VISUALIZATION OF HIGHWAY PROJECT BIDS USING TREEMAPS

Min Peng ¹, William J. O'Brien ² and James T. O'Connor ³

¹ Ph.D Candidate, Dept. of Civil, Architectural and Environmental Engineering, University of Texas, Austin, Texas, USA
² Assistant Professor, Dept. of Civil, Architectural and Environmental Engineering, University of Texas, Austin, Texas, USA
³ Professor, Dept. of Civil, Architectural and Environmental Engineering, University of Texas, Austin, Texas, USA
Correspond to mpeng@mail.utexas.edu

ABSTRACT : Treemaps, a space filling visualization technique, displays a massive data set of hierarchical data interactively on a single computer screen by mapping it to a matrix of rectangles. It allows users to visually inspect and manipulate data to find new relationships or discrepancies that are to difficult to find using traditional techniques. This paper applies treemaps to the evaluation of highway project bids, which contain hundreds or thousands of elements arranged in a hierarchical structure. Through a case study, treemaps are shown to be a potentially effective tool for bid evaluation by both contractors and State or Federal highway officials.

Key words : *Treemap, Visualization, Highway, Bid, Hierarchical data*

1. INTRODUCTION

1.1 Information visualization

Visual information is easier for people to perceive than other types of information, such as text and audio. Since the 1990s, information visualization has become an active area of research, and several new techniques have been developed during this period. Keim identified five classes of visualization techniques, which are standard 2D/3D displays, geometrically transformed displays, icon-based displays, dense pixel displays and stacked displays [1]. All the techniques were developed to help present the data effectively and most of them allow users to explore the data per their needs by customizing the visual display. The principle of information visualization is to display an abstract data set by mapping its attributes [2].

1.2 Visualization techniques in construction engineering and management

Currently in construction industry, the traditional electronic or paper-based drawings and documents are still the main resources of project information for project management teams. In project management meetings, management team members have to face numbers of construction drawings, contract documents, project schedules containing thousands of activities, and other miscellaneous documents. As construction projects are getting more and more complex during the past decades, the conventional tools do not enable project management teams to perceive and communicate the project information quickly and effectively [3][4][5].

However, there is increasing interest in applying visualization techniques to construction practice. Much of this work has centered around 3D/4D visualization of traditional 2D drawings. 3D virtual models, which are usually generated with CAD software, can provide a much more comprehensive display of the ongoing or completed facility [6][7]. Considering the shortcomings of traditional CPM or Gantt chart schedules, such as their complexity and difficulty for interpretation, researchers developed 4D CAD models to help users monitoring and controlling the construction process by integrating schedules (the 4th dimension) into 3D CAD models [8].

While powerful, 3D/4D models are not complete visualization tools. For example, cost control is a central issue for construction management, and tends to have massive data sets that do not lend themselves to visualization in 3D models. Searching for new visualization methods, Songer and Hays recommended four strategies for visualization of cost data: scatter plots, linked histogram, hierarchical tree, and treemaps [9]. By visualizing the budget or cost control information, treemaps can be used to help the project manager to track the budgeted and actual unit costs of activities and help the accountant to monitor the financial situation of projects. Financial problems and significant changes of unit costs can be found easily from the treemap displays, which will help the accountant and the project manager to take immediate actions [9].

This paper applies treemaps to highway bid evaluation. A highway project bid usually contains thousands of pieces of data presenting the information about highway construction bid items, such as their quantities and bid prices. In a traditional bid document, the large amount of data makes it hard for the contractor to obtain a whole and clear picture of

the bid, or for bid evaluators to analyze the bid(s) in details. Considering the hierarchical structure of the data, the treemap technique is proposed in this paper to visualize highway project bids. In the following sections, the rationale and motivation of implementing treemaps on visualization of highway project bids are described, and an example is demonstrated.

2. HIERARCHICAL DATA AND TREEMAPS

It is not difficult to find a hierarchical data structure in our life: file systems in our computers, the academic units in universities, and the addresses of our apartments are all hierarchical data sets. In a hierarchical structure, data are contained in different segments on a certain number of levels which are assembled to be an "upside-down" tree [10]. To visualize the data organized in a hierarchical structure, researchers have invented several techniques, such as hyperbolic tree browser, Bubble trees, and Magic Eye View [11]. Another successful tool for visualizing hierarchical data is the treemap, which was invented by Ben Shneiderman during the early 1990s. The basic idea of this technique is "turning a tree into a planar spacing" [12]. It uses a simple tab-delimited format file (which contains the attributes and tree structures of the data) as the source data, and enables users to display the whole hierarchical data set on a single computer screen by mapping it to a matrix of rectangles. Users can simply assign the attributes of the data to the size and color of the rectangles to exhibit different aspects of the data.
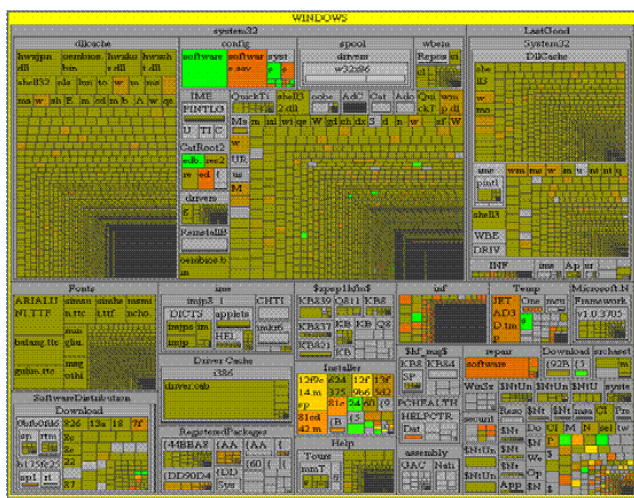

Figure 1. Visualization of computer files system (example)

At first the intent of the inventor was to help finding the large files in the computer and organizing the hard disk space by visualizing the directory tree structures in the hard disk. This space-filling technique utilizes the whole available space to display the data set, which makes it applicable for large hierarchical structures [13]. Although the visualization limit was not the focus of the developers, treemaps can be extended to display even a million items [2]. Figure 1 is the overview of the 16,795 files in the directory C:\Windows in a computer. The computer screen is divided

into numbers of rectangles. Each rectangle represents a file in this directory and the number of rectangles displayed on the screen can be altered by changing the display level in the control window of Treemap Software. The size of each rectangle represents the size of the file, and the color indicates the file age.

Once developed, the treemap has been used as a popular data visualization tool in many different areas: Jungmeiseter developed a visualization prototype for stock portfolio in 1992 showing the different categories in the market [12]; and Asahi, Turo and Shneiderman used treemaps for analytic hierarchy process to help making decision [14]. Another application, DBMap, was developed to help investigating image and non-image data in biomedical data warehouse [15].

3. VISUALIZE HIGHWAY PROJECT BIDS USING TREEMAPS

3.1 Importance of reviewing bid-item level estimates

A highway project bid is a formal offer by a contractor to do all or a part of the construction work of the highway project at a certain price. A typical bid document contains not only the estimated total cost of the project or the part of the project which the contractor is going to bid, but also all the estimated unit prices of the bid items. The distribution of the detailed estimates of the bid items is one of the factors that the decision makers in contractor firms need to consider before they submit bids. The detailed information about the bid items with high costs or high unit prices will be one of the focuses because a little change on the bid prices of these items will significantly affect the whole bid and consequently the chance of wining this bid.

Bid-item level estimates are important as well for bid evaluators in the State Highway Agency (SHA) and Federal Highway Administration (FHWA) because only with the detailed estimates can the bid evaluators compare the bids with engineer's estimate, determine whether the bid is unbalanced, and find out those unit bid prices significantly different with other bids and engineer's estimate. These are three of the twelve factors which bid evaluators should consider when reviewing the bids [16]. No doubt the total cost estimated by the contractor is one of the key issues which will determine whether he or she will win the bid, however, it is not a rule that the lowest bid always wins. As required, evaluators should thoroughly investigate the bids if they are significantly different with engineer's estimate or the bid prices are obviously unbalancing [17]. For instance, it is a policy of the Wisconsin Department of Transportation that materially unbalanced bid will be rejected even though it is the lowest bid [16][18].

There are two types of unbalanced bids. The first one is mathematically unbalanced bids. A mathematically unbalanced bid is defined as "a bid that contains lump sum or unit bid items that do not reasonably reflect the actual costs (plus reasonable profit, overhead costs, and other indirect costs)" [19]. The second one is materially unbalanced bids, which is "a bid that generates reasonable doubt that award to that bidder would result in the lowest

ultimate cost to the Government" [19]. A Mathematically unbalanced bid is not prohibited if there is no specific requirement precluding it, while a materially unbalanced bid may not be accepted [17]. To determine whether the bid is materially unbalanced, the first step is to prove the bid is mathematically unbalanced and find out the items with too low or too high bid prices comparing to engineer's estimates or other bids. There are no specific parameters for proving an unbalanced bid [19]; however, comparing the detailed bid unit prices with engineer's estimate and other bids to see if there are extreme variations could be one of the direct and effective approaches.

3.2 Data structure of a highway project bid

The massive amount of data in highway project bids makes it difficult for bid reviewers to investigate the bids, especially for bid evaluators in SHA and FHWA. Typically, a highway project bid contains all the information about the bid items, such as bid unit prices, bid item quantities, item units, etc. Usually for a highway project, at least two contractors submit bids. It is normal that there are thousands of pieces of data in one bid, leading to tens of thousands of data items across multiple bids. The large amount of data is a problem for both contractors and bid evaluators. Bid reviewers in contractor firms need to find out quickly that which bid items will significantly affect the whole bid and decide whether or not to adjust the bid prices of these items before submitting the bid. Bid evaluators in the SHA and FHWA need to locate the bid items with extremely different bid prices from engineer's estimate from the thousands of pieces of data. To mitigate the troubles caused by the large amount of data, visualization of the bids using treemaps is a proposed approach.
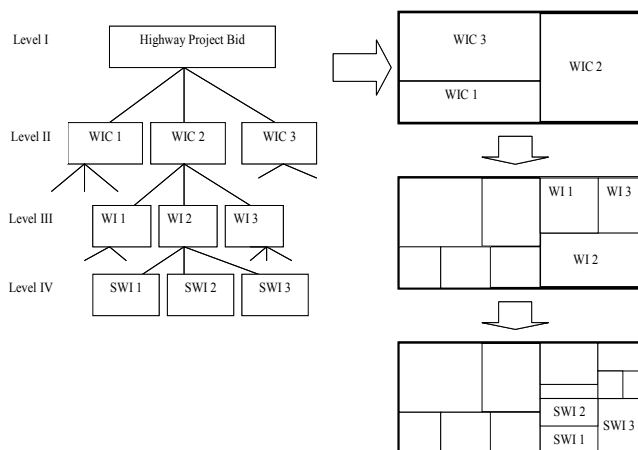

Figure 2. Hierarchical structure (left) and treemaps (right) of a highway project bid

Although the amount is large, the data in a highway project bid are not unordered. They can be organized in a hierarchical structure, which makes it possible to visualize the bid(s) using treemaps. The left part of Figure 2 shows the hierarchy of the bid data. Each work item (WI, Level III) contains one or more sub-items (SWI, Level IV) which are also called bid items; and one or more work items in level III

belong to a work item category (WIC, Level II). On the top of the hierarchy (Level I) is the bid for the highway project or the part of highway project. The right part of Figure 2 is a general view of the treemaps presenting the two-level, three-level and four-level hierarchical structures in a highway project bid. After the data file (tm3 format) with all the attributes which users are interested in is generated, bid reviewers can easily customize the display on the screen by assigning different attributes to the size and color of the rectangles to exhibit different aspects of the bid data per their needs.

3.3 Case study

To illustrate how to visualize highway project bids with treemaps, a project let in December 2004 in Dallas (Texas, USA) is presented. It is a reconstructing and widening an existing roadway project with the project length of 1.072 miles. The engineer's estimate for this project is $7,147,520.38. There were five contractors bidding this project and the bids were between $7,584,616.90 (bid 1) and $8,772,848.97 (bid 5).

ITEM CODE	ITM DES SP	ITEM DESCRIPTION	UNIT	QUANTITY	ENG EST	BIDDER 1	BIDDER 2	BIDDER 3	BIDDER 4	BIDDER 5
100	502	PREP ROW	STA	56.590	2,000.00	5,573.000	2,622.000	1,500.000	310.000	15,000.000
104	505	REMOV CONC (MED)	SY	404.000	9.50	6.000	4.380	7.000	6.000	11.000
104	509	REMOV CONC (SDWLK)	SY	1886.000	6.25	5.250	3.560	7.000	6.000	10.000
104	511	REMOV CONC (DRVWY)	SY	4623.000	7.00	5.250	4.380	7.000	6.000	9.000
104	514	REMOV CONC (CURB)	LF	19315.000	4.50	1.000	2.030	7.000	1.500	4.000

Figure 3. Part of bids tabulation

Figure 3 is a part of the bids tabulation. In the tabulation, the "ITEM CODE" represents the work item number (level III in the hierarchy) and "ITM DES SP" represents the sub-item number (Level IV in the hierarchy). It also shows the unit, quantity, engineer's estimate and all the bid prices for each sub-item (bid item). In this paper, only bid 1 and bid 5 are investigated along with the engineer's estimate using treemaps. The Software used in the following discussion is Treemap4.1 (Non-commercial use, Copyright 2003 University of Maryland).
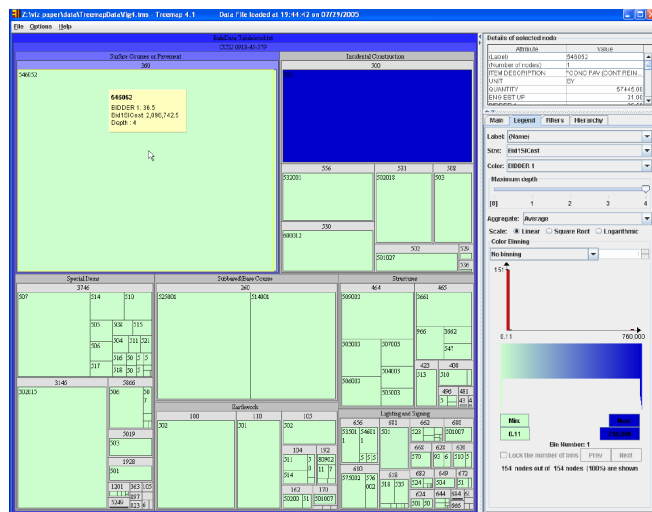

Figure 4. All-level hierarchy of a single bid (rectangle size represents bid item cost; rectangle color represents bid unit price)
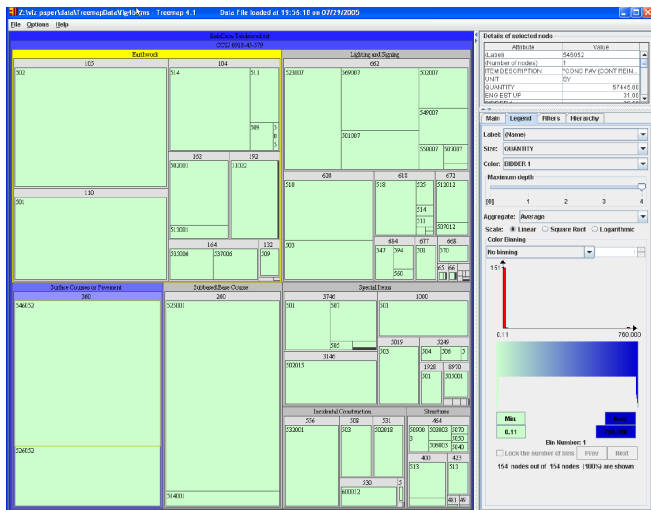
Figure 5. All-level hierarchy of a single bid (rectangle size represents bid item quantity; rectangle color represents bid unit price)

Figure 6. All-level hierarchy of a single bid (filtered display)

Figure 7. Compare bid 5 with engineer's estimate

Figure 4 shows a treemap of the all-level hierarchy of bid 1. It provides a whole picture of the bid for reviewers. When the user clicks the mouse on the rectangle which he wants to explore, all the information about the bid item, such as item description, unit, and quantity are shown in the "Details of selected node" window on the upper-right screen. In the display, the size of each rectangle represents the cost of the bid item (SWI) (the bigger the more costly), and the color represents the bid unit price of the bid item (the darker the higher unit price). Users can easily find out that the most costly bid item is 360-546052 (WI#-SWI#) "CONC PAV – CONT REINF 9in"; and bid item 500-501 "MOBILIZATION" is bid with the highest unit price. If the contractor tries to reduce the total amount of the bid, apparently these bid items are the first objects to look into.

Some users might be more interested in other attributes of the bid, for example, the quantities of bid items. They can assign this attribute to the size (Figure 5) or the color of the rectangles in the "Legend" tab, and then the treemap displays a different layout as the users want. Treemap can also only display the data which meet the requirements of users. For instance, if users are only interested in the bid items with cost% higher than 5%, they can select the data by filtering them in "Filters" tab. The bid items which do not fit the criteria appear grey on the treemap (Figure 6). By changing the layout parameters, users can investigate much more aspects of the bid than mentioned above, for instance, users can control the display of different levels of the hierarchy by changing the "Maximum depth" in the "Legend" tab.
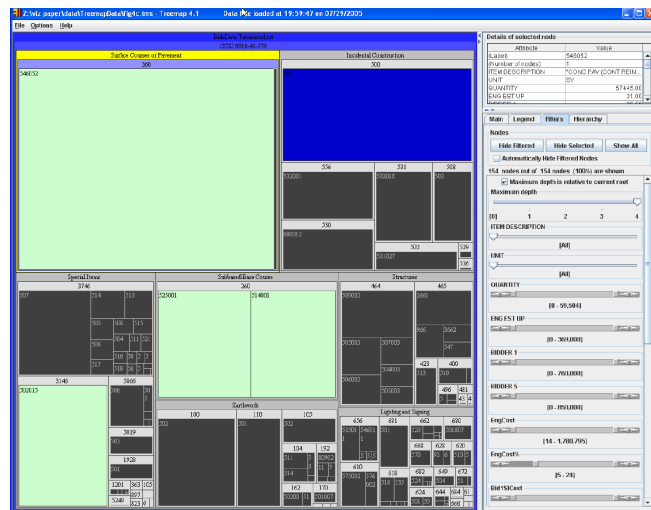
In the bid analysis procedure utilized by the Wisconsin Department of Transportation, "an item will be considered significantly unbalanced if the difference between the low bidder's unit price and the estimate, expressed as a percent of the estimate, is greater than +50% or is less than -75%." [16][18]. Treemaps can help the evaluators to easily capture those items. Figure 7 shows the unit price variances of bid 5 from the engineer's estimates. The sizes of the rectangles represent the engineer's estimates of the bid items; and the colors represent the differences in percentages between the bid unit prices and the engineer's estimates. The pink or red color indicates that the bid unit price is lower than the engineer's estimate and the blue color means that the bid unit price is higher than the engineer's estimate. The darker the color, the larger variance is between the bid price and engineer's estimate. The color widget on the lower-right screen shows the variances of bid 5 from the engineer's estimates are between -97.75% and 950.00%. Comparing the colors of the rectangles with the color bins in the color widget, evaluators can easily find the bid items with large negative or positive variances, such as in this example the bid items 3746-519 (REMOVE AND RELOC WATER METER AND BOX) and 100-502 (PREP ROW). The evaluators can find out the details of these items by simply clicking the target rectangles on the screen and then all the information will be shown in the "Details of Selected Nodes" window. It should be noticed that these items are not necessarily to be the bid items with the largest variances from the engineer's estimates. The reason is that there might
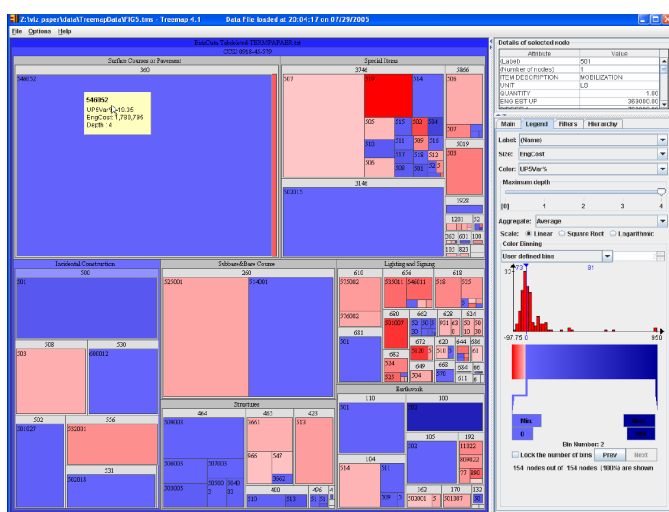
be some other bid items with even larger variances are invisible on the screen because the costs of these items are extremely low which makes the rectangles too small to be seen on the screen. Although with large variances in bid prices, comparing to other higher-cost bid items, those higher-unit-price extremely-low-cost items are not worth analyzing. The bid items with high total costs are also the targets of the evaluators because the variances of bid unit prices of these items significantly affect the variation of the total amount of the bid. Apparently the bid item with the highest cost in this bid is item 360-546052 (CONC PAV – CONT REINF 9in), whose bid unit price is 19.35% higher than the engineer's estimate.

Treemaps can also enable the evaluators to compare other issues which they are interested in, such as cost (or cost percentage) variation of the bid item from the engineer's estimate, or to compare different bids by assigning different attributes to the size and the color of the rectangles. Based on the information exhibited by treemaps, bid evaluators can easily explore the bid data per their needs.

4. CONCLUSION

When looking at thousands of pieces of data in the highway project bid tabulation, reviewers want to draw out the information which they are interested in quickly and efficiently. Visualizing the bids using treemaps is demonstrated as a potentially effective approach. Both contractors and evaluators can benefit from this technique. For contractors, the visualization of the bid provides a whole picture of the bid, displays the cost distribution of the bid items, and helps them to locate the bid items which need more concern. By adjusting the bid based on the information displayed by treemaps the contractor can increase his chance of winning the bid. For bid evaluators, although the visualization of bids using treemaps can not tell them directly that which bid is materially unbalanced because the variance of the bid price from the engineer's estimate is not the only one criteria, however, it can make it easier for the evaluators to locate the target bid items for further analysis from the huge dataset in the bid tabulation.

REFERENCES

[1] Keim, D., "Information Visualization and Visual Data Mining", *IEEE Transactions on Visualization and Computer Graphics*, Vol. 7, No.1, pp. 100-107, 2002.

[2] Fekete, J., and Plaisant, C., "Interactive Information Visualization of a Million Items", *Proc. of IEEE Symposium on Information Visualization 2002 (InfoVis 2002)*, pp. 117-127, 2002.

[3] Liston, K., Fischer, M., and Kunz, J., "Designing and Evaluating Visualization Techniques for Construction Planning", *Proc. of the 8th International Conference on Computing in Civil and Building Engineering (ICCCBE-*

VIII), pp. 1277-1292, 2000.

[4] Issa, R., Fukai, D., and Danso-Amoako, M., "Evaluation of Computer Automatic Modeling for Analyzing Pre-Construction Problems", *Proc. of Construction Research Congress (Honolulu, Hawaii)*, 2003.

[5] Liston, K., Fischer, M., and Winograd, T., "Focused Sharing of Information for Multi-Disciplinary Decision Making by Project Teams", *Proc. ITcon*, Vol. 6, pp. 69-81, 2001.

[6] Heesom, D., Mahdjoubi, L., and Proverbs, D., "A Dynamic VR System for Visualizing Construction Space Usage", *Proc. of Construction Research Congress (Honolulu, Hawaii)*, 2003.

[7] Akinci, B., Tantisevi, K., and Ergen, E., "Assessment of the Capabilities of A Commercial 4D CAD System to Visualize Equipment Space Requirements on Construction Sites", *Proc. of Construction Research Congress (Honolulu, Hawaii)*, 2003.

[8] Koo, B., and Fischer, M., "Feasibility Study of 4D CAD in Commercial Construction", *Journal of Construction Engineering and Management*, July/Auguest, pp. 251-260, 2000.

[9] Songer, A., and Hays, B., "A Framework for Multi-Dimensional Visualization of Project Control Data", *Proc. of Construction Research Congress (Honolulu, Hawaii)*, 2003.

[10] Rob, P., and Coronel, C., *Database System: Design, Implementation, and Management, Sixth Edition*, Thomson Course Technology, 2004.

[11] Chintalapani, G., Plaisant, C., and Shneiderman, B., "Extending the Utility of Treemaps with Flexible Hierarchy", *Proc. of the 8th International Conference on Information Visualization (IV'04)*, 2004.

[12] Shneiderman, B., "Treemaps for Space-Constrained Visualization of Hierarchies", *URL: http://www.cs.umd.edu/hcil/treemap-history*, date accessed: March 15, 2005.

[13] Johnson, B., and Shneiderman, B., "Tree-maps: A Space-Filling Approach to the Visualization of Hierarchical Information Structures", *Proc. of the 2nd Conference on*

Visualization '91, pp. 284-291, 1991.

[14] Asahi, T., Turo, D., and Shneiderman, B., "Visual Decision-making: Using Treemaps for the Analytic Hierarchy Process", *Conference Companion, ACM CHI'95*, pp. 405-406, 1995.

[15] Zhang, M., Zhang, H., Tjandra, D., and Wong, T.C., "DBMap: A Space-Conscious Data Visualizaiton and Knowledge Discovery Framework for Biomedical Data Warehouse", *IEEE Transactions on Information Technology in Biomedicine*, Vol. 8, No.3, pp. 343-353, 2004.

[16] Federal Highway Administration, U.S. Department of Transportation, *Guidelines on Preparing Engineer's Estimate, Bid Reviews and Evaluation*, 2004.

[17] Federal Highway Administration, U.S. Department of Transportation, *Memorandum: Bid Analysis and Unbalanced Bids*, 1988.

[18] The Wisconsin Department of Transportation, *The Wisconsin DOT Construction and Materials Manual*, Section 2.1.2.1.1, Revised Oct. 1998.

[19] Federal Highway Administration, U.S. Department of Transportation, *Contract Administration Core Curriculum Participant's Manual and Reference Guide 2005*, 2005.