Using GIS to Compare All M&R Strategies for Asphalt Road Networks

Antonio Fuentes

CEE 6440: GIS in Water Resources
Dr. Tarboton

Table of Contents

List of Figures

List of Tables

List of Equations

Introduction

Over the past several years, city governments and municipalities have had a difficult time maintaining their transportation infrastructure due to economic hardships in the United States. Within the scope of transportation infrastructure lays the integral element of asphalt pavement. City engineers and public works directors utilize a pavement management system (PMS) as a tool to help them maintain their asphalt pavement network at a high level of service.

A PMS functions as a tool for decision making through the following steps.

1. Description of Asphalt Pavement Network
2. Collection of Asphalt Condition Data
3. Analysis of Pavement Deterioration
4. Analysis of Economic Alternatives
5. Priority Evaluation and Optimization of Maintenance and Repair (M&R)

The ultimate goal of implementing a PMS is to recommend proper M&R treatments at the right time and do so in a way that is most economically adequate for a city or municipality. The Utah Local Technical Assistance Program (LTAP) in conjunction with Utah State University developed a PMS in the form of computer software to help accomplish the goals listed above.

The PMS that was developed is titled "Transportation Asset Management Software" (TAMS). It was developed around 1999 and has been a useful program for collecting pavement condition data and estimating pavement deterioration. The TAMS program utilizes polyline shapefiles as a reference to later store data in an access database. Applications and results of this program will be used in conjunction with ArcGIS in this project. Figure 1 illustrates a screen shot of the TAMS software in use.

Figure 1. TAMS Software Implemented in Brigham City

One of the key aspects of improvements by using GIS is the way the economic analysis is approached; a more detailed estimate of treatment costs could be added within ArcGIS to compare all M&R strategies of a city network. In addition to that, the TAMS software provides a recommended treatment based on current condition, thus an additional toolbox that provides all possible M&R treatments will be developed through the use of Excel, Access, the polyline shapefile and the TAMS database.

The goal of this report and this term project is to illustrate how the TAMS data can be utilized within ArcGIS, as well as provide additional power in comparing M&R treatments side by side when working with the shapefile street segments in the ArcGIS software. The M&R treatments will be estimated using present value costs of treatments, forecasting of future treatments will be done through the use of engineering economics principles.

A toolbox will be developed within ArcGIS, to automate the process of comparing M&R treatments as much as possible. Part of the toolbox's functions will also incorporate converting the shapefile with finalized analysis data to a kmz file that can be referenced in google earth. This implementation will allow smaller cities and municipalities that do not have accessibility of ArcMap to view this work in free mapping programs such as Google earth.

Purpose

The importance of implementing a tool for additional comparison of all M&R treatment options is to add precision and confidence to the decisions being made city officials. Programs like TAMS often recommend one M&R treatment that is based on the current condition of the asphalt pavement, while this information is helpful often times different treatment alternatives must be considered either because of current city planning or low budgets might require an alternative.

The data used to demonstrate the use of this GIS tool will be from the city of Smithfield. The reasoning for using Smithfield are because of its availability, its proximity to USU and because it was surveyed by the Utah LTAP in 2010 through the use of the TAMS software.

Pre-Procedure

The first step this process is to perform a join from the TAMS database to the Smithfield shape-file. The data that is stored in the database is uniquely correlated to the TAMS database through the shapefile attribute of "RIN_No", which stands for Road Identification Number. Once this join is complete the data that was collected in the TAMS software can be portrayed and easily viewed through the ArcGIS software. Figure 2, Figure 3 and Figure 4 below, illustrates the city of Smithfield after the join has been completed they show join between databases, a map or remaining service life and a map of recommended treatments respectively.
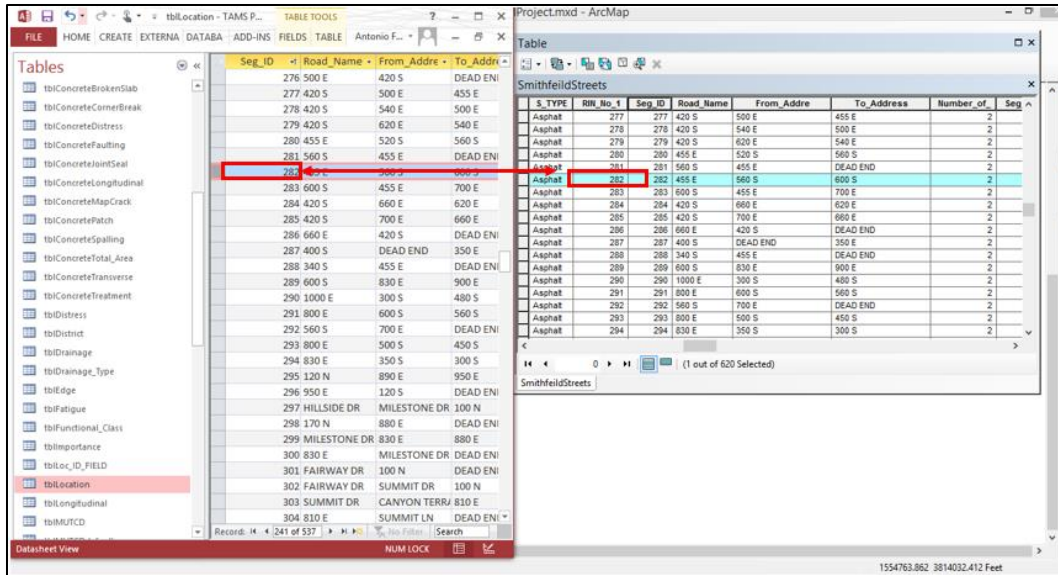
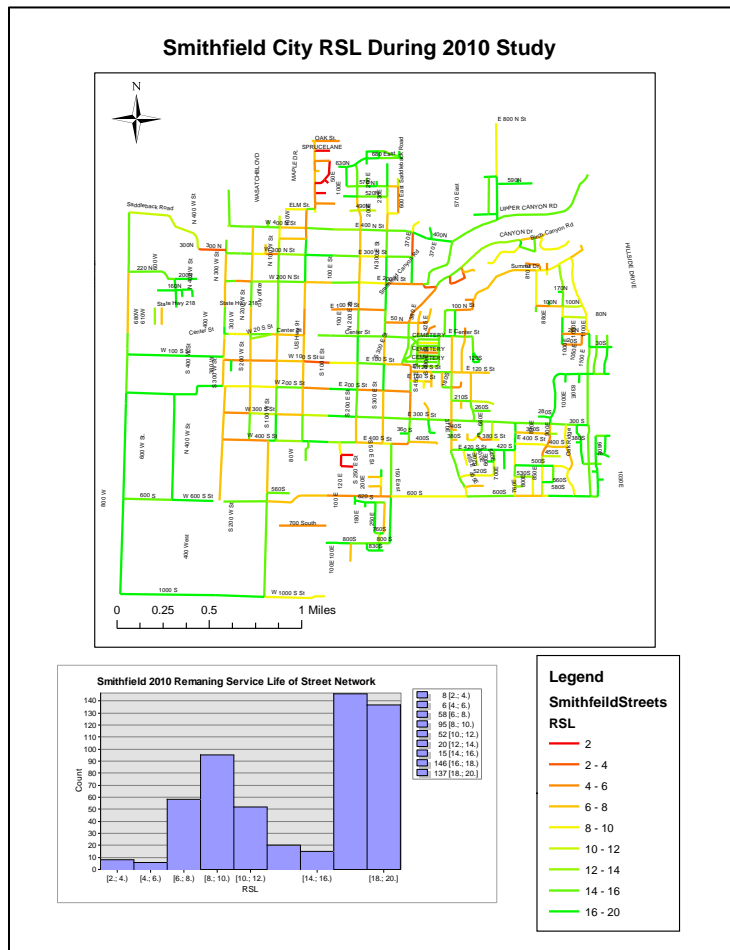Figure 2. Joining of TAMS database to Smithfield City Shapefile

Figure 3. Smithfield City with Streets Illustrating their Remaining Service Life

From Figure 3 above, it is important to discuss the meaning of the Remaining Service Life (RSL). The RSL value of a segment is calculated by TAMS and it is the method in which it predicts pavement deterioration. In the methodology of TAMS, a brand new asphalt pavement has a maximum service life of twenty years, thus every year after its construction if no M&R treatment is conducted it will lose one year of service life.
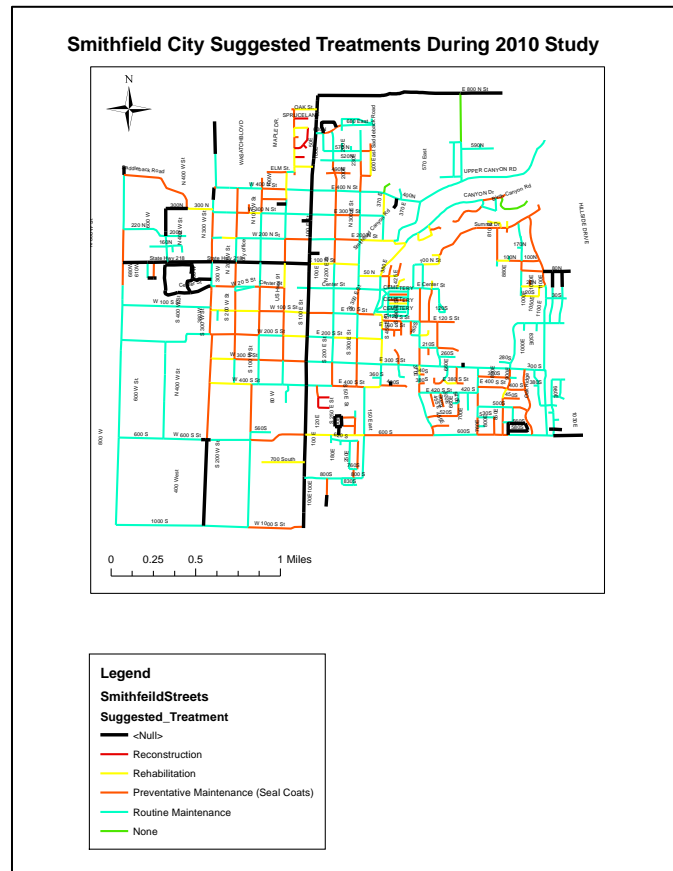
Figure 4. Recommended M&R Proposed by TAMS

Figure 4, above illustrates the types of recommendations that can be produced within the TAMS software. Applying symbology through the use of ArcGIS is an easy way to visually see all the options offered. The drawback of this procedure is that it is generalized based on the type of M&R and does not detail the treatments a city should be using.

The following procedures will take place by exporting the original shapefile with the join already in place. This will enable the TAMS database information to be stored permanently within the new Smithfield shapefile.

Economic Analysis Procedure
The economic analysis will be conducted by exporting the attribute table into an excel document where the engineering economic calculations will be processed. Table 1 illustrates a list with the current cost of treatments based on the area of treatment, which for the purpose of this project is the street segment area. The list shown contains twenty treatments that will be used for

comparison within the GIS model. The list was provided by the Utah LTAP and is made up of M&R strategies that are most common in Utah.

These prices can vary depending on time of implementation and region of cities or municipalities. For the purposes of this project, the present value costs will be estimated using the cost in Table 1, the width data from the TAMS software and length data from the shapefile to calculate the area.

Table 1. Unit Cost of Current M&R Treatments

Treatment ID	Treatment Category	Treatment Type	Unit Cost Per Square Foot
1	Routine Maintenance	Crack Seal	$0.03
2	Routine Maintenance	Cold Patch	$0.03
3	Routine Maintenance	Digout and Hot Patch	$0.03
4	Preventative Maintenance	High Perf. Cold Patch	$0.07
5	Preventative Maintenance	Fog Coat	$0.03
6	Preventative Maintenance	Sand Seal	$0.06
7	Preventative Maintenance	Scrub Seal	$0.10
8	Preventative Maintenance	Single Chip Seal	$0.10
9	Preventative Maintenance	Slurry Seal	$0.13
10	Rehabilitation Maintenance	Microsurfacing	$0.16
11	Rehabilitation Maintenance	Plant Mix Seal	$0.78
12	Rehabilitation Maintenance	Thin Hot Mix Overlay (<2 in)	$1.06
13	Rehabilitation Maintenance	HMA (leveling) & Overlay (<2 in.)	$1.17
14	Rehabilitation Maintenance	Hot Surface Recycling	$1.11
15	Rehabilitation Maintenance	Rotomill & Overlay (<2 in)	$1.33
16	Reconstructive Maintenance	Thick Overlay (3 in.)	$1.58
17	Reconstructive Maintenance	Rotomill & Thick Overlay (3 in.)	$1.69
18	Reconstructive Maintenance	Base Repair\Pavement Replacement	$1.67
19	Reconstructive Maintenance	Cold Recycling & Overlay (3 in.)	$1.81
20	Reconstructive Maintenance	Base/Pavement Replacement	$2.22

In addition to calculating the present value cost of implementing M&R, it is useful for city officials to plan ahead in case current treatments cannot be implemented immediately but are being considered some years down the road. There will only be two economic calculations that will be utilized for analysis, they are the single payment compound amount and the capital recovery. The reason for using these formulas is because they are the only ones that focus on predicting a future or annual value given a present value. These equations are illustrated in Equation 1 and Equation 2.

$$\frac{F}{P} = (1 + i)^n$$

Equation 1. Single Payment Compound Amount

$$\frac{A}{P} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

Equation 2. Capital Recovery

Therefore, these calculations were utilized to determine the cost of implementing all of the M&R options illustrated in Table 1, the parameters that were used for the economic calculations where an interest rate i of 6% and a year of analysis n of 2 years.

Through the shapefile accessible "length" field, accurate lengths can be calculated through the ArcGIS "Field Calculator" function. However, the segment width was attained from the TAMS database. With these two values, an estimated M&R cost per unit area can be approximated quickly. Thus three tables were produced in excel with the implementation cost of all twenty M&R treatments, they were calculated for Present Value, Single Payment Compound and Capital Recovery. The key aspect of this procedure is the fact that each treatment option in Table 1, will become an attribute for the shapefile; thus enabling one to see the cost of each M&R treatment by simply clicking on the shapefile segment.

In order to facilitate the joining process, these tables were imported into an access database table, the access file can be read by ArcMap as a personal geodatabase. Thus in the next section of this report, the toolbox that is used facilitate the reproduction of these steps is described in a simpler manner. Figure 2 and Figure 3 illustrate an example of these tables in excel and after their import into access respectively.

Table 2. Present Value Calculations in Excel

RIN_No	LENGTH (ft)	WIDTH (ft)	AREA (ft²)	Crack Seal-1	Cold Patch-2	Digout and Hot Patch-3	High Perf. Cold Patch-4	Fog Coat-5	Sand Seal-6	Scrub Seal-7	Single Chip Seal-8	Slurry Seal-9	Microsurfacing-10
518	51.64	24	1239.4089	$38.68	$46.42	$47.35	$92.84	$45.96	$83.56	$139.26	$139.26	$182.59	$222.82
197	68.21	31	2114.5923	$66.00	$79.20	$80.78	$158.40	$78.41	$142.56	$237.60	$237.60	$311.51	$380.15
482	70.88	26	1842.768	$57.51	$69.02	$70.40	$138.04	$68.33	$124.23	$207.05	$207.05	$271.47	$331.29
508	80.65	36	2903.4288	$90.62	$108.74	$110.92	$217.49	$107.66	$195.74	$326.23	$326.23	$427.72	$521.97
481	83.76	25	2094.0075	$65.36	$78.43	$80.00	$156.86	$77.64	$141.17	$235.28	$235.28	$308.48	$376.45
79	85.64	40	3425.5737	$106.92	$128.30	$130.87	$256.60	$127.02	$230.94	$384.90	$384.90	$504.64	$615.84
16	87.82	37	3249.5013	$101.42	$121.70	$124.14	$243.41	$120.49	$219.07	$365.11	$365.11	$478.70	$584.18
517	96.38	28	2698.7247	$84.23	$101.08	$103.10	$202.15	$100.07	$181.94	$303.23	$303.23	$397.57	$485.17
547	99.76	31	3092.7033	$96.53	$115.83	$118.15	$231.66	$114.67	$208.50	$347.50	$347.50	$455.61	$555.99
499	107.62	36	3874.2192	$120.92	$145.10	$148.00	$290.20	$143.65	$261.18	$435.31	$435.31	$570.74	$696.49
543	116.08	31	3598.5348	$112.31	$134.78	$137.47	$269.55	$133.43	$242.60	$404.33	$404.33	$530.12	$646.93
416	117.12	32	3747.8178	$116.97	$140.37	$143.18	$280.74	$138.96	$252.66	$421.10	$421.10	$552.12	$673.77
620	121.33	31	3761.3286	$117.40	$140.87	$143.69	$281.75	$139.47	$253.57	$422.62	$422.62	$554.11	$676.20
195	123.02	22	2706.3477	$84.47	$101.36	$103.39	$202.72	$100.35	$182.45	$304.09	$304.09	$398.69	$486.54
333	125.89	30	3776.832	$117.88	$141.45	$144.28	$282.91	$140.04	$254.62	$424.36	$424.36	$556.39	$678.98
619	126.76	31	3929.6268	$122.65	$147.18	$150.12	$294.36	$145.71	$264.92	$441.53	$441.53	$578.90	$706.45
535	128.49	30	3854.7009	$120.31	$144.37	$147.26	$288.74	$142.93	$259.87	$433.11	$433.11	$567.86	$692.98
77	128.69	27	3474.5454	$108.44	$130.13	$132.74	$260.27	$128.83	$234.24	$390.40	$390.40	$511.86	$624.64
179	132.20	30	3965.9094	$123.78	$148.54	$151.51	$297.07	$147.05	$267.37	$445.61	$445.61	$584.24	$712.98
404	135.28	31	4193.721	$130.89	$157.07	$160.21	$314.14	$155.50	$282.72	$471.21	$471.21	$617.80	$753.93
526	135.75	33	4479.6024	$139.81	$167.78	$171.13	$335.55	$166.10	$302.00	$503.33	$503.33	$659.92	$805.33
560	136.72	31	4238.2557	$132.28	$158.74	$161.91	$317.47	$157.15	$285.73	$476.21	$476.21	$624.36	$761.94
445	136.77	36	4923.5454	$153.67	$184.40	$188.09	$368.81	$182.56	$331.93	$553.21	$553.21	$725.32	$885.14
617	138.30	31	4287.4128	$133.81	$160.58	$163.79	$321.16	$158.97	$289.04	$481.73	$481.73	$631.61	$770.77
569	141.15	31	4375.5264	$136.57	$163.88	$167.16	$327.76	$162.24	$294.98	$491.63	$491.63	$644.59	$786.61
298	142.87	31	4428.8262	$138.23	$165.87	$169.19	$331.75	$164.22	$298.57	$497.62	$497.62	$652.44	$796.20
516	144.04	24	3456.9018	$107.89	$129.47	$132.06	$258.94	$128.18	$233.05	$388.42	$388.42	$509.26	$621.47
444	146.00	36	5255.9262	$164.04	$196.85	$200.79	$393.70	$194.88	$354.33	$590.56	$590.56	$774.28	$944.89
178	146.04	25	3650.9265	$113.95	$136.74	$139.47	$273.48	$135.37	$246.13	$410.22	$410.22	$537.84	$656.35
609	146.82	30	4404.6639	$137.47	$164.97	$168.27	$329.94	$163.32	$296.94	$494.91	$494.91	$648.88	$791.85
39	147.33	55	8103.3642	$252.92	$303.50	$309.57	$607.00	$300.46	$546.30	$910.49	$910.49	$1,193.76	$1,456.79
14	147.62	36	5314.2804	$165.86	$199.04	$203.02	$398.08	$197.05	$358.27	$597.11	$597.11	$782.88	$955.38
114	149.73	38	5689.8288	$177.59	$213.10	$217.37	$426.21	$210.97	$383.59	$639.31	$639.31	$838.21	$1,022.89
369	150.48	31	4665.0321	$145.60	$174.72	$178.22	$349.44	$172.97	$314.50	$524.16	$524.16	$687.24	$838.66

Sheet tabs: ShapefileOriginal | Constants | Treatments | AttTable | PresentValue | **FutureGivenPresent(n)** | AnnualGivenPresent(n) | FutureGivenPresent(nf) | AnnualG ...

Table 3. Economic Calculation Tables in Access Database (Personal Geodatabse)

Figure 5 illustrates how the access database is read as a personal geodatabase within the ArcGIS catalog.
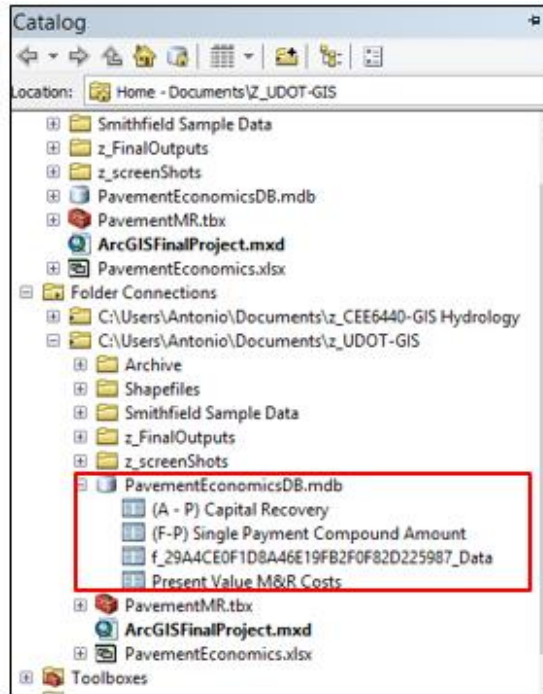

Figure 5. Access Database in ArcGIS

Procedure of Implementation into ArcGIS

At this point in time, the shapefile has been joined and exported so that a permanent shapefile with the TAMS database already incorporated. Because of the multiple tables to compare, a toolbox that does the functions listed below is created.

1. Join Original Shapefile to TAMS database
2. Convert polyline shapefile into three separate polygon shapefile to better visualize pavement area through the use of the buffer tool
3. Re-join shapefile with TAMS data to economic calculation tables from personal geodatabase
4. Perform a conversion to kmz file so that the data can be viewed and referenced in google earth.

The process to building a toolbox is done through the ArcToolbox function. Outlining the steps above, Figure 6 illustrates the completed model.
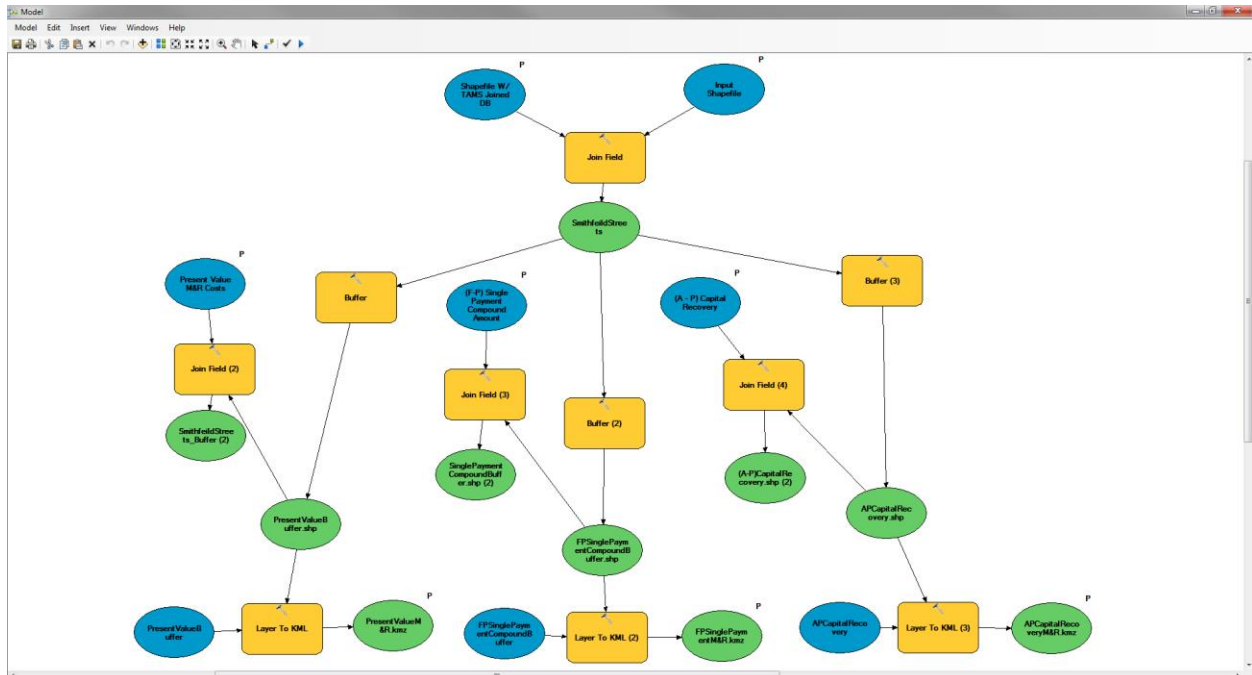
Figure 6. Completed Toolbox in Model Builder

The way the above model works, is through the input of eight basic parameters. The TAMS database will be required before hand to complete an initial join to the original shapefile, also the economic analysis calculations will have to be developed separately and transferred to an access database or otherwise known as a geodatabase.

The required parameters are the original city shapefile, a shapefile joined to the TAMS database, the present value costs table, the single payment compound table, and the capital recovery table. The remaining three parameters are locations of where the kmz file will be saved in the computer. Figure 7 illustrates the request of these parameters in ArcMap.
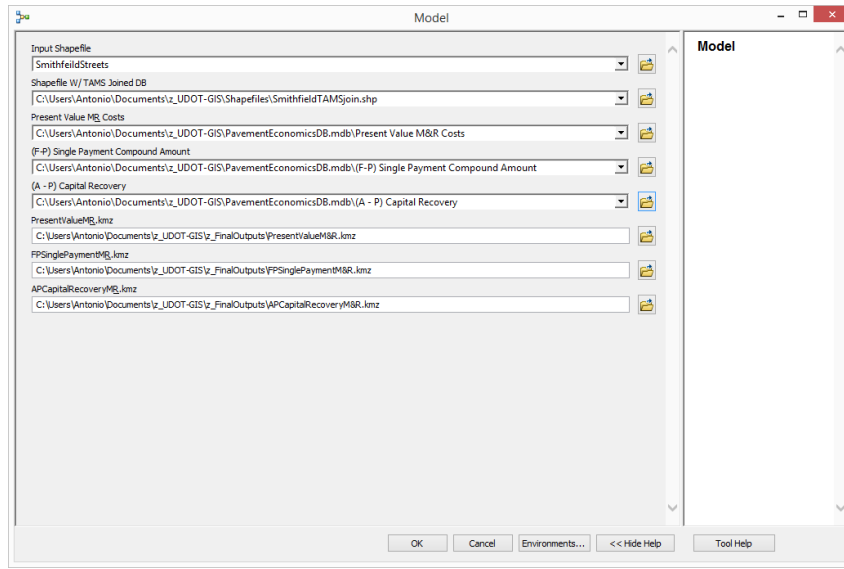
Figure 7. Request of Parameters to Run Model in ArcMap

Results

Thus, after successful implementation of the ArcToolbox model the final results are produced within ArcGIS. Figure 8 illustrates a screen shot of the completed shapefiles within ArcGIS.
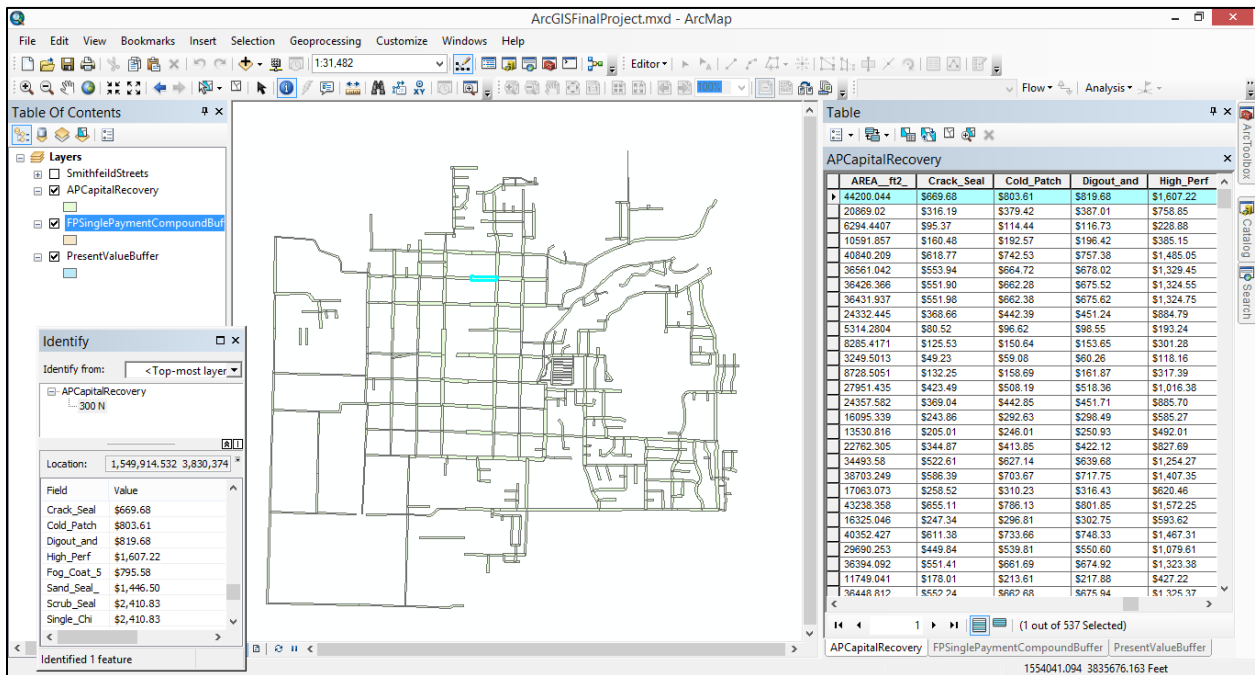
Figure 8. Final Shapefiles Produced

Therefore, the final product are three shapefiles with the TAMS database incorporated into them for reference, but also the treatment costs for all twenty M&R treatments of interest. The costs are of present costs directly using the unit costs of Table 1, but also the single payment

compound amount calculation and the capital recovery calculation. Both of the later are calculated using an interest rate *i* of 6% and a year of analysis *n* of two years.

Along with the production of these shapefiles, three kmz files representing the same data are created in kmz format. These can be opened within Google earth and would be a valuable asset for smaller cities and municipalites that do not have ArcGIS at their disposal. Figure 9 illustrates a screenshot of the final product in Google Earth.

Figure 10 illustrates how the attributes within the shapefile are divided up after the toolbox is successfully utilized. Figure 10 only illustrates the example of the capital recovery table, however there would be a present value and single payment compound amount with similar attributes but different economic values.
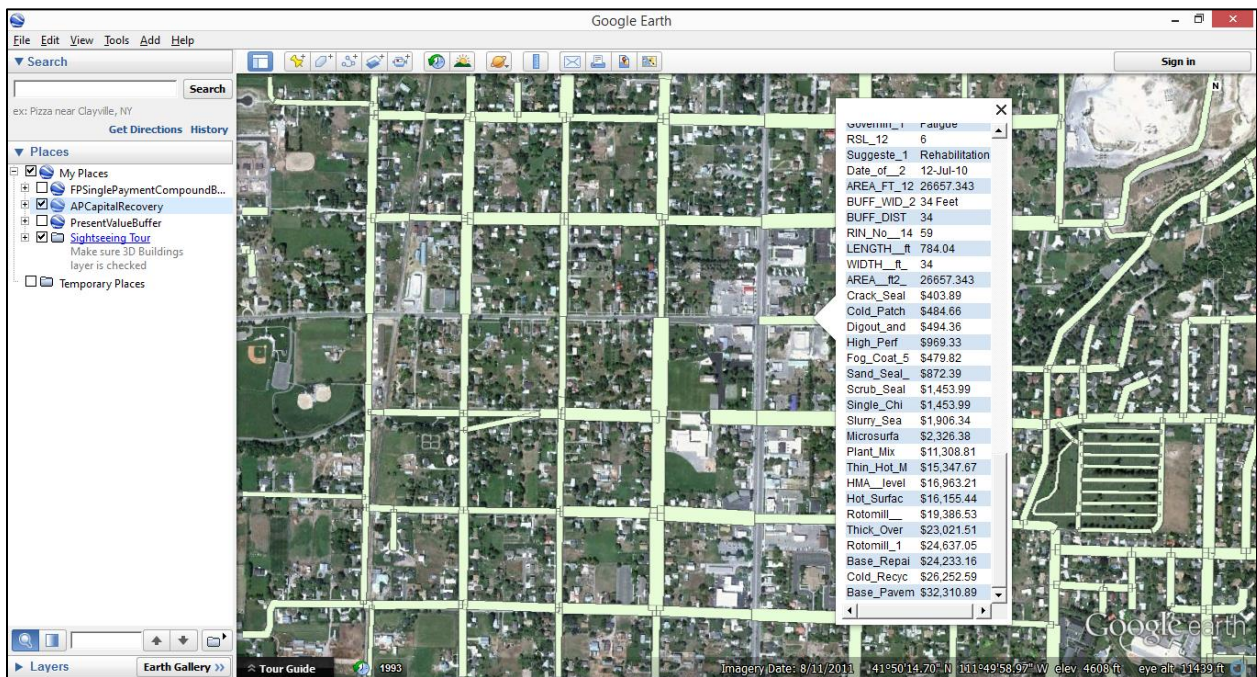
Figure 9. Final Product in KMZ Format Opened in Google Earth
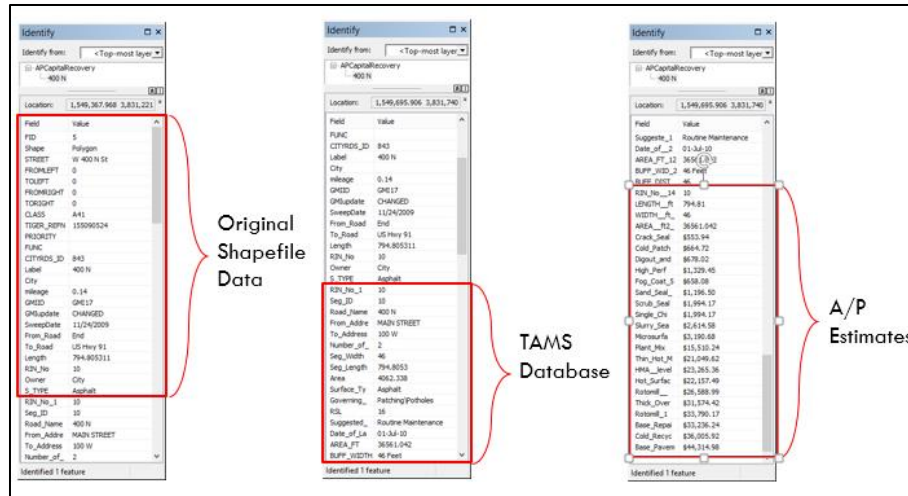
Figure 10. Final Shapefile Attribute Breakdown

Conclusion

In conclusion, through the use of ArcGIS the economic analysis of a city can be greatly enhanced by seeing side by side comparison of implementation costs of M&R treatments. ArcGIS is utilized to better visualize collected data through the TAMS program, and add additional needed information.

By creating an ArcToolbox, the whole procedure is facilitated significantly. However, there are six key pre-requisites that are needed in order to process the toolbox correctly. These are listed below.

1. A TAMS database with length, width, condition and recommended treatment data
2. A list of M&R treatments with their associated unit cost per unit area (square foot)
3. The production of present costs table of all treatments associated with to the segment RIN_No
4. The production of single payment compound table with a known i and n
5. The production of capital recovery table interest table with a known i and n
6. Locations of folder within computer to designate kmz files

Through the production of converting these shapefiles into a kmz format, the availability for cites and municipalities that do not have ArcGIS at their disposal can also benefit from the comparison of all M&R treatments.

The most important feature to take from this project is that based on current costs of M&R strategies, city engineerins and public works director can now compare all of their options by visually selecting their street segment of interest. Ultimately Table 1 shown previously with the unit prices of each M&R treatment becomes an attribute to the city shapefile, and provides a present value cost if implemented at that point in time. Or, if future planning is being conducted the utilization of engineering economics provides a more justifiable estimate to budgets.

Figure 10 summarizes the heart of the project, as each pavement segment contains its estimated cost of M&R implementation. Together with the TAMS database, city engineers and public works directors can make an executive decision with a recommended treatment at hand, and costs of all their options. Ultimately, this is a tool that gives a more comprehensive summary of M&R treatments and does not constraint a recommendation to only one treatment alternative.

Figure 11. Estimate Table becomes Shapefile Attributes

References

Jones, N., (2010) *Analysis and Recommendations for Street Network, Smithfield City*

Shahin, M. Y., Welborn, W., Hammond, L., Kim, S., Meisel R., Cerda, L. (2012) *PAVER^{TM} 6.5 Users Manual.* US Army Corps of Engineers Chapter 13 M&R Plan (95-102)

Utah LTAP (2011). "Utah LTAP TAMS, Transportation Asset Management" *Utah LTAP,* http://utahltap.org/software/tams.php (Nov. 1, 2013)

Utah AGRC. "Road Centerlines" *Roads and Highway system<* http://gis.utah.gov/data/sgid-transportation/roads-system/ *>* (Oct. 2, 2013)