Innovative Street Data Capture And Dissemination Using ESRI Software

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Abstract

The Street Transportation Department has developed several GIS applications to facilitate collection of street assets. One example is the Pavement Capture Application.

When Streets are resurfaced in the city of Phoenix, Street Maintenance staff are required to go to the field and measure the area to be resurfaced using a wheel. The measurements are used to estimate the amount of material needed to complete the resurfacing project. The process of taking manual measurements in the field is labor intensive, time consuming, and sometimes dangerous.

Street Transportation Department saw an opportunity to develop a customized ArcGIS 8.3 application that allows street maintenance staff to make measurements of street areas using highly accurate aerial photos. The application allows Street Maintenance staff to digitize the area of a resurfacing project and store important project details in a relational database. The application has eliminated the need to field measure every resurfacing project.

Background

The City of Phoenix Street Transportation Department is responsible for the maintenance of over 5,000 linear miles of streets within the city limits. Each year the Department does preventative maintenance on over 200 miles of these streets. Approximately 100 miles of seal coating or "Slurry Seal" is applied with a budget of $2.4 million dollars per year. Additionally, 130 miles of pavement overlay is completed with an estimated budget of $10 million dollars per year.

Planning and budgeting for these projects begin over a year in advance as streets are selected based on condition assessments; and the budget is finalized using estimates of the square yardage of street to be repaved. Currently, all the street measurements required for budgeting purposes involve field based manual measurements of the length and width of every street to be repaved. A digital pedometer connected to the wheel of a truck is used to measure the length of a street and a measuring wheel is used to determine the width. The current process of measurement is labor intensive, time consuming, and sometimes dangerous.

Figure 1: Street Transportation Staff Measuring Street Width

The Street Transportation Department began implementing a Department wide GIS based system for asset management in the fall of 2002. CyberTech Systems Inc. was contracted to help create a GIS Implementation Plan and provide onsite technical assistance. Pavement had been identified as an asset of the Department in the GIS Implementation Plan. The GIS team saw an opportunity to use GIS to help obtain more accurate street area measurements in a more efficient manner. Using GIS software and high resolution color aerial photography street pavement area could be captured and stored as polygons in the Department's GIS database.

Figure 2: Pedometer for Measuring Street Width

Determining An Approach

The City of Phoenix has partnered with other municipalities in the area and the Maricopa County Flood Control District to have high resolution color orthophotos taken every year. The photos have 1 foot resolution and have +/- 5 foot horizontal and vertical accuracy. The color aerial photos provided a means to derive accurate area measurements for street projects without having to leave the office.

Two approaches for capturing pavement areas were investigated. One involved using digital image processing techniques to create pavement polygons. The other approach was to have GIS staff capture pavement polygons by performing "heads-up" digitizing from the aerial photos.

The usage of Digital Image Processing techniques for the capture of pavement polygons from aerial photos was perceived to be a simple and time saving approach for the creation of pavement polygons. To evaluate the feasibility of this approach, supervised and unsupervised classification was carried out on a small set of the City's aerial photographs using ERDAS Imagine software. The unsupervised classification yielded the best results, however, it was noticed that features such as parking lots, buildings etc were being clustered with pavement. The results of a supervised classification were even less encouraging because the motor oil, shadows and cars present at various locations along the pavement made it almost impossible to train the classifier. Moreover, the image being used for the classification was a single band image.

Heads-up digitizing while less efficient than digital image processing, produced the best results. Although heads up digitizing is labor intensive when compared to image processing techniques, it is considered significantly more efficient than field measuring. Therefore, the Department GIS team decided to move forward with heads up digitizing. The next step was to convince stake holders in management that a GIS-centric approach to pavement capture was indeed beneficial and more effective than the current methodology.

Proof Of Concept

The managers responsible for street resurfacing projects were initially reticent about changing their business processes to a GIS-centric approach. They were especially concerned that measurements made from aerial photos would be less accurate than field measurements.

To alleviate these concerns a small proof of concept was developed. Several areas projected for resurfacing in 2005 were measured in GIS and in the field. Project managers agreed to back the new approach if measurements made in ArcGIS were within 3% of measurements calculated in the field. A prototype ArcGIS application was quickly developed to facilitate capturing pavement area from the color aerial photos. In all but one project area the measurements from GIS were within 3% of the area calculated in the field. In one project area the total in GIS was 7% higher than the area measured in the field. The GIS team began comparing measurements on a street by street basis to try and explain the discrepancy.

The process of comparing measurements was beneficial and emphasized some obvious problems with using linear measurements to calculate street surface area. In areas where streets have a uniform width, area measurements from a wheel work well. However, in the project area with the discrepancy, there was a high rate of street tapers, bulbs, and cul-de-sacs. These features are difficult to measure using the field measurement approach employed by the Department. In fact when these issues were pointed out, project managers admitted that they added a 3% "fudge factor" to all project measurements to account for these phenomenons. The exercise of comparing measurements illustrated the limitation of using linear measurements for the calculation of areas and the ease of capturing non uniform features in GIS.

Figure 3: Irregular Pavement Area

In addition, to measurement accuracy, the GIS team took the opportunity to point out the time savings gained by using GIS for pavement measuring. The GIS team went out with field staff to make measurements for the proof of concept area. A breakdown of time required to collect and record the information is shown below:

Figure 4: Field Measurement Statistics

#	Activity	Time (in minutes)
1	Drive to location	15
2	Measure length and width of streets	150
3	Drive back to office	15
4	Enter field measurement information in MS Access database	90
	Total	**270 (4.5 Hours)**

The time to digitize the same area in GIS took approximately 2 hours. The difference in time represents a 56% decrease in the time required to do the work in GIS. With a successful proof of concept Street Transportation Department Management was ready to adopt GIS as the primary tool for capturing resurfacing measurements.

Additional Findings

During the proof of concept phase additional opportunities to capture or improve existing data sources became apparent. For example, when digitizing pavement with median islands, the geometry of the median has to be subtracted from the pavement area. To accomplish this task the median is digitized and then "clipped" from the pavement polygon. The GIS team realized that this was an excellent opportunity to capture additional asset of the Department identified in the GIS Implementation Plan. Therefore, median islands were captured in a separate feature class prior to being clipped from the pavement polygons.

Figure 5: Digitized Median and Pavement Polygons

In the process of developing a prototype application the GIS team discovered that there were many issues with the geometry of the city street centerline layer. It appeared that while new developments had been captured quickly and accurately, street realignments and street abandonment in existing areas were not captured. The GIS team decided to cleanup the street centerline layer while pavement and medians were being captured. The city color orthophotos are used to assess centerline accuracy. If an existing street centerline falls outside a paved area than the centerline geometry is moved to the center of the pavement. If the aerial photos show that a street has been abandoned the centerline segment is deleted.

Initially the GIS team planned to train field staff to use the GIS application so they could capture pavement polygons as projects dictated. Unfortunately, field staff proved reluctant and too busy to embrace the technology. Moreover, the GIS Implementation Plan advocated digitizing all pavement maintained by the City, not just areas required for upcoming resurfacing projects. Capturing all the pavement areas maintained by the City would satisfy GASB-34 requirements. As a result the GIS team elected to hire GIS temporary staff to digitize all pavement maintained by the Department.

Maintenance Application

Having determined that the best approach was to manually digitize pavement and median polygons using the City's color aerial photographs, the GIS Team started working on the development of a customized ArcMap application for the purpose. Based on its findings during the proof of concept exercise, it was decided to include the maintenance of Street Centerline and Street Intersection datasets in the same application.

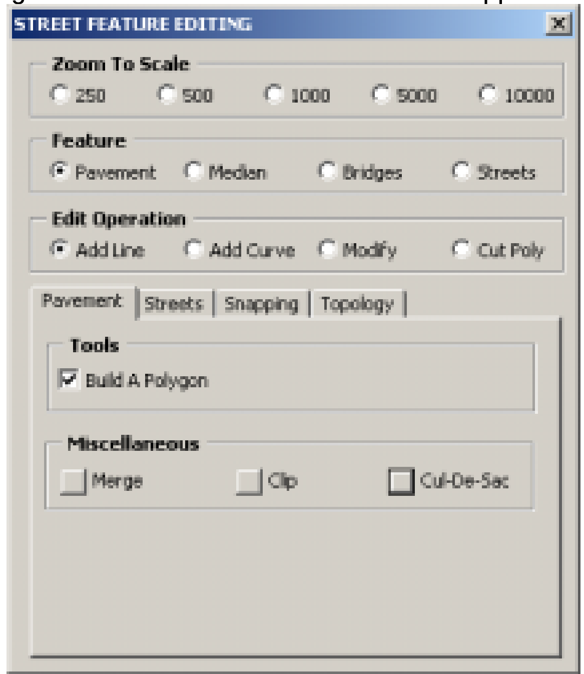
Feature classes to store the Pavement, Median, Street Centerline, and Street Intersection datasets were created in the Department's ArcSDE 8.3, Microsoft SQL Server 2000 database. Other reference datasets such as City Limits, Parcels, Quarter Sections, Aerial Photos etc. required for the maintenance of the street feature datasets were identified and included in the application. Most of the reference datasets are available in the City's enterprise ArcSDE based Oracle database maintained by the IT Department.

Thus, the GIS team setout to build a custom application that provided easy access to required data sets with custom tools to make data capture and maintenance as simple and efficient as possible.

The GIS Team decided to create the data maintenance application using the ArcMap application available in the ArcGIS suite of ESRI software. ArcGIS was chosen because a large number of functions required for the maintenance process are available out-of-the-box. Moreover, it is possible to add custom tools to ArcMap using ArcObjects and VBA. The result was a customized ArcMap, Map document (.mxd), file with custom functions and tools written using VBA and ArcObjects.

One concern that the Team addressed in regards to ArcMap was that the built-in tools were distributed in various toolbars along with a large number of other tools that could confuse the average user. To eliminate this confusion almost all the tools were incorporated on a single form. Interfaces to the built-in ArcMap tools were also included on the same form to ensure ease of use and to avoid any possible confusion among the users. Some of the tools were added to ArcMap's context sensitive menus, again to facilitate easy access.

Figure 6: Main form of the Maintenance Application



Some of the highlights of the application follow:

- The Start and Stop Editing operations are done programmatically as a part of the form load and unload events respectively
- Default Edit Task and Target Layer are set when the form loads
- Edit Task and Target Layer are programmatically updated based on the user's selection of options on the main form
- An easy to use interface is available to set up the Snapping Environment
- A checkbox to disable snapping is available
- Option buttons to zoom to predefined map scales are available
- A context menu item to return to the last edit tool used allows users to return to their edit sketch after using the Pan or Zoom tools
- Interfaces to the built-in tools for Validating Topology and launching the Error Inspector are also provided
- Custom functions that use the Topology functionality of the Geodatabase to identify and fix errors programmatically

Details of some of the custom functions and tools developed for the data maintenance application follow:

Build Connectivity Tool: The Build Connectivity Tool is used when new street segments are added to the Street Centerline dataset. Using Topology, the tool works on the street centerlines in the current view extent and ensures that existing streets are split at locations where the new street intersects them. Address ranges attributes of the street being split are also distributed proportionally between the new street segments.

Figure 7: Street Centerline before and after the use of the Build Connectivity Tool

Build Polygon Tool: Most local Phoenix streets have a standard width of between 28.5 and 30 feet. On these standard local streets one side of the street is a mirror of the opposite side of the street. The build polygon tool allows the GIS technician to digitize the edge of pavement on one side of the street. The function then prompts the user to enter the street width. The edge of pavement line is copied parallel at the width supplied. The end points of the two parallel lines are connected with two new segments. The geometry of these four segments then is assembled into a single polygon. While the build polygon tool cannot be used on all streets, it reduces the time and effort to digitize pavement area for a standard street significantly.

Figure 8: Build Polygon Step 1, Digitize Edge of Pavement

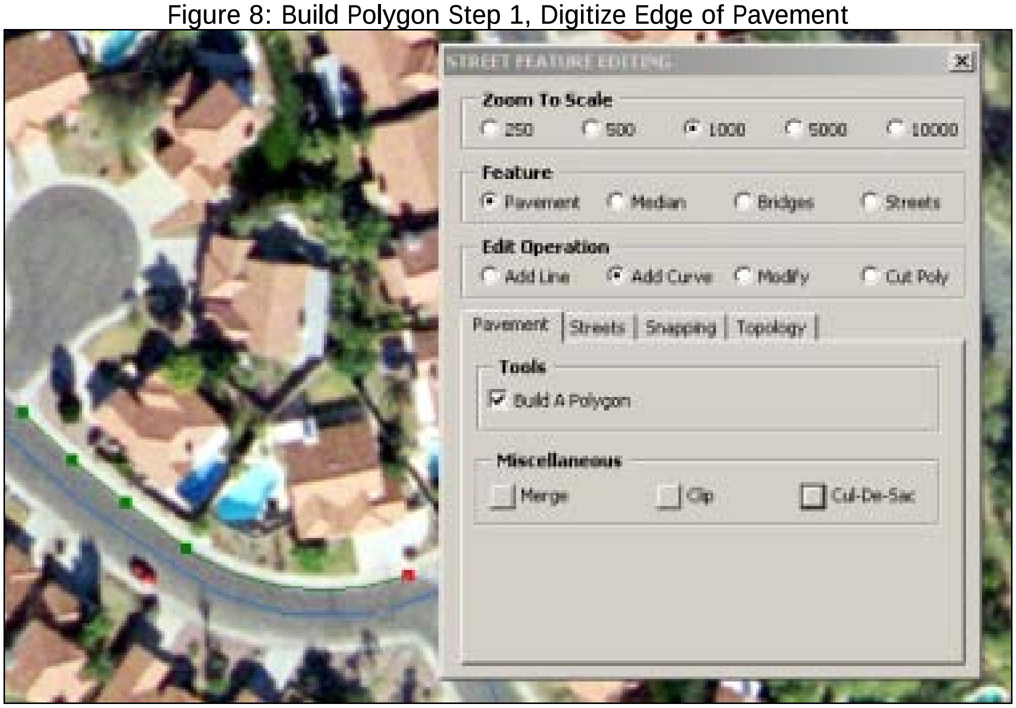
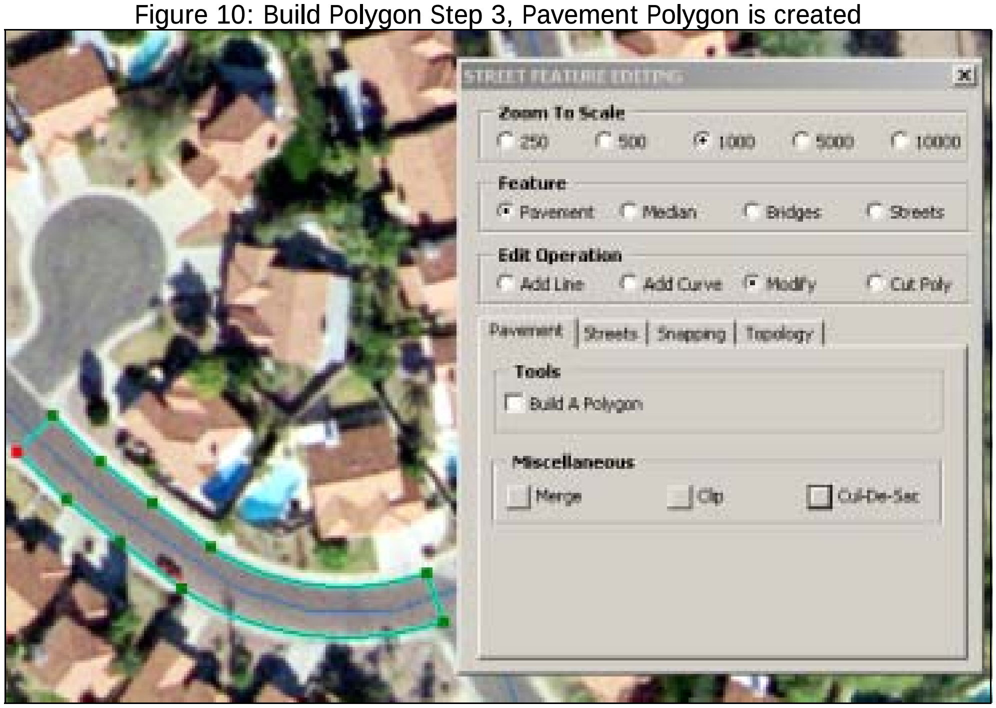


Figure 9: Build Polygon Step 2, User Enters Street Width

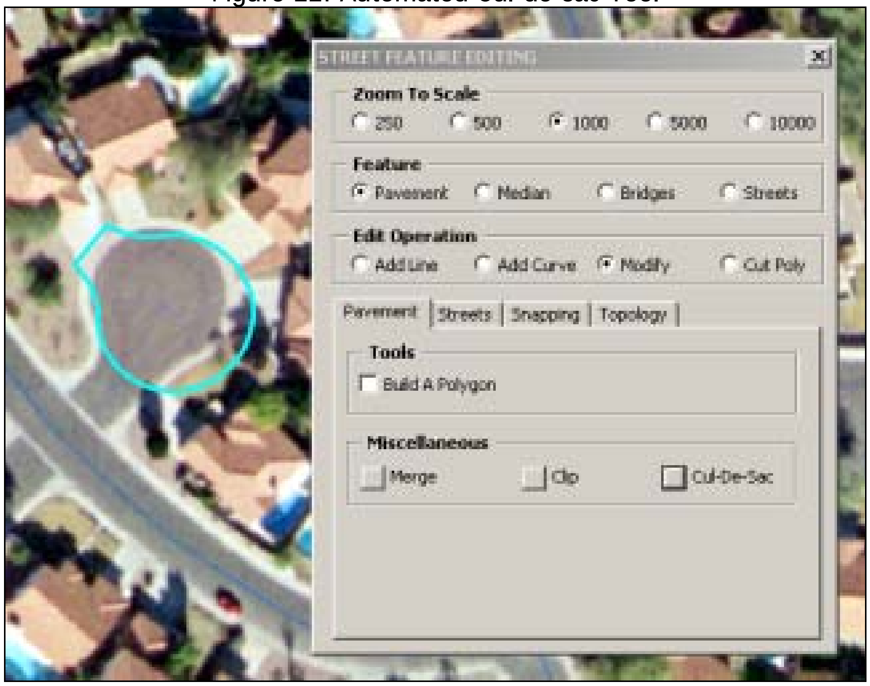
Figure 10: Build Polygon Step 3, Pavement Polygon is created



Copy Geometry Tool: The Copy Geometry tool is a custom tool to copy the geometry for Street segments from other City reference data such as Engineering Department's Monument line dataset or Development Services Department's New Streets dataset.

Cul-De-Sac Tool: Most cul-de-sacs in the City of Phoenix have standard dimensions. The geometry of a standard cul-de-sac was stored in a table. When the GIS technician hits the cul-de-sac button on the editing form the geometry of a standard cul-de-sac is copied into the pavement feature class and moved to the center of the map display. The new cul-de-sac feature can then be rotated or moved into position using standard editing tools.

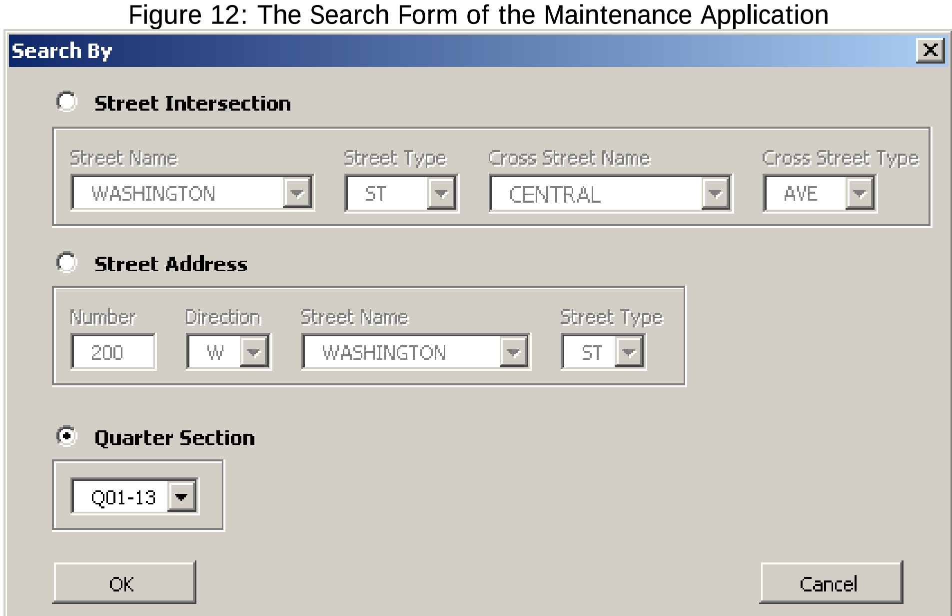
Figure 11: Automated Cul-de-sac Tool



Delete Pseudo Nodes Tool: Pseudo nodes are locations where two street segments representing the same physical street intersect. Such points are considered errors in the Street Centerline dataset and this tool uses Topology to identify and delete such points and merges the two street segments into one. Street Intersection points existing at such locations are also deleted automatically.

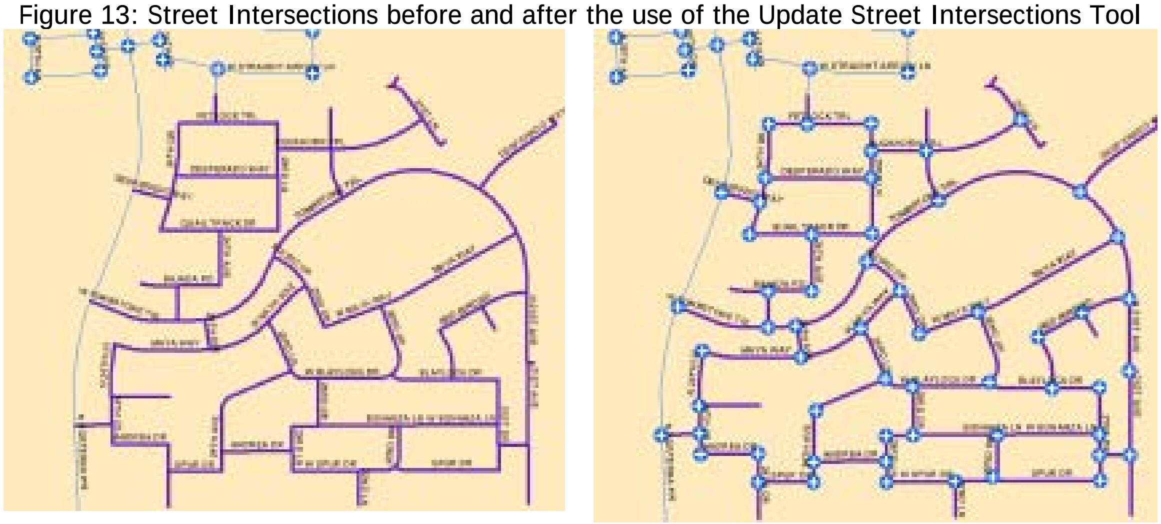
Search Tool: A custom tool to zoom to a Street Intersection or Address has been included in the application to help the users of the application. The facility to zoom to a Quarter Section is also available.

Figure 12: The Search Form of the Maintenance Application



Update Street Intersections Tool: Street Intersections are represented by point locations in the Street Department's GIS data model. Using topology, this tool locates all the Street Intersections in the current view extent and creates points in the Street Intersection feature class. Attributes of the Street Intersection, such as the names of the intersecting streets and the block numbers are also populated by the tool.

Figure 13: Street Intersections before and after the use of the Update Street Intersections Tool



FIELD VERIFICATION

The color orthophotos have proven to be a valuable resource for the Street Transportation Department. However, they have not completely eliminated the need to do some amount of field verification. In some cases due to ground conditions or shadows on the orthophotos it is difficult to ascertain the edge of pavement. The GIS team decided on an approach to leverage existing field staff resources that would utilize the ArcGIS field collection application, ArcPad. The solution was to have GIS technical staff digitize pavement to the best of their ability. In difficult areas the pavement data is checked out to the Department's Trimble GeoExplorer unit with ArcPad 6.03 installed. Department field staff then adjust the boundary area of a resurfacing project by moving the bounding vertices of a polygon to the coordinates provided from the Trimble unit. Once completed the pavement data is checked back into the Department's ArcSDE database and a GIS technician verifies the alignment and connectivity with adjacent pavement polygons.

Figure 14: Field Verifying Pavement with ArcPad/GPS

BENEFITS

Using GIS to capture pavement areas from ortho-photography is a major benefit for the City of Phoenix Street Transportation Department. Using GIS is quicker and less labor intensive than capturing data using a wheel in the field. In addition, the results of measuring in GIS provide a more accurate estimate of the amount of material needed to resurface a street. Accurate measurements help ensure that the amount budgeted is sufficient to complete the yearly resurfacing projects. Using GIS software for area measurements eliminates the need to have field staff visit every location. Not having to measure in the field is a major savings for the Department. Fuel costs are reduced by not having to drive to distant locations to measure and labor time is saved by not having field staff walk the length and width of 200 miles of street with a measuring wheel

Capturing pavement area in GIS makes the data accessible to a much larger audience. The data is stored in the Departments ArcSDE 8.3 data base. Department staff and potential users in other Departments can view and query the data from ArcGIS or the Department's ArcIMS website. In addition, the data can be provided easily to outside contractors in a digital format.

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