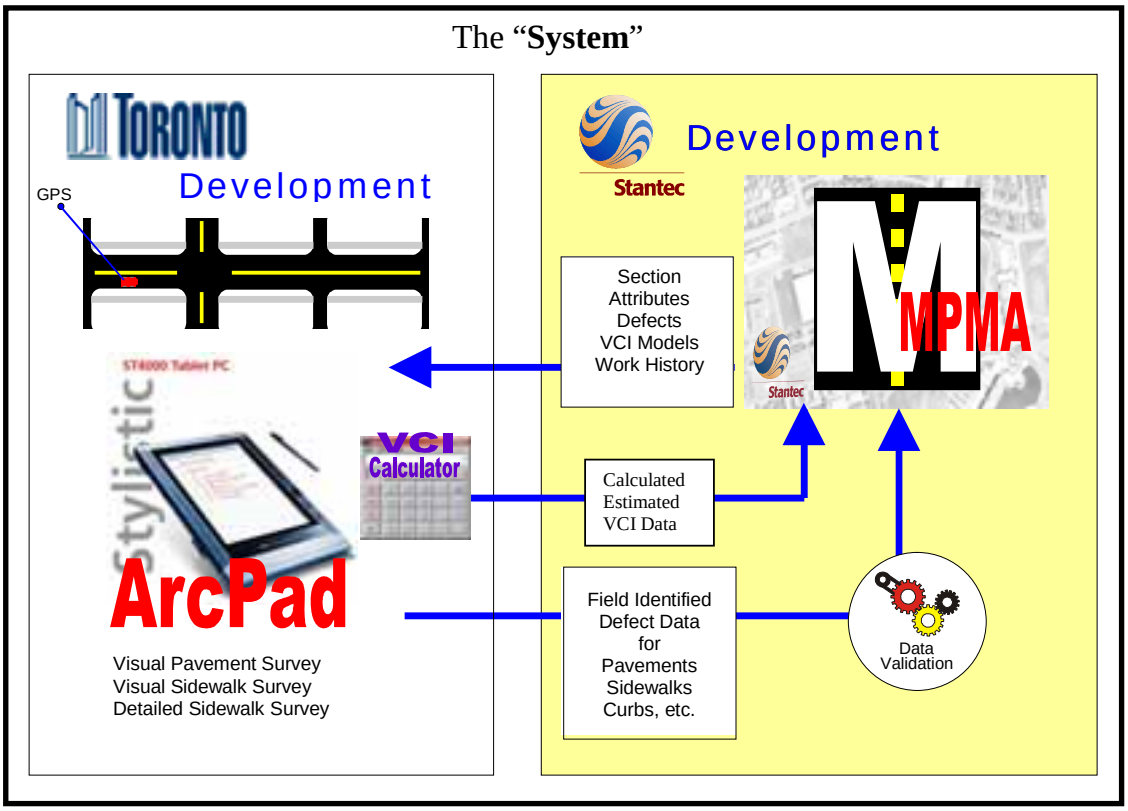

Figure-6: Conceptual diagram of the 'System' designed to enhance MPMA.

DIS developed two types of ArcPad applications for the Transportation. These include:

- Visual survey tools for both pavement and sidewalk windshield surveys
- Detailed survey tools for sidewalks

The windshield visual survey is conducted by either a drive-by of the site in a vehicle or by walking the site. The windshield survey is the most commonly used method in the field and is described in the following sections.

Sidewalk and Pavement VCI Calculators

One of the key features of this customised ArcPad applications was the integration of the condition index calculators. The calculators are built-in as a part of the sidewalk visual survey and pavement visual survey ArcPad electronic forms.

For different types of surface distresses, the severity level and extent range is assigned by the surveyor using the dropdown lists exist in the VCI calculators. The calculators calculate sidewalk or pavement condition index ratings on the fly as the visual field observations are recorded. The condition index calculations are based on an industry standard method called the MicroPAVER system [MYS]. The theories and the formulas used for the calculations are explained in detail in the Appendix.

FIELD SURVEYS USING CUSTOMIZED ARCPAD TOOLS

Customized Search, Reference, and Redline Toolbar and Tools

Customized Search, Reference, and Redline tools that the surveyor finds useful and assists in the surveys include search locations by street address or street intersection, manage reference layers, and redline features. Figure-7 shows the Customized Search, Reference, and Redline toolbar and the tools that were built as a customized applet to the ArcPad application.

Figure-7: ArcPad Customized Search, Reference, and Redline Toolbar and Tools.

Examples of the customized reference layer management tool and standard ArcPad identify tool are provided in Figure 7A, 7B and 7C. The surveyor will typically start with limited layers in order to find the general location as illustrated in Figure 7A.

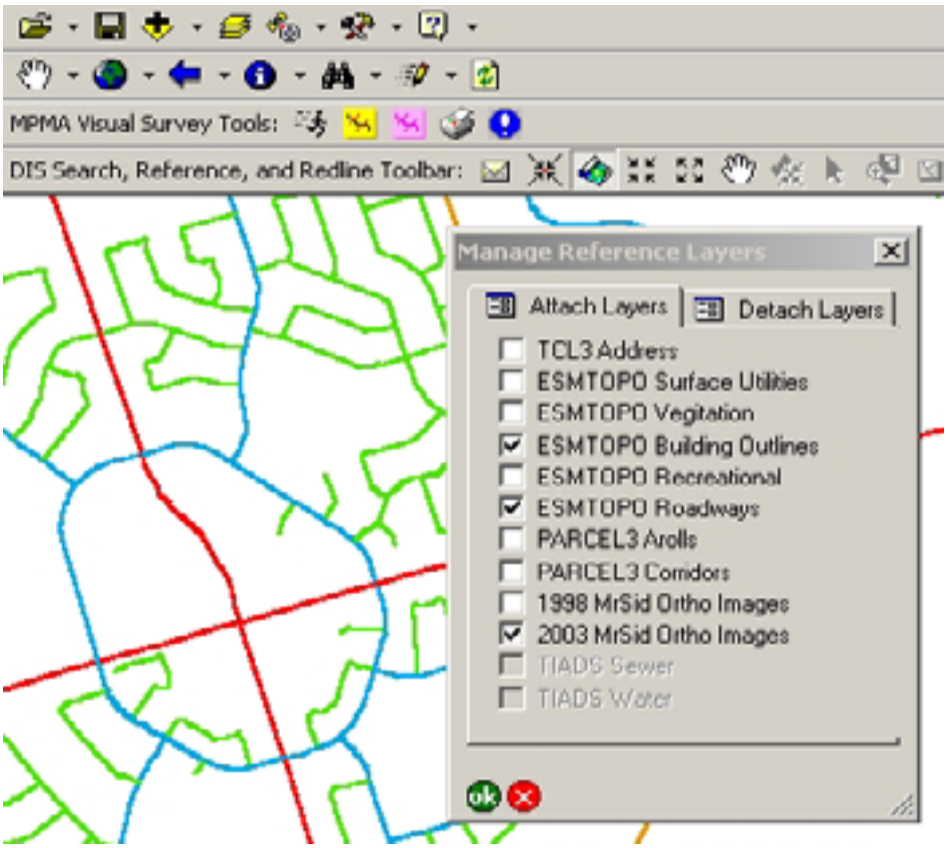

Figure-7A: Map with TCL and reference layer management tool enabled

Once at the right location, the surveyor can attach additional layers as required (see Figure-7A) using the customized Reference Layer Management Tool (3rd tool from the left) to produce a map as shown in Figure-7B. This tool allows attaching or detaching the City's tile based geospatial data as reference layers to an ArcPad map. Reference data includes orthoimages, curbs, building outlines, surface, utilities, parcels, etc. Using the standard Identify tool, the surveyor can also determine feature properties as shown in Figure-7C.

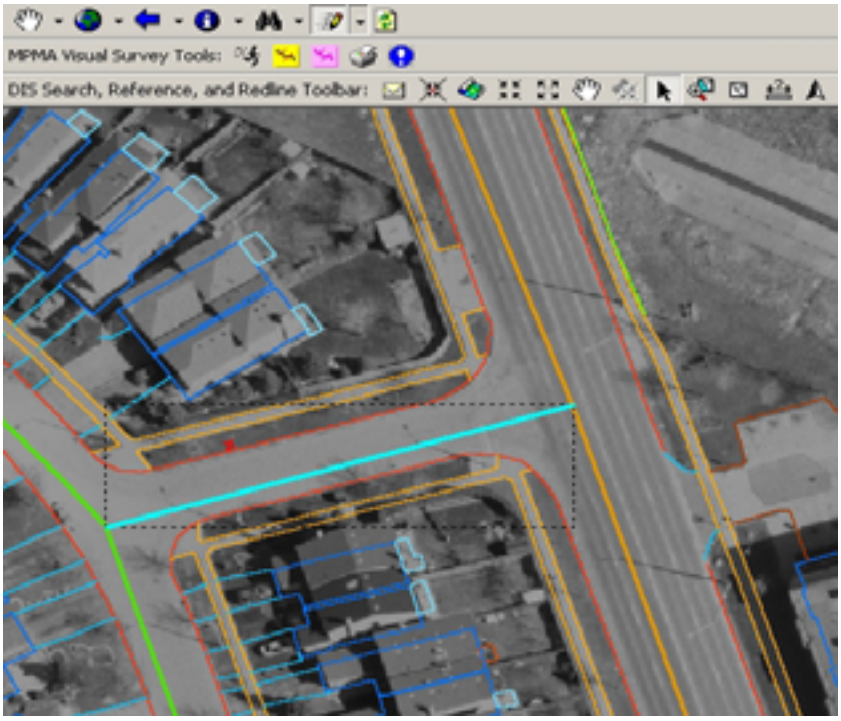

Figure-7B: Additional reference layers attached to the map.

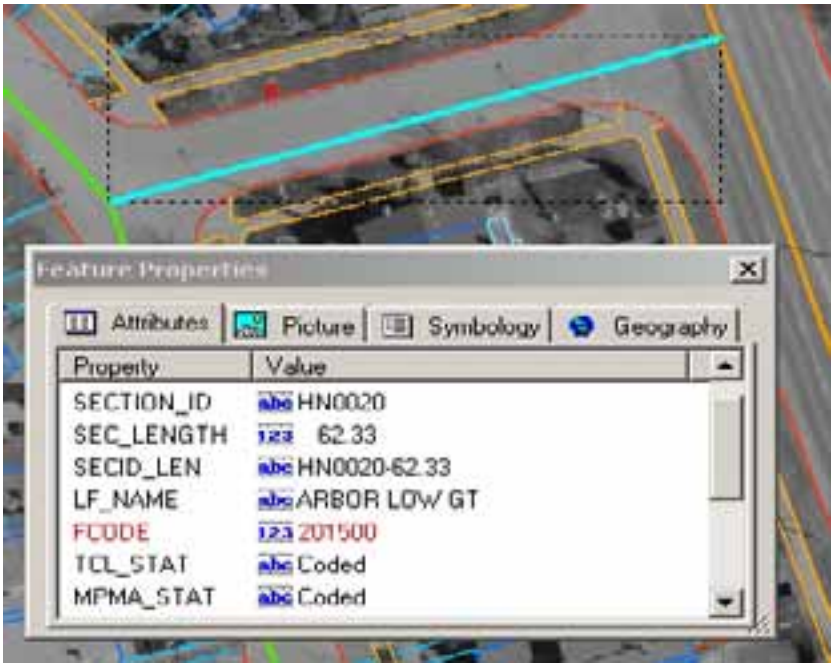

Figure-7C: Map with standard ArcPad identify tool enabled

ArcPad Visual Survey Customized Toolbar and Tools

Figure-8 illustrates the customized ArcPad Visual Survey Toolbar (VST) designed for the MPMA Windshield Surveys. This toolbar is loaded as a customized applet to ArcPad.

Figure-8: ArcPad customized toolbar for MPMA windshield visual surveys.

The first customized tool (from left in VST) is used to identify and locate a road section called MPMA Section on the ArcPad Map Document. The ArcPad Map Document contains a collection of layers that make up the map. This tool allows user to search for a MPMA Section and navigate to the section location. MPMA Section is a road segment that has been given a unique identification number in the MPMA system for field surveys and data management purposes.

The TCL segments that have been given the same MPMA Section IDs are joined into single MPMA sections to create a customized shapefile; this shapefile is used to search and locate a MPMA Section on the ArcPad map as illustrated in Figure-9.

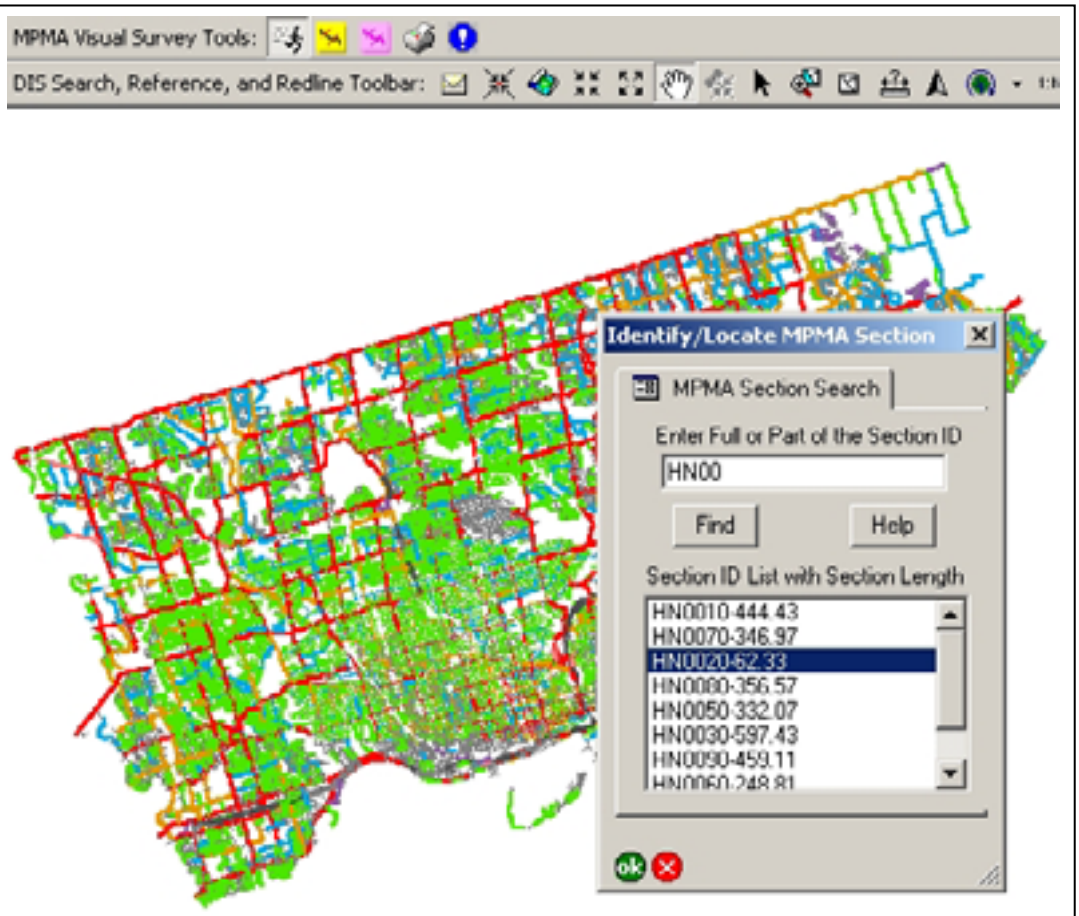

Figure-9: Example of the MPMA section search tool with searched results.

An example for a located MPMA section from the search results shown in Figure-9 is displayed in Figure-7B (highlighted by a dotted rectangle), with the City's geospatial data attached to the map to assist in the field surveys.

Windshield Visual Surveys for Sidewalk

The second customized tool (from left in VST) is used to identify a MPMA Section for sidewalk survey. Once the field surveyor identified a section, sidewalk items (PeriKeys) associate with this section will be listed in the ArcPad form as displayed in Figure-10

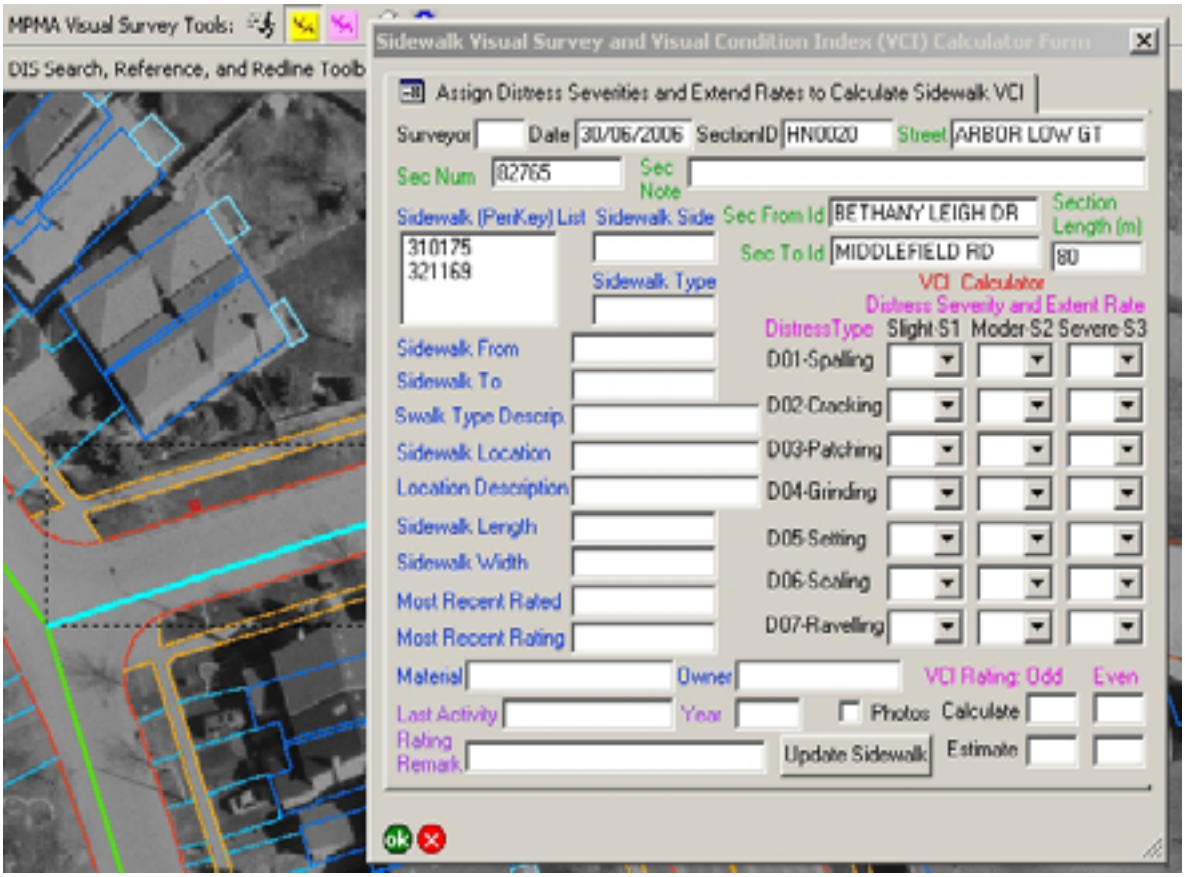

Figure-10: Windshield ArcPad form for sidewalk visual survey.

Next, the surveyor can select a sidewalk item from the 'Sidewalk (PeriKey) List' as shown in Figure-10; the historical data related to the selected sidewalk item will be populated in the form as shown in Figure-11. If the historical distress data is available for a selected sidewalk items, those attributes will also be populated on the VCI calculator for the field update.

The surveyor can assign the severity and extent rates for each observed sidewalk distress using drop down lists exist in the VCI calculator. At the same time the built-in condition index calculator will automatically calculate the sidewalk visual condition index (VCI) rating for the selected sidewalk asset. The sidewalk distress extent range number is estimated instead of converting the recorded number of slabs. The VCI Calculator in Figure-11 shows how the VCI rating is calculated and displayed on the form as the observed distresses are recorded.

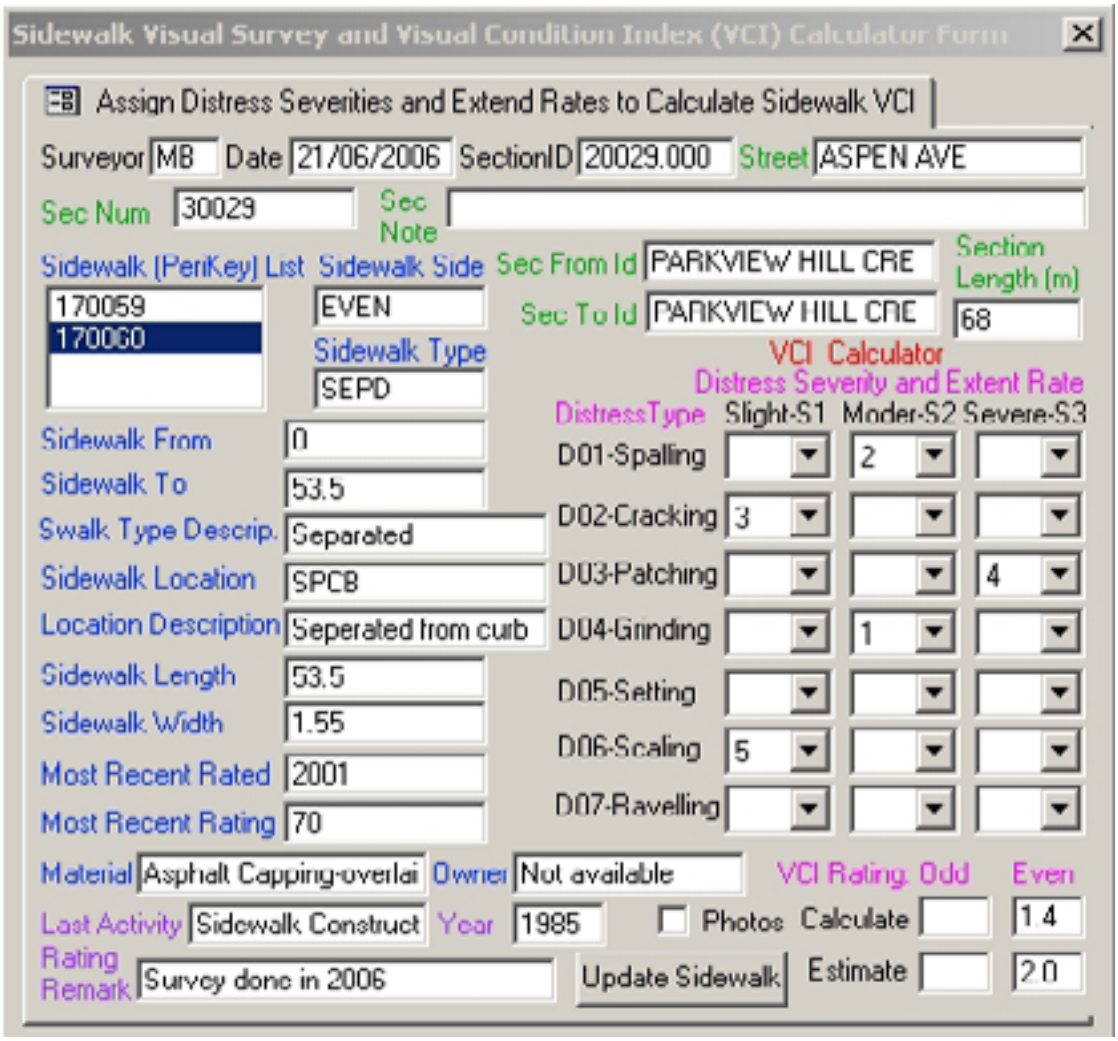

Figure-11: Example of the calculated sidewalk condition index.

The calculated VCI may not encompass all cases, so an experienced surveyor may need to subjectively assign an estimated VCI value by observation (using Appendix Table-1).

To complete the field survey for a sidewalk item, the surveyor should click (or tap with the pen) on the Update Sidewalk button on the form. The recorded distresses, calculated and estimated condition index rating values, and other required information (e.g., surveyor, date, remarks, etc.) will be saved to the external standalone database file called sidewalk distress table, SW_DIST.dbf, on the TabletPC's hard drive. The surveyor can then select another sidewalk item from the 'Sidewalk(PeriKey) List' to continue the field survey on the same MPMA section or close the form via form's OK button to identify another MPMA section in a different location.

At the end of field surveying, the MPMA system field data import tool is used to import the sidewalk survey database file SW_DIST.dbf into the MPMA system.

Windshield Visual Surveys for Pavement

The third customized tool (from left in VST) is used to identify a MPMA Section for pavement survey. The methods and the techniques used for the pavement windshield visual survey is similar to the sidewalk survey except that only one survey can be completed for each section and there are more types of surface distresses for pavements. When the surveyor selects a MPMA Section for pavement survey the historical data and section characteristics are displayed as shown in Figure-12.

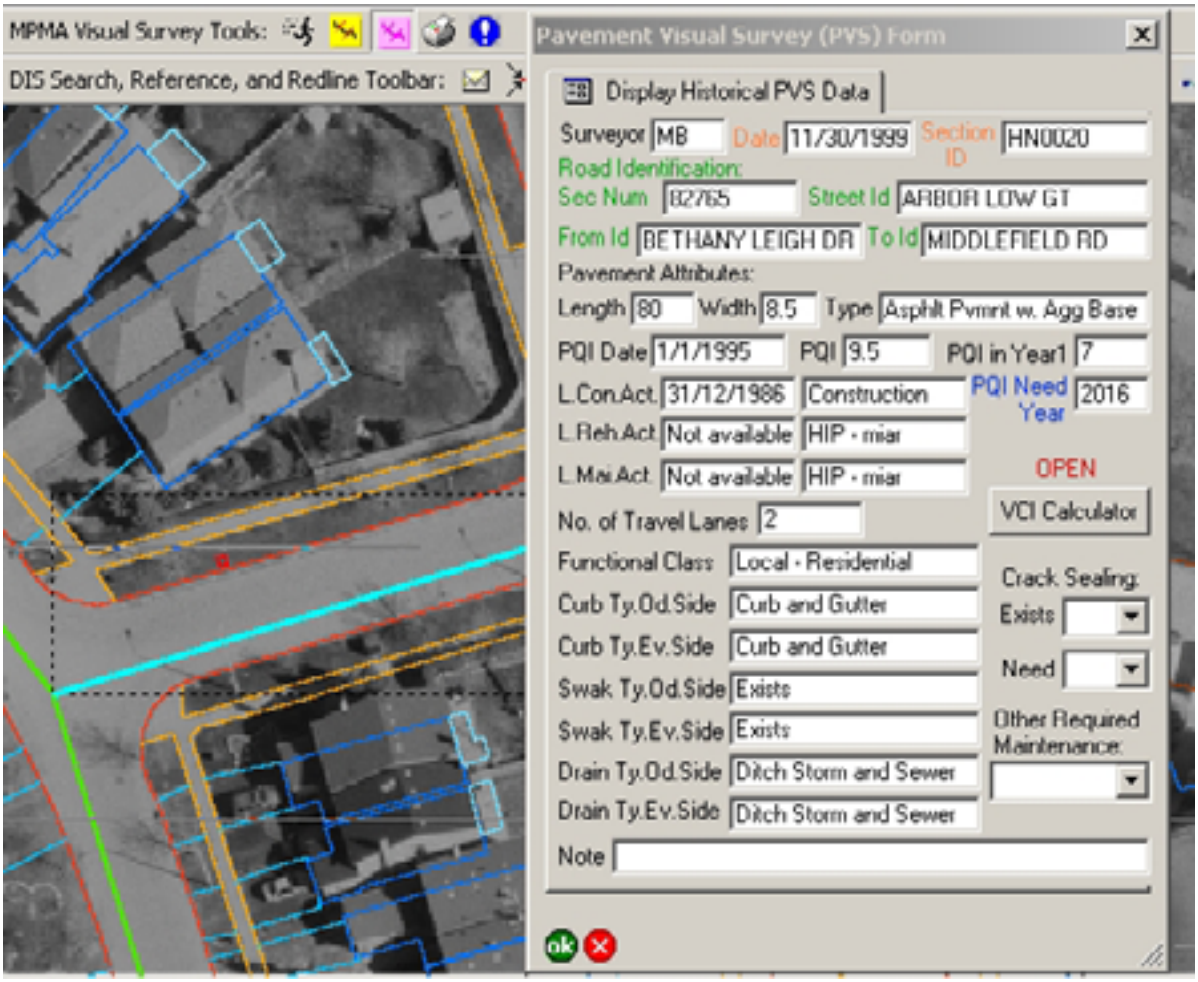

Figure-12: Windshield form for pavement visual survey.

To record the pavement distress data, the surveyor needs to open the VCI Calculator that is built into a separate 'Visual Condition Index' form. This form was required because of the large number of pavement distresses that exist. When the surveyor clicks (or tap with the pen) on the VCI Calculator button on the 'Pavement Visual Survey' form the 'Visual Condition Index' form is enabled as illustrated in Figure-13. Figure-13 shows an example of ArcPad pavement visual survey form and the VCI Calculator form with field assigned distress severities, extent ranges, and calculated and estimated VCI ratings.

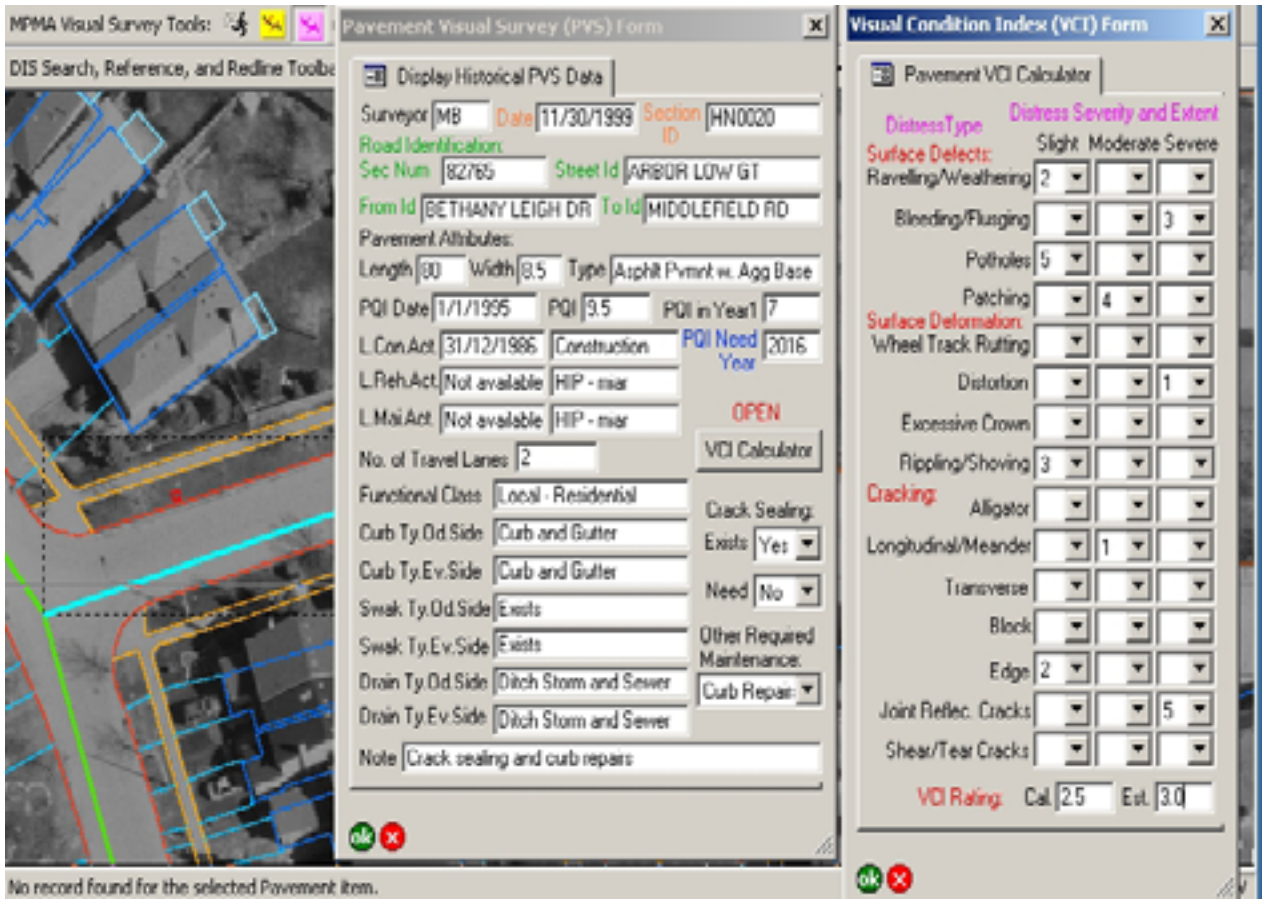

Figure-13: Example of pavement visual survey form and visual condition index (VCI) calculator.

Using the dropdown list on the VCI Calculator, pavement distresses are recorded in the calculator to calculate the VCI rating for a pavement section. The calculated VCI may not encompass all cases, so an experienced surveyor may need to subjectively assign an estimated VCI value by observation.

To complete the survey, the surveyor first needs to close the VCI Calculator using the form's OK button. The recorded distresses, calculated and estimated VCI rating values, and other required information related to pavement section (e.g., surveyor, date, remarks, etc.) will be saved to the external standalone database file called detailed pavement distress table, DTL_FDIST.dbf, on the TabletPC's hard drive. Next, surveyor needs to close the pavement visual survey form via form's OK button in order to continue the survey for another pavement section.

At the end of field surveying, DTL_FDIST.dbf database is imported to the MPMA system using the MPMA field data import tool.

MPMA / ARCPAD INTERFACE

Two external standalone database files SW_DIST.dbf and DTL_FDIST.dbf are used to save the sidewalk and pavement visual survey field data. These tables interface with both MPMA and ArcPad application. Both systems can read and retrieve the information from these two database

files. Figure-14 shows an example of the two database files and how the field data is recorded. These two tables are imported into MPMA system for data inventorying and further analysis purposes thus enabling staff to make necessary recommendations for the effective management of the City of Toronto's sidewalk and pavement assets.

Attributes of SW_DIST

SECTION_ID	SEC_NUM	PERI_KEY	RATE_DATE	RATING_CAL	RATING_EST	SWALK_SIDE	SWALK_TYPE	SURVEYOR
HN0010	82764	310174	15/06/2006	3.3	3.5	EVEN	Unknown	SU
00529.11	101060	313270	15/06/2006	1.8	2	EVEN	Unknown	SU
02458.000	2838	45163	27/06/2006	8.3	8	EVEN	Monolit	MB
02458.000	2838	45164	27/06/2006	1.3	1.5	EVEN	Monolit	MB
02458.000	2838	45162	27/06/2006	6.5	7	ODD	Monolit	MB

Record: 0 Show: All Selected Records: (0 out of 5 Selected.) Options

Attributes of DTL_FDIST

SECTION_ID	SEC_NUM	LANEID	STATN	DATADATE	SSDI_CAL	SSDI_EST	SURVEYOR	NOTE	D01_S1
HN0010	82764	P1	430	15/06/2006	9.8	10	MB	Sidewalk Reconstruction	1
00529.11	101060	P1	781	15/06/2006	6.9	7	MB	Curb Repair	0
23110	41311	P1	450	15/06/2006	7.3	7	FF	Bay Maintenance	0
40650	43065	P1	825	15/06/2006	3.7	4	FF	Curb Construction	3
17940	40794	P1	140	15/06/2006	9.4	0	FF	Track Construction	1

Record: 0 Show: All Selected Records: (0 out of 5 Selected.) Options

Figure-14: Examples for the two output database tables from ArcPad application.

CONCLUSIONS

Implementation of the ArcPad Mobile GIS Technology as a GIS application for the City of Toronto serves as a powerful platform for the collection of field data and integration within Transportation's MPMA. It also brings the following efficiencies and improvements to Transportation's assets collection and management techniques:

- Significantly reduces the time consuming procedures and processes followed in the past.
- Improves the data quality and accuracy.
- Enables data transfer between ArcPad and MPMA systems more efficiently, in a seamless and timely manner.
- Allows direct data integration using systems like ArcGIS for analysis and mapping purposes.

In addition, by collaborating with the City's Data Integration Services, additional benefits were recognized including first-hand understanding of the City's spatial data sets and the opportunities to further customize and modify the ArcPad application to suit the City's needs.

ACKNOWLEDGEMENTS

The preparation of this work involved many individuals and sources to whom the authors are greatly indebted. From the beginning of this project, the City of Toronto staff, especially the Manager of the Data Integration Services, Dan Lymer who gave us the utmost support in every aspects including approving required software and hardware infrastructure used for the application development, testing, and implementation is greatly appreciated. We also acknowledge the former Supervisor of the Graphic Data Section Michel Robertson for his initiatives, guidance, and encouragements to adopt the ArcPad Mobile GIS Technology as a part of the DIS regular activities. Thanks to Ryk Karczuga and Vlad Kormilitsyn for their assistance.

Special thanks go to the Transportation Services Division staff including Frank Facchini, Engineer, for his valuable contributions and feedbacks and Joe Condarcuri, Infrastructure Asset Management & Programming Manager, for his support which played a major role in the successfully completion of this project. We are also grateful to the City's Transportation and Technical Services IT Staff and Database Administrators for their technical support.

Finally, we would like to acknowledge Stantec Consulting Limited and staff including Jim Lee and Mo Lan for their co-operation in this collaboration.

APPENDIX

SIDEWALK CONDITION INDEX CALCULATION:

Calculation of a Sidewalk Condition Index Rating

Each section of sidewalk is assigned a maximum rating of 10, and a specific number is deducted from this based on severity and extent of the distresses prevalent throughout the section to reduce the value to a number on a scale of 0 (worst) to 10 (best) that would reflect the condition of the sidewalk. The sidewalk condition index rating system is provided in Table-1. There are seven typical distresses for sidewalks including, abbreviations in parentheses:

1. Spalling (Sp)
2. Cracking (C)
3. Patching (P)
4. Grinding (G)
5. Settling (S)
6. Scaling (Sc)
7. Ravelling (R)

Deduct Value Generation

Each distress has three individual calculations, for each level of severity, which is necessary to record in order to properly calculate a value that was deducted from the initial rating of 10. This value, referred to as the Deduct Value (DV), is generated with the following equation:

$$DV = 10^{(a+bLog\%)}$$

Once a DV is determined for each distress present on the section, the individual DVs are summed up to obtain a Total Deduct Value (TDV). Since some distresses are more influential than others, and some distresses can be the cause of yet another distress, the TDV must be adjusted in order to correct for the effect of summing of multiple DVs.

Adjusted Deduct Value

The Adjusted Deduct Value, or ADV, is calculated using the TDV and Number of Equivalent Distresses (NED). The NED is the sum of the ratios of each individual DV to the maximum DV found. This can be seen in the following equation:

$$NED = \sum \left(\frac{DV_i}{DV_{\max}} \right)$$

DV_i is the deduct value for a given distress, and $DV_{\max}$ is the largest deduct value calculated from the observed distresses. After the NED value is obtained the Adjusted Deduct Value (ADV) can be calculated using the following equation:

$$ADV = 10^{((1.11-0.1)\times NED)\times(LogTDV))}$$

Visual Condition Index (VCI) Calculation

The VCI is then calculated with the equation:

VCI = 10 - ADV

Note: Visual Condition Index (VCI) ~ Sidewalk Condition Index (SCI) ~ Pavement Condition Index (PCI)

Table-1: Sidewalk Condition Index (SCI) Rating System

SCI	Condition	Typical Visual Appearance	Replacement Costs	Rehabilitation Time
9.0-10	Excellent	No to few signs of distress	Less than 10%	>15 years
7.5-9.0	Very Good	Few slight cracks Slight surface weathering	0-10%	
6.5-7.5	Good	Intermittent slight cracks Few slightly uneven slabs Slight surface weathering	8-20%	
5.0-6.5	Fair	Frequent moderate cracks Intermittent slightly uneven slabs Lightly deteriorated surface	15-40%	
4.0-5.0	Fair to Poor	Frequent severe cracks Few moderately uneven slabs Moderate surface weathering	35-70%	
3.0-4.0	Poor	Extensive severe cracks Frequent moderately uneven slabs Moderate surface weathering	50-100%	5-15 years
2.0-3.0	Poor to Very Poor	Extensive severe cracks Frequent moderately uneven slabs Severe surface weathering	70-100%	3-10 years
0-2.0	Very Poor	Extensive severe cracks Intermittent severely uneven slabs Severe surface weathering	100%	1-5 years

END NOTES

[EN1] **Severity**: A description based on crack width, condition and multiplicity. There are three categories of severity slight, moderate and severe. For each distress see the detailed severity definitions.

[EN2] **Extent**: A description based on percent of total pavement surface area in the pavement section affected by defect. Extent can be defined from a level 1 to 5, 1 being the least amount affected by defect.

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