WHITE PAPER # 1- iTRAVEL (infovis for Transportation-Related Asset Visual-Expression Language)

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INTRODUCTION

The infusion of data has permeated virtually every facet of society, from communication, to social networking, to homeland security. In each case, the challenge has been to channel information to users in ways that clearly improves decision-making, and not complicate it. With information reaching users in many different formats (e.g., voice, text, visual), the challenge often manifests itself in difficulties in reconciling data of different types, i.e., how to merge visual information with textual data, or how do we effectively integrate information of varying resolutions. These are all issues that – in one form or another – have shaped the way in which technology is adopted by the broader end-user community.

In no other case has Data and Visual Analytics (DAVA) had a greater opportunity to ignite a major shift in decision-making as in transportation infrastructure management. With over 5 million miles of highway network in the U.S. and billions of dollars spent each year on maintenance and repair, the opportunity to improve data collection, analysis, processing and dissemination technologies is enormous. Transportation departments are beginning to reap the fruits of more advanced sensing technologies; however, significant progress in both short-term and long-term planning continues to lag because the tools needed to better assess the efficacy of new transportation management strategies have yet to be developed. For example, remote sensing technologies that have emerged in recent years as a viable infrastructure monitoring solution (see USDOT RITA program on Remote Sensing, USDOT, 2006) has not been fully integrated into the field-based systems that are typically used by transportation departments to determine the current state of highways and bridges. Because of this, the ability of transportation departments to launch long-term maintenance programs is hampered, resulting in deteriorating highway systems and increasing costs to the public through traffic congestion, decreased highway and traffic safety, damage to vehicles, higher rates of energy consumption, and pollutants expelled.

The visual analytics community is correct in its assessment that the state of visualization practice in the surface transportation field continues to focus predominantly on the geo-spatial attributes of ‘structures’ (their form, their location, etc.), and to a lesser extent on performance attributes (e.g., their ‘capacity’ expressed in allowable weight limits, daily or hourly traffic volumes, etc.) [1]. There is an emerging recognition that major infrastructure improvements are not solely dependent upon ‘structures’ and ‘facilities,’ but on ‘operations.’ A ‘functionally deficient’ rating for bridges, for instance, can have as much an impact on overall system performance as a ‘structurally deficient’ bridge that results in some of the traffic stream having to be re-routed. This shift constitutes an important ‘research need’ within the area of transportation visualization (see TRB Research Need Statements [2]).

The goal of effective transportation infrastructure management is to maximize the performance of highway networks by identifying the current state-of-repair of a network and implementing preventive or remedial measures to reduce future damage and disruption. Most state transportation agencies have implemented various infrastructure management programs (bridge management, pavement management, safety management; some have actually created positions of "transportation asset managers" or something similar. However, the data used to achieve the goal above are limited. Ideally, a state agency would collect robust datasets of different modalities and use this information to prioritize surveys, maintenance and repairs, and reconstruction projects. In order to do this, they would need methodologies that would fuse the information together to better populate the decision-making tools used in their normal workflow process. A stronger foundation in DAVA-related applications would help to achieve the goal of cost-effective infrastructure management.

To address the need of enhancing visual analytic applications to transportation engineering applications, there is a need to establish the proper tools that would allow transportation engineers to: 1) appreciate DAVA; 2) utilize DAVA; and 3) generate DAVA. Towards this goal, this research aims to develop a universal visualization language that is adaptive enough to allow transportation asset professionals the ability to create domain-specific, knowledge-revealing data visualization methodologies to improved infrastructure management decision-making. The research seeks to establish a methodological framework for integrating data of different modalities that will complement existing infrastructure management processes. It will synergistically exploit quantitative and qualitative information, textual-based and visual data, and time-variant information, enhancing the value of all and facilitating a deeper understanding of what strategies work best in improving the performance of our nation's highways. The methods developed will be replicable for different locations of the country; the methods will also be designed with an eye towards other infrastructure. The multi-disciplinary team of investigators brings together the necessary background and skills to achieve the research goal above.

RESEARCH OBJECTIVES AND GENERAL GOALS

The proposed research study will achieve the following specific objectives:

1. **Universal Visualization Language.** Develop a language that will allow analysts to fuse data of different modalities, resolutions and temporal patterns in order to more effectively assess the state of a transportation mode.

2. **Visual Analytic Standards for Transportation Operations and Asset Management.** Develop a data-driven approach to model system-level management processes that will significantly enhance transportation utilities and optimize resources for transportation asset management.

3. **Prototype DAVA Tools for State Transportation Agencies.** Develop a suite of tools that can easily be adapted to transportation agencies' focus on damage assessment, traffic control, maintenance, and asset management. Transportation systems are ideal for DAVA applications since they utilize large visualization datasets (directional signs, markings, dynamic message boards, traffic flow monitoring systems) and often depend on multi-modal communication systems (traffic reports from TV, radio and portable traffic information receivers).

4. **Case Study.** Utilize an existing testbed to demonstrate the efficacy of the results above. The UNCC/ImageCat research team is currently performing a study for the U.S. Department of Transportation to augment bridge evaluation techniques by introducing remote sensing technologies [3]. We are collaborating with approximately 10 state and local transportation agencies to develop this system. These testbeds and their associated datasets will be used to evaluate and validate the methodologies and tools described above.

5. **End-User Participation.** The research team has engaged several end-user organizations in the preparation of this proposal. We intend to continue their participation by establishing a

project steering committee that will help to evaluate research progress and to ensure end-user participation, support and adoption.

INTELLECTURAL MERITS

The intellectual merit of this research can be summarized in our five objectives, which address the challenge in establishing DAVA foundation by using transportation asset management as a visual analytic testbed. By conduct critical data collection and establishing a universal visualization language for transportation, which will be embedded in a DAVA prototype tool, we allow domain experts to acquaint with visual analytics and start to generate their own visual analytics expertise. The DAVA foundation is then established via an integrated study that engages both end-users and research team which is an assembly of experts of the transportation domain including transportation operations (Edd Hauser), transportation data visualization expert (Ron Hughes), disaster management expert (ImageCat Inc), bridge and road engineer (Shen-En Chen) and government and industry liaison (Kelley Rehm). The team will operate under DAVA specialist and FODAVA-liaison, Bill Ribarsky. The monitored outcome of this study will then provide the information necessary to establish the DAVA foundation.

The area of operations and system performance introduces a very large, real time data component, one that is not readily handled by a purely structural approach to transportation asset management. Thus, the challenge for visualization as it is presently practiced in transportation is how to move from a representation of how things are constructed and how things ‘look’ to a representation of how things ‘operate.’ It is no longer, for example sufficient to show a ‘structural’ visualization of a roundabout. Now one is expected to show a visual simulation of how it ‘operates.’ Furthermore, there is the expectation that designers understand the basic functional relationships between system demand and system design such that traffic simulations are able to confidently project the performance of systems that have yet to be constructed.

This research effort will consider a wide variety of data sources/formats. Transportation management studies typically utilize a broad set of heterogeneous data: aerial photographs, in-situ photos, survey data, video showing traffic conditions, hand-written and digital reports, topographic information. These data are brought together in a useful and meaningful way to help make decisions regarding traffic management, new design, repair and maintenance, and emergency routing. Merging this information is not so much a data integration or data formatting issue. Rather, it is a building a <u>*new form of mathematics*</u> (or a possible consistent mathematical structure) that will maximize the reliability of every highway assessment by “triangulating” into solutions using multiple data sources and visualizing the results through multi-functional interfaces [4].

Table 1 shows an incomplete list of common mathematics used in different disciplines. While commonality such as statistical methods, matrix analysis can be identified. However, data and models can be very different. Missing in the list include text analysis, many documentations are in text format (i.e. bridge inspection reports). Hence, a meaningful semantic overlay on different types of data and the models so that both data and results can be extracted and related at the level of human reasoning will be the drive for current research – within the context of transportation management.

Table 1. Relationships among mathematics and computer applications associated with transportation

Domain discipline	Examples of Math Used	Computer applications
Multivariate Data Analysis	Statistics, regression theory	Statistical analysis, principal component analysis
Temporal data analysis	Advanced calculus, Laplace, Z, Fourier and Wavelet transformation; time- frequency analysis	Digital signal processing, spatial data analysis
Operations research	Linear programming, sequence theories	Optimization, discrete event simulation
Mechanics – fluid, gas, thermal and solids	Linear algebra, matrix analysis, differential equations, Fourier and Laplace transforms	Numerical simulation, computational fluid dynamics, linear elastic/plastic analysis.
Environmental science	Statistics, differential equations, matrix analysis	Numerical simulation, computational fluid dynamics, pathogen studies
Disaster Management	Statistics, numerical analysis, differential equations, sequence theories	Data driven dynamic simulations, geo-spatial information displays,
Video and Image Analysis	Linear algebra, matrix analysis, transformations	Digital image processing

RESEARCH SIGNIFICANCE

This research project will produce unique, comprehensive collections of multiple types of transportation data, including new remote sensing-based data and previously underutilized statistic data. With the support of our project steering committee, the data will be systematically and rigorously examined to develop insights regarding more effective infrastructure management. Developing new methods and tools for analyzing and visualizing multi-modal transportation data will benefit those who manage, operate, design, and retrofit transportation systems. Having such methods and tools will help in addressing the following questions:

- What is the current state-of-repair of our highway system? And how rapidly is it degrading?
- What factors are contributing most the degradation of our highway systems?
- What datasets are needed in order to effectively monitor the state of our highway systems?
- What is the most cost-effective means of improving the overall performance of our highways?
- What strategies would be most effective in reconstructing highway systems after major disasters, e.g., earthquake, hurricanes, terrorist attacks?

By enhancing our ability to address these questions, this research will bring many practical societal benefits. It will offer transportation agencies, and ultimately all infrastructure operators, new ways to measure, monitor and evaluate the performance of key lifeline systems. The research will also help lay the groundwork for future research in DAVA in order to establish a true scientific foundation. The research team will engage FODAVA-Lead scientists in soliciting results and opinions that would enhance the proposed research and the formation of the Steering Committee (see tasks). The data generated and collected in this transportation-related research will be submitted to the FODAVA testbed database. Towards this effort, Dr. Ribarsky will attend the annual program reviews and discuss with FODAVA – Lead on possible opportunities in using current project to establish a critical scientific basis to quantify DAVA and the sense-making mechanism for transportation engineers. To address these questions, this research will specifically:

- Help standardize transportation operations data display to make complex data more comprehensive to the managers and reduce abstract Information to visible language.
- Establish the industrial standard that represents best practices in the integrated display of physical data and visual analytics.
- Generate the tools to enhance the education and potential future curricular development.

4. Brief Summary of Previous Research on DAVA Applications in Transportation Planning

The Transportation Research Board (TRB) has held visualization symposia since 1995. Recent publication of the *Synthesis of Highway Practice* (2006) identified the specific visualization applications in public and private sectors of transportation systems including:

- Visualization as a business tool
- Integration of visualization as data sharing among agencies
- Project-oriented visualizations including design/build, context-sensitive solutions and homeland securities
- Visualization as a staff training tool
- Improvement of public involvement in the development of transportation projects
- Application toward institutional issues. [5]

Currently, there is an extensive literature base that is devoted to the use of visualization to support transportation simulations and planning. For example, both VISSIM [6] and CORSIM [7] are widely used to visualize traffic simulations and microscopic traffic controls. Also, complex 3D visualizations are often adopted to facilitate the transportation design and maintenance processes, such as NC3D [8], a 3D visualization tool for the design of high speed railroads.

On the other hand, the use of visualizations to perform data analysis and management is still in a preliminary stage, which means that a full DAVA approach has not been studied or implemented. Although some simulation-based highway management systems have been developed by Plaisant et al. [9], the main thread in this research focuses on depicting and extending knowledge from the geospatial nature of transportation information. Geospatial visualization is a well-established area of research, especially in the field of Geographical Information Systems (GIS), such as GeoVista by Takatsuka et al. [10] and GeoTime by Kapler et al. [11], and commercialized GIS systems have been developed to specifically help depict transportation data. For instance, the GeoTrAMS [12] is specifically designed to manage the train transit and rail assets, while TransCAD [13] focuses on road management. To the best of our knowledge, the only system that is used to manage transportation data from both geospatial and multi-variate aspects is developed by Wongsuphssawat et al.[14] to perform data analysis of federal highway incidents.

As complex as transportation networks are, involving bridges, roads, tunnels, other structures, and all the different inspections and sensing technology, only depicting from the geospatial facet could frequently limit the transportation managers understanding. Our approach, however, will provide transportation managers the ability to comprehend the information on not only geospatial and multivariate aspects but also on meaningful details of the transportation infrastructure and temporal aspects.

Figure 1 provides a recent example of how the current research team has applied visual analytics to a bridge management system [2]. This system was created from observations and discussions with bridge managers at the North Carolina Department of Transportation (NCDOT) and the Charlotte Department of Transportation (CDOT). The visual analytics system shown in Figure 1 not only provides for novel interactive data exploration, but it can serve as a decision-making tool to prioritize bridge inspections for repair and maintenance.

There are three main elements in this system. First, by utilizing advanced visualization and analysis methods, the system supports a highly-interactive visual environment that can assist bridge managers understand and quantifying their assets. Second, with coordinated views, the system can also provide important information on current bridge conditions that would minimize errors caused by limited or subjective reports. Finally, by incorporating temporal information on the condition of a bridge, the system helps a bridge manager monitor and analyze potential damage trends and patterns over time, thus providing an important database to understand the potential causes of damage. The intent of this proposal is to extend the methodology presented here to include other forms of data that can help with infrastructure management programs.

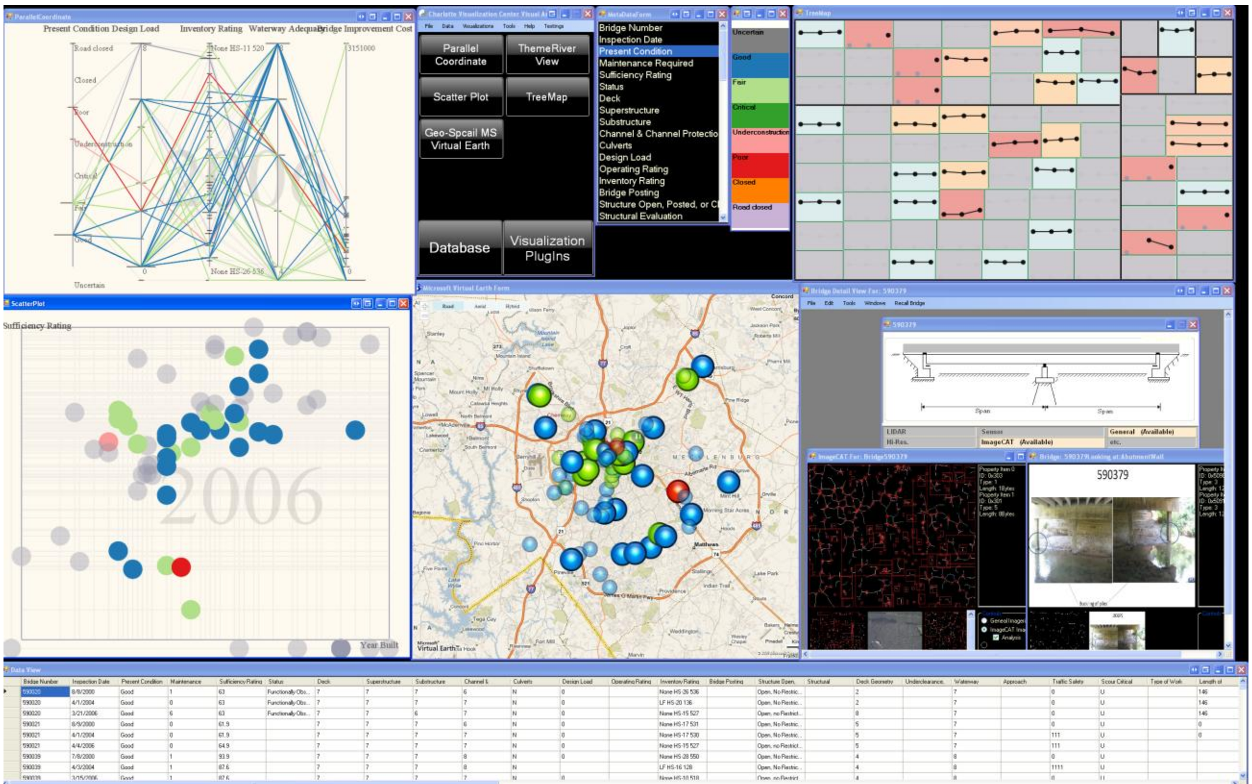

Figure 1. Visual Analytics Example for Bridges [6]

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