Twenty-Seventh Annual

GEOSPATIAL INFORMATION SYSTEMS FOR TRANSPORTATION SYMPOSIUM

To provide a forum for transportation officials from State, Province, Federal, and Municipal Agencies to discuss GIS and transportation issues

May 6 – 8, 2014
Workshops – May 5, 2014
Burlington, Vermont
# Table of Contents

**OVERVIEW OF THE GIS-T SYMPOSIUM** .................................................................................................................. 3

**THE 2013 GIS-T SYMPOSIUM** .......................................................................................................................... 3

- SYMPOSIUM BACKGROUND ................................................................................................................................. 3
- SYMPOSIUM STRUCTURE ........................................................................................................................................ 4
- WORKSHOPS ......................................................................................................................................................... 6

**STATE SUMMARY REPORT** ............................................................................................................................... 12

- GIS ORGANIZATIONS ............................................................................................................................................. 12
- DATABASE SOFTWARE .......................................................................................................................................... 13
- ROAD CENTERLINE NETWORKS ....................................................................................................................... 13
- BENEFITS AND COSTS OF GIS-T APPLICATIONS ............................................................................................. 13
- CURRENT ACTIVITIES ........................................................................................................................................ 13

**STUDENT PAPER CONTEST** ............................................................................................................................. 14

**GIS-T GALLERY** .................................................................................................................................................. 15

**CONCURRENT SESSIONS** ................................................................................................................................... 16

**SYMPOSIUM SUMMARY** .................................................................................................................................... 16

**APPENDIX A – ROLL CALL OF STATES** .................................................................................................................. 17

**APPENDIX B – STATE GIS-T CONTACTS** .............................................................................................................. 43

**APPENDIX C – GENERAL SCHEDULE** .................................................................................................................... 46

**APPENDIX D – WINNING STUDENT PAPER** ........................................................................................................... 47
Overview of the GIS-T Symposium
The twenty-seventh annual Symposium on Geospatial Information Systems for Transportation (GIS-T) was held in Burlington, Vermont from May 5, 2014 through May 8, 2014. The Symposium focuses on providing a forum for transportation professionals interested in the design and use of GIS-T. It brings together individuals from education, the private sector, and all levels of government for a full day of workshops and two and a half days of professional development. The Symposium provided opportunities for participants to network with peers to discuss emerging issues and concerns.

Season for Change” was chosen as the 2014 Symposium theme. The theme was an acknowledgement to GIS-T’s continuing evolution and expansion into varied functional business areas. The logo is shaped like the state of Vermont, with pictures of seasonal changes, a metaphor for GIS-T utilization for all business seasons.

A total of one-hundred and twenty-two (122) professional abstracts were submitted during the Call for Presentations. The Program Committee rated the abstracts, selected eighty-four (84) for inclusion in the program, and developed “like categories” for thematic presentation. The selected technical papers and abstracts are available through the GIS-T web page (http://www.gis-t.org). The State Summary Report, Roll Call of States, and the State GIS Contacts list can be downloaded too.

Again, the 2014 program included the GIS-T Roll Call Round Tables. The Roll Call Round Tables’ topics were chosen by compiling appearances on the Roll Call of States’ Issues List. The GIS-T planning committee then selected two round table topics: Developing, Building, and Using a Statewide Road Base Map and Data Life-Cycle; Collecting, Managing, Updating, and Disseminating Data. At the Symposium, facilitated open discussions were held. Broad participation was observed from both the public and private sectors. Notes were taken and subsequently published on the GIS-T web site.

The 2014 GIS-T Symposium
Symposium Background
The GIS-T Symposium is sponsored by the American Association of State and Highway Transportation Officials (AASHTO), and affiliated with the Transportation Research Board (TRB), the Urban and Regional Information Systems Association (URISA), the Federal Highway Administration (FHWA), the Federal Transit Administration (FTA), National Association of Regional Councils (NARC), American Metropolitan Planning Organizations (AMPO), U.S. Department of Transportation, Research and Innovative Technology Administration, National Association of Regional Councils and the American Society of Photogrammetry and Remote Sensing (ASPRS). The Symposium originated to provide:

- education
- information sharing with other transportation agencies
- exhibitor displays of new and current technology
information for individuals who are facing similar problems in other transportation organizations

The Symposium is managed by a Task Force and organized by a Planning Committee. The Task Force is a seven-member group representing DOT’s by the four (4) AASHTO regions, and a chair person, FHWA, and AASHTO. The Task Force members are also Planning Committee members. The Planning Committee is a larger group comprised of subcommittees for each of the Symposium organizing tasks, such as program development, moderators, local arrangements, technology hall, workshops, registration, publicity, student paper, emerging issues, State Summary Report, Roll Call of States, Roll Call Round Tables, map gallery, and web site. This year’s Symposium continued the focus on opportunities and issues of applying GIS technology to the business of transportation agencies.

**Symposium Structure**
The Symposium registration started on Monday morning, May 5, 2014. The registrant demographics were three hundred and fifty-two (352) total attendees; forty (40) states were represented as well as the District of Columbia, county and local governments, federal agencies, regional planning organizations, academia, and Canadian Provinces (attendees and vendors).

A General Symposium Schedule is found in Appendix C.

Workshops were conducted on the Monday before the Symposium start. This year, eight (8) half-day workshops were held. A Monday evening technology hall reception signaled the Symposium kick-off. Twenty-Six (26) exhibitors; including software companies, consultants, and data and equipment suppliers were present. The technology hall exhibits were available through Thursday; a second technology hall reception was held Tuesday evening.

The formal Symposium started Tuesday morning with welcomes from Frank DeSendi, Pennsylvania Department of Transportation, AASHTO GIS-T Chair, and Eric Filkorn, Public Outreach Manager at the Vermont Agency of Transportation. Mr. Filkorn introduced Sue Minter, Deputy Secretary at the Vermont Agency of Transportation.

Ms. Minter welcomed the attendees and then discussed her first 7 months at the agency. With three declared disasters and Tropical Storm Irene, Ms. Minter quickly learned GIS’s value in the agency’s ability to respond to the crises:

- Set-up command centers
- Identify isolated communities
- Facilitating internal communications
- Disseminating information publicly

Additionally, Ms. Minter offered lessons learned managing the disasters such as using mobile computing to collect asset information, documenting lessons learned, building culverts to handle the load, not simply replace them, and cross train and empower staff.

The GIS-T 2014 Symposium keynote speaker was Frank Winters. Mr. Winters is Director of the New York State GIS Program Office.
Mr. Winters shared his experiences and lessons learned working on Hurricane Sandy recovery in New York City. His overarching lesson is unclear communication and the making of assumptions can cost time, money and lives.

- Because data was not real-time it should be noted with validity date/time. Often decisions are made on data that is expired.
- External data supplied should be verified before decisions are made. Recovery team received a database of gas stations they could use to set up emergency deliveries, but the locations included many business offices that owned the gas station not the stations themselves.
- Most areas impacted by Sandy’s storm surge were the man-made areas of Manhattan.

Mark Sarmiento, of FHWA, next presented the State Summary Report. The State Summary Report (GIS-T Activities) section begins on page twelve (12). The Roll Call of States with other transportation agencies followed. The Roll Call of States is a tradition that provides an opportunity for a representative from each agency to introduce himself or herself and any other delegates from the agency. Each state was called alphabetically starting with the 2014 host state, Vermont. Roll call allows all attendees to connect faces with names and helps people to make contacts and initiate conversation over the course of the Symposium. Copies of the Roll Call of States and State GIS Contacts can be found as appendices A and B in this report.

Tuesday afternoon consisted of two paper sessions with four concurrent technical tracks each.

A GIS Gallery exhibit displaying posters and web sites from transportation related agencies started with a session Tuesday evening before the technology hall reception. The session provided an opportunity for organizations to share their techniques and applications with peers in the GIS-T community. Attendees were able to vote on their favorite poster for the People’s Choice Award. Additional awards were presented based on formal judging. The award recipients are listed on pages fourteen (14) and fifteen (15). Posters were exhibited for the duration of the Symposium.

Wednesday morning started with the Roll Call Round Tables: Developing, Building, and Using a Statewide Road Base Map and Data Life-Cycle; Collecting, Managing, Updating, and Disseminating Data. Attendance was down slightly with approximately one-hundred eighty (180) participants. The round tables were conducted concurrently. The facilitated discussions delved into difficulties DOT’s are having as well as ways to overcome them.

Three more paper sessions with four concurrent technical tracks each were offered through mid-afternoon.

Thursday morning’s schedule consisted of two paper sessions with four concurrent technical tracks each.

During lunch, awards were distributed, individuals who contributed to the symposium’s success were acknowledged, and door prize drawings were held.

The Symposium concluded with the Wrap-Up session, where the Symposium is “debriefed” by all interested attendees. This is where the Symposium is critiqued and ideas for next year’s Symposium are first discussed. Discussions are organized topically and facilitated by the GIS-
T Task Force Chair and key planning committee members. The topics covered were Workshops, Program, Panels, Key Note, Moderators, Technology Hall, Vendors, Emerging Issues, Student Papers, GIS Gallery, State Summary, and Roll Call.

Additional information for future Symposia is derived from evaluation surveys. The surveys capture scores and opinions about all plenary, breakout, and social activities.

**Workshops**

There were four tracks for workshops presented at the 2014 GIS-T. All workshops were one-half day in length. Participants could pick one from the morning and one from the afternoon.

**MORNING SESSIONS**

Due to a scheduling issue with the hotel, the workshops were held on a Monday this year. It resulted in 159 people registering for workshops.

**Workshop 1, UPLAN ASSHTO TIG: Implementing UPLAN in Your State**

Instructors:  
John Parker, Pennsylvania DOT  
John Farley, North Carolina DOT  
Jesse Pearson, Minnesota DOT

This workshop focused on the different experiences that several of the 13 States had in implementing UPlan. After an initial overview of the AASHTO Technology Implementation Group (TIG) project for UPlan, several States demonstrated their version of UPlan and discussed the challenges and benefits of implementing UPlan in their State.

UPlan is a powerful yet easy to use web based decision-support mapping and informational tool for completing complex planning and project development tasks. It allows complete or selective data sharing among various work units within the state DOT. It also allows selective data sharing between state DOTs and with the public.

Uplan is a GIS based tool that organizes data into a spatial format and viewed in a user friendly way that allows ‘data to become information’. It is a web based application that allows collaboration with agencies, utilities, and others in a way that is very unique. Currently, 13 States are implementing their version of UPLAN to strengthen partnerships with local governments, MPO’s, Transit Agencies, utilities, SHPO and many others. They share data in a common location and can view, analyze and discuss it in ways they have never had before. The transparency of information and analysis is the hallmark of UPlan.

Thirteen (13) States across the nation have been selected to participate in implementation efforts on UPLAN as part of the AASHTO Technology Implementation Group (TIG). This workshop was aimed at discussing progress of the implementations that have happened so far, challenges that have been met and overcome in terms of technology and organizational acceptance, specific examples and use cases of the technology and the lessons learned. It is a great forum for other States to see if a UPLAN or other internet based collaboration effort will help them and to make contacts that can help them get started.

Thirty Five (35) people registered for this workshop.
Workshop 2, GIS Safety Analysis Tools

Instructors: Craig Thor, FHWA
William Johnson, Colorado DOT

A transportation data system that operates on a GIS platform can link crash, roadway, traffic, and other data sources through common geographical references. Many State and local jurisdictions recognize the benefits of a transition to a GIS-based traffic data system to support their safety decision making processes. At the same time, other States and jurisdictions are just beginning to identify the role of a GIS-based transportation data system to support their future needs. In either case, the improved analytical capabilities offered by GIS-based safety analysis tools can streamline and inform safety decisions effectively and more completely than traditional safety analyses of isolated data sources. Opportunities to capitalize on these benefits come in many forms including “off the shelf” tools, advanced analytical processes, or data visualization methods. Various jurisdictions are already implementing these tools and capabilities and have identified the benefits and challenges of specific approaches. In response to the momentum in the direction of GIS-based safety decision making, there will be an opportunity to highlight successes, discuss challenges, and identify out next steps during this workshop. Topics of conversation in this workshop included the availability of tools, the level of implementation, and the resulting benefits and challenges. There were presentations, discussions, and a Peer Exchange session to directly discuss challenges and future needs.

Forty nine (49) people registered for this workshop.

Workshop 3, Keeping the Street Layer Current

Instructors: Jay Clark, Critical Infrastructure Mapping LLC
James E. Mitchell, Louisiana Dept. of Transportation & Development

This workshop was targeted to individuals who are responsible for the management of transportation related street and POI data. They covered the topics below in a mixed lecture/participation format to allow each participant to leave with an understanding of how they can provide a continuously maintained data set that will support Map-21 infrastructure goals.

The material explained the process of understanding what kind of service levels and ROI the data must provide. They concentrated on a clear Database Feature Model description for tasks like Geocoding, Routing, LRS Management, and specific use cases provided by the attendees. The workshop covered the process for doing the “carpentry of conflation” and how to go about accepting data using a sampling plan. Emphasis was placed on releasing updates early and often.

Samples of Database Feature Modeling Docs, Generic Record Layouts, and Quality Documents will be provided. Agenda:

1. Making the plan
   a. Scope
   b. Method
   c. Quality Control
2. Executing the Plan
3. Accepting the Data
   a. Sampling Model
   b. Redo-avoidance
   c. Change Orders
4. Keeping it Going
   a. Local Source Data
   b. Keep the plan alive!

Forty two (42) people registered for this workshop.

**Workshop 4, Use of FHWA Probe Data – Impacts on State LRS**

Instructors: Keith Hangland, HERE Corp.
Jared Causseaux, Florida DOT

In 2013, FHWA issued a contract to the HERE, Inc, a Nokia Business (formerly NAVTEQ), to prove traffic speed data in the National Performance Management Research Data Set (NPMRDS). The NPMRDS will support the Freight Performance Measures and Urban Congestion Report efforts of FHWA. As part of the contract the data was made available to State DOTs and MPOs. As of October 2013, 21 States, 49 MPOs and 1 Canadian agency had signed agreements to use the data. The data set includes average travel times for passenger vehicles and large trucks in 5 minutes time intervals, 24 hours a day, 7 days a week for the entire National Highway System. The travel times are derived from a number of sources including mobile phones, vehicles, and portable navigation devices. Freight probe data is obtained from the American Transportation Research Institute leveraging embedded fleet systems. The summary data is provided on Traffic Massage Channel sections. Given the interest by States and MPOs in making use of the NPMRDS, this workshop covered what the data is, how Agencies can access it, the geospatial formats of the information and how it can be conflated to the State’s linear referencing system.

Thirty two (32) attendees registered for workshop four.

**AFTERNOON SESSIONS**

**Workshop 5, Implementing SHRP II C40 Environmental Databases and Tools**

Instructors: Debra Nelson NYS DOT
Stephen Andrle TRB
Steven Ziegler, ICF International, Inc.
Nary Grace Lewandowski, East-West Gateway Coordinating Council
Mary Gray, Parsons, Inc.
Patrick Huber, University of California Davis

Substantial strides have been made in addressing the process- and policy-related challenges that impede integrated transportation and ecological decision making. The work conducted through the Strategic Highway Research Program (SHRP 2) projects on “Integration of Conservation, Highway Planning, and Environmental Permitting Using an Outcome-Based Ecosystem Approach,” and “Development of an Ecological Assessment Process for
Enhancements to Highway Capacity” enhanced the process by developing the Integrated Ecological Framework (IEF) to guide the flow of work.

A barrier to applying the new methods is access to reliable environmental data at the planning stage of projects or programs of projects. To address this, SHRP 2 launched four projects in the C40 Series. The first is C40(A) - *Integration of National-Level Geospatial, Ecological Tools and Data*. The primary objective of this project is to develop an integrated, geospatial, ecological screening tool for early transportation planning that produces results that can carry through and inform the environmental review process. This tool will advance both *Eco-Logical* and the IEF by providing the transportation community with the means to identify and analyze environmental impacts at a regional scale. There are many emerging tools, but none appear to meet this objective.

This objective was accomplished through development of a geospatial tool, accessed on the Web, which draws much of its data and perhaps analytical capabilities from existing tools largely through Web services. This will leverage, possibly through portals established by others, existing and emerging tools and data sets for efficient and effective environmental analysis in transportation planning, corridor planning, and programming. The tool will, at a minimum, help users investigate, identify, and obtain data and other information useful for environmental screening in transportation planning. A secondary objective is to support collaborative decision making as embodied in the Integrated Ecological Framework.

It is recognized that some jurisdictions are already using geospatial tools for ecological analysis in transportation planning and programming. They have a lot to offer to a developer of a national one-stop-shopping tool and may have already developed approaches that are transferable to others.

Three projects were awarded under C40B to agencies with some form of an ecological screening tool or process to improve what they are doing and explore transferability to other locations. The objectives of C40(B) project are to:

1. Provide proof-of-concept that application of geospatial tools and data in the transportation planning and programming (pre-NEPA) phases of delivering new highway capacity is workable and can be of sufficient quality to be used in subsequent project-level environmental review.
2. Demonstrate this capability in the partnership context of the Integrated Ecological Framework described above. (From SHRP 2 C06 projects)
3. Show how methods they developed could be transferred to other geographical areas and identify what other jurisdictions would have to do to follow this approach.
4. Work with the C40A contractor to collaborate on the design of an integrated geospatial ecological screening tool and test the tool on a real project.
5. Evaluate the integrated geospatial tool developed by the C40-A researchers.

This workshop talked about the GIS tool development through the SHRP projects and the ones used in the proof of concept studies. This workshop was considered the end of active research by TRB on the project and now TRB and FHWA are discussing what implementation is needed based upon the workshop results.

Nineteen (19) people registered for the workshop.
Workshop 6: GIS Capability Maturity Model

Presented by the URISA GIS Management Institute®

Instructors:  Al Butler, City of Ocoee, FL
              Allen Ibaugh, Data Transfer Solutions

The GIS Management Institute helps organizations identify and implement enterprise GIS management practice improvements. GIS managers will increase return on investment and maximize the effective use of GIS for their enterprise business goals with GMI products and services. Both the GIS Capability Maturity Model and the Geospatial Management Competency Model are key components of the GIS Management Institute.

GIS development typically starts as an idea and progresses towards full maturity. However, the reality of enterprise GIS operations is that development is limited by available funds. Often GIS starts as a capital project with the system designed to create the 'best GIS possible' with the funds at hand. This development scenario leads to frequent compromise and deferral of many aspects of ideal GIS development in order to ‘go operational’ quickly and start delivering value for the agency’s investment. Even if a GIS implementation project is completed successfully, it does not mean that an agency has a mature GIS, or even a cost-effective GIS operation. A ‘Capability Maturity Model’ is defined as a tool to assess an organization’s ability to accomplish a defined task or set of tasks. Typically a numeric rating system is used for a high-level comparison and analysis purposes.

During the workshop, the newly revised URISA GIS Capability Maturity Model (GISCMM) was described, along with its relationship to the GIS Management Institute®, including development of the GIS Management Body of Knowledge. The current development status of the GISCMM was discussed and future uses and activities outlined. These included development of new GIS management best practices and the offering of an enterprise GIS accreditation service.

Workshop attendees received copies of the GISCMM. An exercise was conducted during the workshop, where attendees were asked to perform an initial assessment of their agency by applying the GISCMM. This workshop was of value to those interested in the development, implementation, and use of GIS management professional standards and best practices.

Workshop Outline:
1. What is a capability maturity model?
2. Origins of the GIS Capability Maturity Model
3. URISA steps in
4. The URISA Geospatial Management Competency Model
5. Babinski’s Theory of GIS Management
6. Development of the revised, peer-reviewed URISA GIS Capability Maturity Model
7. Exercise: The URISA GIS Capability Maturity Model – Step by Step
8. Exercise: Attendee discussion and feedback
9. The pivotal role of the GIS CMM in the GIS Management Institute®
10. The role of the GIS Management Institute® in enhancing sustainable Enterprise GIS
11. The role of the GIS Management Institute® in developing professional GIS managers
12. The GIS Management Institute® next steps
By the time of the workshop, URISA had developed an online tool to assist agencies in walking through the process and focusing on how to move forward in maturity. The objective of this workshop was exposing the participants to the GIS CMM process and to facilitate a discussion of how State DOTs can apply this process to their organizations.

Eighteen (18) people registered for this session.

Workshop 7: Enhancing the Use of GIS to Support Asset Management Requirements Under MAP-21

Instructors: Katie Zimmerman Applied Pavement Technology  
Frances Harrison, SpyPond Partners, Inc.  
Connie Gurchiek, Transcend Spatial Solutions, Inc.  
William Johnson, Colorado DOT

The MAP-21 legislation requires states to develop risk-based asset management plans for pavements and bridges on the National Highway System (NHS). Agencies are encouraged to expand the content of these plans to include all assets within the highway right-of-way.

At a minimum, an asset management plan should include a summary of assets and their condition, asset management objectives and measures, a summary of gaps between actual and targeted conditions, lifecycle cost and risk management analysis, a financial plan, and investment strategies. GIS technology can significantly contribute to the development of an effective asset management plan by integrating data sets and analyzing geospatial data to support investment decisions. In addition to data integration and analysis, GIS can also effectively communicate the outcomes and benefits of asset management.

During this workshop, which drew on the results of a study currently being completed under the National Cooperative Highway Research Program (NCHRP 08-87), participants learned how states have successfully used GIS to support the following asset management efforts:

1. Understanding the state of the assets.
3. Identifying needs and work candidates.
4. Packaging projects into effective programs.
5. Managing and tracking work activities.

Participants were introduced to a new Implementation Guide that will help them advance use of GIS for asset management. The group also discussed how the Colorado DOT has been applying techniques from this Guide, and saw a demonstration of new GIS capabilities for risk-based asset management that may be added in the future.

Workshop 8: The All Public Roads Study (ARNOLD) and Functional Classification update.

Instructors: Joe Hausman, FHWA,  
Tom Roff, FHWA  
James Meyer, Arizona DOT

FHWA recently issued requirements for State DOTs to provide a Measured Route Basemap of all public roads in each state as part of the HPMS Submittal. These requirements are based on needs to analyze Safety, Bridge and performance data at the local level. They are
also based on growing concerns that there are several versions of a “National” highway network within the Federal Government. The Office of Management and Budget (OMB) has given clearance to the HPMS for the collection of All Public Roads from State DOTs. Language in the 2012 USDOT MAP-21 legislation identifies funding opportunities for State DOTs to submit a complete roadway network for all public roads starting in 2014. This workshop covered the Guidance for creating this statewide LRS for all roads, including local roads, will be presented. In addition, the new functional classification manual was covered, including the different delineation of Urban Areas by the Census Bureau as compared to DOTs, and how functional classification data is expressed in GIS. The workshop included several non-DOT speakers to enhance the discussion of State and Local GIS / data collection efforts and the relationship to Transportation for the Nation (TFTN).

Forty six (46) participants registered for the ARNOLD session.

State Summary Report

This is the nineteenth (19th) year that the GIS-T Symposium has conducted a survey of GIS administrative activities at State DOT’s. The survey was administered using a web-based survey instrument. The survey’s purpose is to inventory the current state of practice, identify potential needs, and discover wide ranging topics for discussion. The result was an eighty-five percent (85%) response, with forty-four (44) respondents.

GIS Organizations Structure and Development Stage

A highest percentage of States responding, forty-four percent (44%), report having an organizational structure consisting of a GIS core unit, providing technical support to a much larger group of end-users throughout the agency. This is slightly down from forty-eight percent (48%) in 2013. Generally unchanged from last year is the thirty-nine percent (38%) citing an “enterprise” GIS organization with agency-wide data integration.

This year, the organizational location of GIS core units was weighted towards being located in Planning (41%). Twenty-five percent (25%) of the respondents had their GIS core unit within an IT services office with fifteen percent (34%) reporting other locations. The unusual changes in percentage from one year to the next could be a result of who the responding for the agency.

The average size for GIS staff was eight (8) full-time and four (4) part-time employees with one (1) on-site and one (1) off-site contractors. All of these numbers are down from 2013.

Forty-eight percent (48%) of the States reported having a certified GIS professional on staff. This is consistent with 2013 figures. Twenty percent (20%) of respondents claimed certification was an important hiring consideration; that count is an increase from the 2013 survey. The allocation of GIS staff time across core functions has not changed much since the 2010 survey. However, 2014 marks a slight departure from the norm. Formerly the emphasis was on road base map development and enhancement. This year, that category fell four percent (4%) down to sixteen percent (16%). The new highest accounted staff time went to Linear Referencing System development and maintenance at eighteen percent (18%). Web Application Development was fell from last year to fifteen percent (15%). Data warehouse development and maintenance was at sixteen percent (16%) while GIS technical support and training was unchanged at sixteen percent (16%).
GIS Software
Respondents were asked to identify what software products were used for GIS analysis and web mapping by core and user staffs. Thirty-three (33) separate products from nine (9) different vendors were identified. The most widely used products are from Esri® in both core and distributed user groups; Bentley Microstation® was also prevalent. To a lesser degree states cited Intergraph® and Caliper® products and finally, GeoCortex®.

Most States use commercial relational database management software (RDBMS) in combination with GIS software to manage their geo-spatial data. Oracle® is used by seventy percent (70%) of the States, either alone or in combination with other database software. Other commercial database software used by the States includes SQL Server® (65%), and Microsoft Access® (25%).

ArcSDE at eighty-one percent (81%) and Oracle Spatial® at fifty (50%) are the principal software packages used to manage the geo-spatial attributes in enterprise data warehouses.

Road Centerline Networks and Other Geo-Spatial Databases
A key component of most transportation GIS activities is the road centerline network database. All but one (1) respondent reported that they maintain a digital road centerline database. Both the spatial accuracy and coverage of these databases continue to improve.

Sixty-four percent (64%) of the respondents report that their road centerline databases have a spatial resolution of 1:5,000 scale or better. Much of the improved accuracy has been achieved through the use of high-resolution ortho-imagery and/or kinematic GPS.

Benefits and Costs of GIS Applications
Several questions introduced in 2006 regarding the perceived benefits and costs of geospatial technology were asked again in this year’s survey. Asset Management, at sixty-eight percent (68%) of respondents has overtaken Enterprise Data Integration (43%) as yielding the greatest benefit and also cited as the most costly/difficult to implement. Trending third for benefits was in both costs and benefits were CAD / GIS integration.

Current Activities
Respondents were asked to list up to four of their current GIS activities for the Roll Call of States. Listed activities were grouped into similar categories and then ranked based on the number of times that they were cited by the respondents. Table 1 lists those GIS activities cited five or more times by the State DOTs.

<table>
<thead>
<tr>
<th>GIS Activity (Categories with at least 5 citations)</th>
<th># of Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of web-based GIS applications / Portals</td>
<td>28</td>
</tr>
<tr>
<td>Migrating to New Hardware / Software</td>
<td>19</td>
</tr>
<tr>
<td>Enterprise Applications</td>
<td>13</td>
</tr>
<tr>
<td>Road Centerline DB Dev / Enhancement</td>
<td>12</td>
</tr>
<tr>
<td>Asset Management – Pavement / Bridge</td>
<td>10</td>
</tr>
<tr>
<td>Geotechnical / Environmental / Cultural Analysis</td>
<td>9</td>
</tr>
<tr>
<td>Field Data Collection / Mobile</td>
<td>7</td>
</tr>
<tr>
<td>5-1-1 / Operations / ITS</td>
<td>6</td>
</tr>
<tr>
<td>Right of Way</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1 - High priority GIS activities at State DOT’s
A recent trend continues, the Roll Call of States revealed half of the DOTs working at the enterprise level with GIS portals and web applications. A major component in the count is the AASHTO Arc GIS Online UPlan TIG and implementations. Coupled with the Enterprise Applications category, and there is significant effort being expended on large enterprise initiatives. Zooming to second place is software migrations and implementations. Although Esri Roads and Highways accounts for much of the rise, there are desktop GIS and database migrations too. Past experience indicates this category rises and falls cyclically. Although HPMS drew no mentions by any of the states, Road Centerline Database Development Enhancement is had several mentions of FHWA’s ARNOLD and expanding netwroks.

**Student Paper Contest**
The GIS-T Symposium opened the Student Paper Contest for 2014. Thirteen (13) papers were submitted for consideration. The quantity and quality of the papers was exceptional. Several submissions were worthy of winning. All submissions were scored based on the same criteria by a panel of judges from the planning committee. In the end, the winning paper was submitted by Dapeng Zhang, from Rensselaer Polytechnic Institute. His paper was titled Transit Ridership Estimation with Network Kriging: A Case Study of Second Avenue Subway, NYC. Dapeng was awarded an AASHTO GIS-T 2014 registration, travel expenses, and $100.00 for incidentals. Dapeng Zhang’s paper can be found in Appendix D.

**GIS Gallery**
The 2014 GIS-T Symposium entries showcased the use of GIS technology to analyze data as well as cartographic skills. This year included a web mapping category. Web sites and posters were reviewed and the following awards were given:

- **Effective Cartography**
  - 1st Place: Vermont Agency of Transportation
    *United States - Her Natural and Industrial Resources*
  - Honorable Mention: Vermont Agency of Transportation
    *Vermont General Highway Map Urban Compact of Essex Center 2013*
  - Honorable Mention: Pennsylvania Department of Transportation
    *Corridor Modernization*

- **Use of Information**
  - 1st Place: Vermont Agency of Transportation
    *Vermont County Series Lamoille County*
  - Honorable Mention: Vermont Agency of Transportation
    *State of Vermont 2012 Traffic Flow Map*
  - Honorable Mention: Colorado Department of Transportation
    *CNG Fuel Stations in Colorado*
  - Honorable Mention: Abu Dhabi Department of Transport
    *Crash Analysis VS Speed Monitoring Enforcement*

- **Best Transportation Publication**
  - 1st Place: Colorado Department of Transportation
    *Colorado State Travel Map*
Public Presentation

- **Honorable Mention: Nebraska Department of Roads**
  *Official Nebraska State Highway Map*

- **Honorable Mention: US DOT - Bureau of Transportation Statistics**
  *United States Transportation Infrastructure Map*

- **Public Presentation**
  - **1st Place: Arizona Department of Transportation**
    *State of Arizona Scenic Roads - Photo Log 2013*

- **Honorable Mention: Vermont Agency of Transportation**
  *Digital Index for the Vermont 1962 Low Altitude Photo Series: VT-62-L*

- **Honorable Mention: Abu Dhabi Department of Transport**
  *Maritime Safety Zones*

**Best Savvy Web Mapping Application**

- **1st Place: Colorado Department of Transportation**
  *Colorado Bicycle and Byways*

**People’s Choice Award**

- **Vermont Agency of Transportation**
  *United States - Her Natural and Industrial Resources*

**Concurrent Sessions**

During the Symposium, concurrent technical sessions were attended in large numbers.

**Tuesday:**

- Federal Programs
- Transportation Planning
- Real Time Technology
- Disaster Response Tools
- Federal Initiatives
- Enterprise Planning
- Technology Solutions
- Environmental Management

**Wednesday:**

- Multi-Level LRS
- Routing
- Process Improvements
- Dashboards and Visualization
- All Roads Network
- Transportation Modeling
- Asset Management
- Web Portals and Viewers

- Multi-Level Road Networks
- Crash Analysis
- Managing Assets
- Data Management and Visualization
Thursday:
Local Roads and HPMS
Web Planning Tools
LiDAR and Imagery
Interactive Data

A Comprehensive Network
Mobile GIS
3D Visualization
Geospatial Data Management

Symposium Summary
The twenty-seventh annual Symposium on Geospatial Information Systems for Transportation (GIS-T) was held in Burlington, Vermont from May 5 through May 8, 2014. The Symposium identified emerging issues and technologies impacting the Transportation Information Technology Community. The Symposium included a selection of eight (8) half day workshops; a technology hall with Twenty-six (26) exhibitors; Mr. Frank Winters, Director of the New York State GIS Program Office, State Summary Report, Roll Call of States, eighty-four (84) paper presentations, GIS Gallery, and concurrent round table discussions complete the Symposium agenda. Appendix C in this report contains the General Symposium activities schedule.

Technical papers presented at the Symposium are available, along with their abstracts, through the GIS-T web page (http://www.gis-t.org). The State Summary Report, Roll Call of States, State GIS Contacts list, and Symposium attendee list can also be obtained from this site.

AASHTO GIS-T 2015 will be hosted by the
Iowa Department of Transportation
Appendix A - Roll Call of States

Alabama
Dan Manley
(Jennifer Bleiholder, Jeromy Barnes, Darryl Spears & John Formby attending)

Recent Project(s)/application(s)
1. Analysis of LRS and GIS Data Requirements
2. Dev Single LRS & Geodatabase Model
3. New Web-based Photolog Viewer

Interested in the following issue(s):
1. Dev New Roadway Inventory System
2. Dev Enhanced Traffic Monitoring System
3. Dev New HPMS
4. Dev Executive GIS Dashboard

FOLLOWED BY Alaska THEN Arizona

Arizona
James Meyer

Recent Project(s)/application(s)
1. Roads and Highways Implementation
2. Centerline Unification for ARNOLD
3. Implementing and integrating ESRI R&H
4. ArcGIS Online

Interested in the following issue(s):
1. Statewide Data Clearinghouse
2. Coordination of Centerline Unification

FOLLOWED BY Arkansas THEN California
Arkansas
Sharon Hawkins

Recent Project(s)/application(s)
1. Continued ARNOLD Development
2. Department-Wide Data Standards
3. Asset Data Collection/Management
4. Google Maps Engine/Travelers Website

Interested in the following issue(s):
1. CADD-GIS Workflows
2. LiDAR -Using and Sharing
3. Preservation/Performance Measures
4. Enterprise GIS/Data Management

FOLLOWED BY California THEN Colorado

California
Harold Feinberg

Recent Project(s)/application(s)
1. Geospatial Data Clearinghouse
2. Ent. Culvert Inspection Application
3. Planned Projects WebApp (state/local)
4. Statewide LRS for MAP-21

Interested in the following issue(s):
1. Integrated Geospatial Data Management
2. Enterprise Geospatial Data Governance
3. Asset Management GIS
4. Geospatial Data Visualization

FOLLOWED BY Colorado THEN Connecticut
Colorado

Erik Sabina (Will Johnson & Allison Bejarano attending)

Recent Project(s)/application(s)
1. Roads and Highways Implementation
2. Storm Water Inventory Tool (SWIT)
3. Bike/Scenic Byways Map App

Interested in the following issue(s):
1. Asset Management and GIS
2. Big Data and GIS
3. Roads and Highways
4. Safety Fundamental Data Elements

FOLLOWED BY Connecticut  THEN Delaware

Connecticut

James Spencer

Recent Project(s)/application(s)
1. New Digital Road Network and LRS
2. ArcGIS Online Development
3. Enterprise GIS

Interested in the following issue(s):
1. New Digital Road Network and LRS
2. ArcGIS Online Development
3. Enterprise GIS
4. ARNOLD

FOLLOWED BY Delaware  THEN Washington D.C.
Delaware
Jay Gerner

Recent Project(s)/application(s)
1. Implementation of ArcGIS Online
2. Migration of official map to GIS format
3. Parcel-based land use analysis for TIDs
4. Functional Classification Update in GIS

Interested in the following issue(s):
1. Data catalog & security classifications
2. Shifting data into map & image services
3. Statewide funding mechanisms for aerials
4. Integrating ArcGIS.com w/ state systems

FOLLOWED BY Washington D.C.  THEN Florida

Washington - District of Columbia
José Colon

Recent Project(s)/application(s)
1. ESRI Roads and Highways
2. Street Level Panoramic Imagery
3. RideDC Transportation Portal
4. AGOL and Operation Dashboards

Interested in the following issue(s):
1. Right-of-Way Management System
2. Truck Automated Routing System
3. Roadway Sign Inventory
4. Multi-Modal Applications

FOLLOWED BY Florida  THEN Georgia
Florida
Jared Causseaux

Recent Project(s)/application(s)
1. Enterprise GIS Framework
2. GIS Enterprise View
3. GIS License Analysis
4. CADD\GIS Interoperability

Interested in the following issue(s):
1. Mobile Mapping
2. ArcGIS Online
3. CADD\GIS Interoperability

FOLLOWED BY Georgia
THEN Hawaii

Georgia
Teague Buchanan

Recent Project(s)/application(s)
1. Fatal Crash Reporting System
2. Transportation Board Book
3. ArcGIS 10.2.1 Citrix Rollout
4. Esri Roads and Highways

Interested in the following issue(s):
1. Agile Assets
2. 10.2.2/HTML5 application upgrades
3. Esri Geoportal Enhancement
4. ArcGIS Online

FOLLOWED BY Hawaii
THEN Canadian Provinces
Hawaii
Goro Sulijoadoikusumo

Recent Project(s)/application(s)
1. Coloring lidar w/ photolog images
2. Building DEMs
3. Refing 3d networks

Interested in the following issue(s):
1. Automated asset extraction from lidar
2. Standardizing lidar data and GIS tools

FOLLOWED BY Canadian Provinces THEN Federal Agencies

Illinois
Dan Wilcox

Recent Project(s)/application(s)
1. OSOW Bridge Analysis
2. Mobile Data Collection ADA
3. 10.2.1 Desktop Migration
4. Geometry for all local roads in Roadway

Interested in the following issue(s):
1. 3D Design, Modeling & Visualization
2. Repurposed Traveler Information System
3. Transportation Asset Management
4. Mobile Workforce

FOLLOWED BY Indiana THEN Iowa
Indiana

Joel Bump (Kevin Munro attending)

Recent Project(s)/application(s)
1. ESRI Roads & Highways Implementation
2. Integration of R&H with enterprise
3. Public GIS driven ITS interface
4. Public GIS driven RWIS interface

Interested in the following issue(s):
1. Roads & Highway deployment
2. LiDAR bridge clearance
3. CAD/GIS standards
4. Defined Local Coordinate Systems

FOLLOWED BY Iowa  THEN  Kansas

Iowa

Eric Abrams

Recent Project(s)/application(s)
1. Public Access to GPS/AVL data
2. Field Data Collection
3. ArcGIS Online rollout
4. Enterprise Geospatial Architecture

Interested in the following issue(s):
1. Enterprise Geospatial Architecture
2. Automated field data collection
3. Asset Performance and management
4. Portals or mini portals

FOLLOWED BY  Kansas  THEN  Kentucky
Kansas

Kyle Gonterwitz (Mary Beth Prang attending)

Recent Project(s)/application(s)
1. wichway.org Wichita KS 511 website
2. ksdot.maps.arcgis.com "KanPlan" Portal
3. "city connecting links" GIS application
4. Mapping Bridges, Airports, FRA crossings

Interested in the following issue(s):
1. shared road centerlines HPMS/NENA/DOT
2. Visualizations, Straight Line Diagrams
3. lidar/image feature extraction
4. OpenStreetMap/FOSS/Raspberry Pi

FOLLOWED BY Kentucky THEN Louisiana

Kentucky

Will Holmes

Recent Project(s)/application(s)
1. Web Maps Rewrite in HTML5/JS
2. Mobile Pipe/Culvert Inventory
3. Heliport Surf. & Obstr. Analysis
4. Mobile Post-Construction BMPs Collection

Interested in the following issue(s):
1. Mobile Disconnected Editing
2. "Cloud" GIS Integration
3. LiDAR Data Service for Consultants
4. Real-time Common Operating Picture

FOLLOWED BY Louisiana THEN Maine
Louisiana
James Mitchell

Recent Project(s)/application(s)
1. ESRI Roads & Highways Implementation
2. Statewide All-Roads Data Collection
3. Severe Winter Weather Emergency Response
4. Completed Statewide NHD Hydrography

Interested in the following issue(s):
1. ArcGIS and AgilAssets Interoperability
2. Implementing ESRI Production Mapping
3. Overweight Truck Routing/Bridge Analysis
4. Making Statewide IT Consolidation Work

FOLLOWED BY Maine THEN Maryland

Maryland
Michel Sheffer (Erin Lesh attending)

Recent Project(s)/application(s)
1. One Maryland One Centerline
2. GIS Right of Way
3. eGIS
4. Climate Change

Interested in the following issue(s):
1. Asset Management
2. Performance Based Planning
3. GIS Data Management and Dissemination
4. Resilient Networks

FOLLOWED BY Massachusetts THEN Michigan
Massachusetts
Kevin A. Lopes

Recent Project(s)/application(s)
1. Roads and Highways Migration
2. Custom Web Map Creation Tool

Interested in the following issue(s):
1. ArcGIS Online Data Portal

Michigan
Cory Johnson

Recent Project(s)/application(s)
1. Enterprise Asset Management RFP
2. ArcGIS Online Pilot
3. Performance Based Metrics
4. Filling Enterprise Data Gaps

Interested in the following issue(s):
1. ArcGIS Online
2. EAM
3. ArcGIS Pro
4. EAM Software vendors

FOLLOWED BY Michigan THEN Minnesota

FOLLOWED BY Minnesota THEN Mississippi
Minnesota
Peter Morey (attending)

Recent Project(s)/application(s)
1. Implementing Roads & Highways LRS
2. Shared Centerlines Initiative w/Locals
3. Data Center Consolidation (A program)
4. IFAMS (Fiber Optic Management)

Interested in the following issue(s):
1. Data Governance
2. LIDAR for As-builds & Asset Mgmt
3. Asset Inventory, Mobile ASAP collection
4. ArcGIS Online

Followed by Mississippi

Mississippi
Mike Cresap

Recent Project(s)/application(s)
1. Stormwater Inspection Application
2. Adopt-A-Highway
3. RIMS
4. MLRS Web Services

Interested in the following issue(s):
1. Asset Data Collection Using LiDAR
2. MAP-21, FMIS 5.0 & HPMS Integration
3. Enhancing MLRS
4. Interfacing with Locals for Data ACQ

Followed by Missouri

Followed by Missouri

Montana
Missouri
Joseph Carter (attending)

Recent Project(s)/application(s)
1. Completed State Highway Map in GIS
2. Modernization of data to spatial
3. US Bike Route 76 GIS AASHTO Application
4. Lidar use for urban ADA projects

Interested in the following issue(s):
1. CAD/GIS Integration
2. GIS Data sharing
3. GIS education/mentoring to K-12

FOLLOWED BY Montana THEN Nebraska

Montana
Ed Ereth

Recent Project(s)/application(s)
1. Implementing New Safety Mngmnt System
2. AGOL Pilot Complete, Adopted/Implemented
3. Oracle 11g Spatial Migration Started
4. Restricted Bridge Height App

Interested in the following issue(s):
1. New LRS Management System
2. New Maintenance Management System
3. Aeronautics Search and Rescue App
4. Various Mobile Data Collection App

FOLLOWED BY Nebraska THEN Nevada
Nebraska
Rose Braun

Recent Project(s)/application(s)
1. Enhance internal web portal
2. Test Apollo for statewide big data mgt
3. Local road network for HPMS reporting
4. Statewide NG911 study

Interested in the following issue(s):
1. Discuss risks of open source GIS tools
2. Collecting statewide address points
3. Purchase 12" imagery as a base
4. Purchase new profler vans this summer

FOLLOWED BY Nevada THEN New Hampshire

Nebraska
Ryan Aglietti

Recent Project(s)/application(s)
1. Road Network Conflation
2. ArcGIS Server Deployment
3. Route and Location Finder Web Map
4. ADA Compliance Datasets and Mobile App

Interested in the following issue(s):
1. Asset Management/GIS Integration
2. ArcGIS Roads and Highways
3. Mobile Data Collection

FOLLOWED BY New Hampshire THEN New Jersey
New Hampshire
Glenn Davidson

Recent Project(s)/application(s)
1. Guardrail
2. Project Web Viewer

Interested in the following issue(s):
1. GIS integration with FMIS
2. ArcGIS Roads and Highways

FOLLOWED BY New Jersey THEN New Mexico

New Mexico
Mel Herrera (attending)

Recent Project(s)/application(s)
1. Serving maps through ArcGIS online.

Interested in the following issue(s):
1. Migrating our LRS into Road and Highways

FOLLOWED BY New York THEN North Carolina
New York

Kevin Hunt

Recent Project(s)/application(s)
1. Enterprise Linear Referencing System
2. Accident Location Information System
3. GIS integr with new Capital Prgm system

Interested in the following issue(s):
1. Esri R&H implementation/integration
2. Statewide GIS services architecture

FOLLOWED BY North Carolina THEN North Dakota

North Carolina

John Farley

Recent Project(s)/application(s)
1. LRS Upgrade (to include all local roads)
2. Automated Project Prioritization
3. GO!NC (http://ncdot.maps.arcgis.com/)

Interested in the following issue(s):
1. ArcGIS Online
2. Mobile Computing and Data Collection
3. Esri’s Roads and Highways

FOLLOWED BY North Dakota THEN Ohio
North Dakota
Brian Bieber

Recent Project(s)/application(s)
1. Upgrade to systems to ArcGIS v10.2

Interested in the following issue(s):
1. Esri’s Roads and Highways
2. HPMS submittal
3. Roadway Inventory

FOLLOWED BY Ohio THEN Oklahoma

Ohio
David Blackstone

Recent Project(s)/application(s)
1. Roadway Information Management Modernization
2. Enterprise Architecture
3. HPMS All Roads Requirement
4. Web Mapping

Interested in the following issue(s):
1. Field Solutions
2. Snow Plow Tracking
3. System Integration
4. HPMS All Roads Requirement

FOLLOWED BY Oklahoma THEN Oregon
Oregon
Brett Juul (attending)

Recent Project(s)/application(s)
1. Crash Locator Tool
2. TransGIS 2.2.1 Enhancements
3. CHAMPS/Rd Approach Inv. Integration
4. Environmental Justice Map

Interested in the following issue(s):
1. Asset Management
2. MAP 21 Requirements
3. Data Warehousing
4. GIS Application Development

FOLLOWED BY Pennsylvania THEN Puerto Rico

Pennsylvania
Frank DeSendi

Recent Project(s)/application(s)
1. Strategic Planning
2. All Roads
3. Posted/Bonded Roads
4. Scour Critical Bridges

Interested in the following issue(s):
1. Scour Critical Bridges
2. MapTile and Cache
3. Federal FMIS Modernization
4. Asset Management

FOLLOWED BY Puerto Rico THEN Rhode Island
Puerto Rico
Miguel Martinez-Yordan

Recent Project(s)/application(s)
1. Kilometers posts replacements with GPS
2. Historical aerial images rectification
3. Municipality roads integration into GIS
4. Historical roads inventory scanning

Interested in the following issue(s):
1. Web application kilometer post finder
2. Web application for HPMS data
3. GPS integration into field inventories
4. GIS integration into all DOT projects

FOLLOWED BY Rhode Island THEN South Carolina

Rhode Island
Stephen Kut

Recent Project(s)/application(s)
1. Historical and Archeological Resource MS
2. VueWorks Maintenance MS
3. Rhodeways Traffic MS
4. Cross Asset Analysis

Interested in the following issue(s):
1. LRS Management
2. MIRE data collection
3. Project Development and Analysis
4. As-Builts Plans

FOLLOWED BY South Carolina THEN South Dakota
South Carolina
Donald McElveen

Recent Project(s)/application(s)
1. LADC (Local Agency Data Collection)
2. ITMS enhancements
3. PST (Planning Screening Tool)
4. New Functional Class/Urban Areas

Interested in the following issue(s):
1. Web Applications for Public
2. LiDAR use, sharing, storage
3. Right of Way

FOLLOWED BY South Dakota THEN Tennessee

South Dakota
Terry Erickson

Recent Project(s)/application(s)
1. SD Interactive map - ArcGIS Online
2. One Stop Asset Inventory Application
3. Inventories using ArcGIS Collector

Interested in the following issue(s):
1. ROW data integration
2. Mobile LiDAR

FOLLOWED BY Tennessee THEN Texas
Tennessee
Kim McDonough (Van Colebank attending)
Recent Project(s)/application(s)
1. TAPS - TN Activity and Project Status
2. IRIS - ROW Mgmt App.
3. SWIFT - Traffic Incident Reporting

Interested in the following issue(s):
1. Intelligent Transportation Systems (ITS)
2. 3D GIS
3. True CAD/GIS Integration (Not impt/exp)
4. Integrated Hwy Proj. Management

FOLLOWED BY Texas

Texas
Darryl Zercher
Recent Project(s)/application(s)
1. Drive Texas - roadway conditions web app
2. GRID - LRS management system
3. ENV Field Mapping using iPads
4. ROW parcel mapping

Interested In the Following Issue(s):
1. Roads and Highways Solution from Esri
2. GIS data warehousing
3. Google Maps Engine

FOLLOWED BY Utah

Utah

FOLLOWED BY Vermont
Utah
Becky Hjelm (attending)

Recent Project(s)/application(s)
1. Enterprise geospatial data warehouse
2. LiDAR asset data collection
3. ArcGIS Online Implementation
4. CADD to GIS Workflow

Interested In the Following Issue(s): 
1. LRS - All Public Roads
2. Geospatial Data warehousing
3. CADD to GIS workflow
4. 3D Data management

FOLLOWED BY  Canadian Provinces      THEN  Federal Agencies

Vermont
Johnathan Croft

Recent Project(s)/application(s)
1. VTrans-E911 Road Centerline Conflation
2. Right of Way Data Modernization - Viewer
3. Rail Asset Management
4. Route Logs - Straight Line Diagrams

Interested in the following issue(s):
1. Asset Management - Inventory Inspection
2. Statewide LiDAR
3. Statewide Parcel Mapping
4. All Road Linear Reference System

FOLLOWED BY  Virginia      THEN  Washington
Washington

Alan Smith

Recent Project(s)/application(s)
1. Community Planning Portal, ArcGIS Online
2. Title6, transit/demographic analysis
3. Functional Class & Roads & highways
4. ArcGIS Online Enterprise implementation

Interested in the following issue(s):
1. Roads and Highways implementations
2. "Collector" editing implementations
3. Multi jurisdictional LRS stewardship
4. Processing traffic TMCs and probe data

FOLLOWED BY West Virginia THEN Wisconsin

Wyoming

Brian Peel (David Clabaugh & Neal Perkins attending)

Recent Project(s)/application(s)
1. Esri Roads and Highways Implementation
2. On going 511 related Web applications
3. ArcGIS for Aviation
4. On going intranet viewer improvements

Interested in the following issue(s):
1. Snow Plow Mobile Application
2. Statewide Roads Clearinghouse
3. Enterprise GIS Consolidation
4. HPMS Reporting

FOLLOWED BY Alabama THEN Alaska
Canadian Provinces

- Alberta
- British Columbia
- Manitoba
- New Brunswick
- New Foundland
- Northwest Territories
- Nova Scotia
- Nunavut
- Ontario
- Prince Edward Island
- Quebec
- Saskatchewan
- Yukon

FOLLOWED BY Federal Agencies  THEN Vendor Sponsors

Federal Agencies

FOLLOWED BY Vendor Sponsors  THEN Other Participants
Bureau of Transportation Statistics
Steve Lewis

Recent Project(s)/application(s)
1. National Transportation Atlas (web app)
2. Structurally Deficient Bridges (web app)
3. State Facts & Figures (web app)

Interested In the Following Issue(s):
1. GIS Platform as a Service
2. Enterprise GIS using a license server

Federal Railroad Administration
Raquel Hunt

Recent Project(s)/application(s)
1. Grade Crossing Mobile Application for iOS
2. Utilizing ArcGIS Online
3. JavaScript API for web apps
4. FRA’s REST End Point

Interested In the Following Issue(s):
1. Coordinating to reduce duplication
2. Converting the Mobile App for Android
3. Mobile Apps: HTML5, native, or hybrid?
4. State Rail Plan and using GIS
US Dept. of Transportation
Alisa Fine and Paige Colton – USDOT Volpe Center

Recent Project(s)/application(s)
1. Quarterly GIS newsletters/webcasts
2. Research on State DOT data-sharing efforts

Interested In the Following Issue(s):
1. Helping State DOTs achieve GIS goals.

Federal Highway Administration
Mark Sarmiento, Craig Thor, Ben Williams, Joe Hausman, Nelson Hoffman, Dan VanGilder, Ronald Vaughn & Tom Roff

Recent Project(s)/application(s)
1. Integrated Transportation Information Platform (ITIP)
2. ARNOLD
3. GIS & Construction Project Management
4. GIS Needs and Obstacles Related to Safety Analysis

Interested In the Following Issue(s):
1. Trans. Performance Mgt, NEPA
2. Cloud-based data sharing & web mapping
3. Coordinating GIS-related activities in one agency
4. The role of GIS in supporting safety decision making
2014 Vendors

- AgileAssets Inc.
- Applied Geographics, Inc.
- Applied Imagery
- AssetWorks, Inc.
- Bentley
- Cyclomedia Technology, Inc.
- Data Transfer Solutions, LLC
- Delasoft, Inc.
- Esri
- Fugro Roadware
- GeoDecisions
- Gistic Research, Inc.
- HP
- Infogroup
- Infor
- Intergraph
- Leica Geosystems
- Mandli Communications, Inc.
- MapMerger by ESEA
- Michael Baker Jr, Inc.
- MS2
- PMG Software
- Safe Software Inc
- TerraGo
- Transcend Spatial Solutions, LLC
- Yotta
<table>
<thead>
<tr>
<th>State</th>
<th>Primary Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>Dan Manley&lt;br&gt;GIS &amp; Engineering Support Manager&lt;br&gt;1409 Coliseum Blvd.&lt;br&gt;Montgomery, AL 36110&lt;br&gt;334-242-6585, 353-263-6520 (fax) &lt;br&gt;<a href="mailto:manleyd@dot.state.al.us">manleyd@dot.state.al.us</a></td>
</tr>
<tr>
<td>Alaska</td>
<td>Talena Adams&lt;br&gt;Transportation Geographic Information Section (TGIS) Manager&lt;br&gt;3132 Channel Drive&lt;br&gt;Juneau, AK 99801&lt;br&gt;907-465-6441, 907-465-6984(fax) &lt;br&gt;<a href="mailto:talena.adams@alaska.gov">talena.adams@alaska.gov</a></td>
</tr>
<tr>
<td>Arizona</td>
<td>James Meyer&lt;br&gt;GIS Manager&lt;br&gt;206 S. 17th Avenue, 310B&lt;br&gt;Phoenix, AZ 85007&lt;br&gt;602-712-8037 &lt;br&gt;<a href="mailto:JMeyer@azdot.gov">JMeyer@azdot.gov</a></td>
</tr>
<tr>
<td>Arkansas</td>
<td>Sharon Hawkins&lt;br&gt;Section Head; Mapping and Graphics&lt;br&gt;10324 Interstate 30&lt;br&gt;Little Rock, AR 72203-2261&lt;br&gt;501-569-2205, 501-569-2597 (fax) &lt;br&gt;<a href="mailto:sharon.hawkins@arkansashighways.com">sharon.hawkins@arkansashighways.com</a></td>
</tr>
<tr>
<td>California</td>
<td>Harold Feinberg&lt;br&gt;Branch Chief, Office of GIS&lt;br&gt;Mailstop 38, PO Box 942874&lt;br&gt;Sacramento, CA 95814&lt;br&gt;916-654-6585, 916-654-6583 (fax) &lt;br&gt;<a href="mailto:harold_feinberg@dot.ca.gov">harold_feinberg@dot.ca.gov</a></td>
</tr>
<tr>
<td>Colorado</td>
<td>Erik Sabina&lt;br&gt;Information Management Branch Manager&lt;br&gt;4201 East Arkansas Avenue, Shumate Bldg.&lt;br&gt;Denver, CO 80222&lt;br&gt;303-757-9811, 303-757-9727 (fax) &lt;br&gt;<a href="mailto:Erik.Sabina@state.co.us">Erik.Sabina@state.co.us</a></td>
</tr>
<tr>
<td>Connecticut</td>
<td>James R. Spencer&lt;br&gt;GIS Section Manager&lt;br&gt;2800 Berlin Turnpike&lt;br&gt;Newington, CT 06131-7546&lt;br&gt;860-594-2014, 860-594-2056 (fax) &lt;br&gt;<a href="mailto:James.Spencer@ct.gov">James.Spencer@ct.gov</a></td>
</tr>
<tr>
<td>Delaware</td>
<td>Jay Gerner&lt;br&gt;800 Bay Rd., P.O. Box 778&lt;br&gt;Dover, DE 19903-0778&lt;br&gt;302-760-2530, 302-739-2251 (fax) &lt;br&gt;<a href="mailto:Jay.Gerner@state.de.us">Jay.Gerner@state.de.us</a></td>
</tr>
<tr>
<td>Florida</td>
<td>Jared Causseaux&lt;br&gt;Florida DOT GIS Coordinator&lt;br&gt;605 Suwannee Street, MS 5-L&lt;br&gt;Tallahassee, FL 32399-0450&lt;br&gt;850-245-1715, 850-245-1557(fax) &lt;br&gt;<a href="mailto:jared.causseaux@dot.state.fl.us">jared.causseaux@dot.state.fl.us</a></td>
</tr>
<tr>
<td>Georgia</td>
<td>Teague Buchanan&lt;br&gt;Assistant Administrator&lt;br&gt;600 West Peachtree Street, N.W., One&lt;br&gt;Georgia Center, 20th floor, Room 2004&lt;br&gt;Atlanta, GA 30308&lt;br&gt;404-631-1077, 404-631-1999 (fax) &lt;br&gt;<a href="mailto:tebuchanan@dot.ga.gov">tebuchanan@dot.ga.gov</a></td>
</tr>
<tr>
<td>Hawaii</td>
<td>Goro Sulijoaidikusumo&lt;br&gt;Planning Survey Engineer&lt;br&gt;869 Punchbowl Street, Suite 301&lt;br&gt;Honolulu, HI 96813&lt;br&gt;808-587-1839, 808-587-1787 (fax) &lt;br&gt;<a href="mailto:Goro.Sulijoaidikusumo@hawaii.gov">Goro.Sulijoaidikusumo@hawaii.gov</a></td>
</tr>
<tr>
<td>Idaho</td>
<td>Wendy Bates&lt;br&gt;GIS Manager&lt;br&gt;3311 West State Street&lt;br&gt;Boise, Idaho 83703&lt;br&gt;208-332-7889, 208-334-4432 (fax) &lt;br&gt;<a href="mailto:Wendy.Bates@itd.idaho.gov">Wendy.Bates@itd.idaho.gov</a></td>
</tr>
<tr>
<td>Illinois</td>
<td>Dan Wilcox&lt;br&gt;State GIS Coordinator&lt;br&gt;2300 South Dirksen Parkway&lt;br&gt;Springfield, IL 62764&lt;br&gt;217-524-0031, 217-782-8822 (fax) &lt;br&gt;<a href="mailto:dan.wilcox@illinois.gov">dan.wilcox@illinois.gov</a></td>
</tr>
<tr>
<td>Indiana</td>
<td>Joel Bump&lt;br&gt;Enterprise Data and Systems Architecture Manager&lt;br&gt;100 N Senate Ave. IGCN 901&lt;br&gt;Indianapolis, IN 46204&lt;br&gt;317-234-3106, 317-460-3660 (fax) &lt;br&gt;<a href="mailto:jbump@indot.in.gov">jbump@indot.in.gov</a></td>
</tr>
<tr>
<td>Iowa</td>
<td>Eric Abrams&lt;br&gt;Geospatial Infrastructure and Coordination Manager&lt;br&gt;800 Lincoln Way&lt;br&gt;Ames, IA 50010&lt;br&gt;515-239-1949, 515-239-1854 (fax) &lt;br&gt;<a href="mailto:eric.abrams@dot.iowa.gov">eric.abrams@dot.iowa.gov</a></td>
</tr>
<tr>
<td>Kansas</td>
<td>Kyle Gontweritz&lt;br&gt;Cartography/ GIS Manager&lt;br&gt;700 S.W. Harrison Street, 3rd Floor&lt;br&gt;Topeka, KS 66603-3754&lt;br&gt;785-296-4899, 785-296-8168 (fax) &lt;br&gt;<a href="mailto:kyleg@ksdot.org">kyleg@ksdot.org</a></td>
</tr>
<tr>
<td>Kentucky</td>
<td>Will Holmes&lt;br&gt;GIS Branch Manager&lt;br&gt;200 Mero Street, Suite W-4&lt;br&gt;Frankfort, KY 40622&lt;br&gt;502-564-8900 &lt;br&gt;<a href="mailto:will.holmes@ky.gov">will.holmes@ky.gov</a></td>
</tr>
<tr>
<td>Louisiana</td>
<td>James E. Mitchell, Ph.D.&lt;br&gt;IT GIS Manager&lt;br&gt;1201 Capitol Access Road&lt;br&gt;Baton Rouge, LA 70802-4438&lt;br&gt;225-379-1881, 225-379-1850(fax) &lt;br&gt;<a href="mailto:jim.mitchell@la.gov">jim.mitchell@la.gov</a></td>
</tr>
<tr>
<td>State</td>
<td>Name</td>
</tr>
<tr>
<td>-------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Maine</td>
<td>Nate Kane</td>
</tr>
<tr>
<td>Maryland</td>
<td>Mike Sheffer</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>Kevin A. Lopes</td>
</tr>
<tr>
<td>Michigan</td>
<td>Cory Johnson</td>
</tr>
<tr>
<td>Minnesota</td>
<td>Peter Morey</td>
</tr>
<tr>
<td>Mississippi</td>
<td>Mike Cresap</td>
</tr>
<tr>
<td>Missouri</td>
<td>Joseph Carter</td>
</tr>
<tr>
<td>Montana</td>
<td>Ed Ereth</td>
</tr>
<tr>
<td>Nebraska</td>
<td>Rose Braun</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>Glenn Davison</td>
</tr>
<tr>
<td>New Jersey</td>
<td>Cynthia Dey</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Mel Herrera</td>
</tr>
<tr>
<td>New York</td>
<td>Kevin Hunt</td>
</tr>
<tr>
<td>North Carolina</td>
<td>John C. Farley</td>
</tr>
<tr>
<td>North Dakota</td>
<td>Brian Bieber</td>
</tr>
<tr>
<td>Ohio</td>
<td>David Blackstone</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>Craig Moody</td>
</tr>
<tr>
<td>State</td>
<td>Name</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Oregon</td>
<td>Brett Juul</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>Frank DeSendi</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>Stephen Kut</td>
</tr>
<tr>
<td>South Dakota</td>
<td>Terry Erickson</td>
</tr>
<tr>
<td>South Carolina</td>
<td>Donald McElveen</td>
</tr>
<tr>
<td>Texas</td>
<td>Michael Chamberlain</td>
</tr>
<tr>
<td>Vermont</td>
<td>Johnathan Croft</td>
</tr>
<tr>
<td>Washington</td>
<td>Alan Smith, GISP</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Dale Matenaer</td>
</tr>
<tr>
<td>District of Columbia</td>
<td>Jose L. Colon Jr.</td>
</tr>
<tr>
<td>Puerto Rico</td>
<td>Miguel A. Martinez-Yordan</td>
</tr>
</tbody>
</table>
Appendix C – General Schedule

AASHTO GIS-T 2014 Seasons for Change

General Schedule

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 AM Registration Breakfast Workshop: Attendees Only</td>
<td>7:00 AM Registration Breakfast</td>
<td>7:00 AM Registration Breakfast</td>
<td>7:00 AM (Sleep In!!!)</td>
</tr>
<tr>
<td>8:00 AM Workshops (see p5)</td>
<td>Opening Session Welcome To Vermont</td>
<td>Roll Call Round Table Sessions Developing, Building, and Using a Statewide Road Basemap The Data Life-cycle (see p7)</td>
<td>Roll Call Round Table Sessions Developing, Building, and Using a Statewide Road Basemap The Data Life-cycle (see p7)</td>
</tr>
<tr>
<td>9:00 AM 1. AASHTO TIG II Implementing UPLAN in your State 2. Safety Analysis, Modeling &amp; GIS</td>
<td>Keynote Speaker Frank Winters (see p6)</td>
<td></td>
<td>Session 6 (see p15) 1. Local Roads and HRMS 2. Web Planning Tools 3. LOAR and Imagery 4. Interactive Data</td>
</tr>
<tr>
<td>10:00 AM Break</td>
<td>Break</td>
<td>Break</td>
<td>Break</td>
</tr>
<tr>
<td>12:00 PM Lunch - Workshop Attendees Only Lunch Provided Lunch Provided</td>
<td>Lunch Provided</td>
<td>Lunch Provided</td>
<td>Lunch Provided</td>
</tr>
<tr>
<td>1:00 PM Workshops (see p5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:00 PM Break</td>
<td>Break</td>
<td>Break</td>
<td>Break</td>
</tr>
<tr>
<td>5:00 PM Break</td>
<td>Break</td>
<td>Break</td>
<td>Break</td>
</tr>
<tr>
<td>6:00 PM GIS Gallery Voting ends at 8:30 (see p7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7:00 PM Technology Hall Reception (see p16)</td>
<td>Technology Hall Reception (see p16)</td>
<td>Wednesday Night Social 5:30pm to 10:00pm (see p7)</td>
<td></td>
</tr>
<tr>
<td>8:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:00 PM</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix D – Winning Student Paper
Transit Ridership Estimation with Network Kriging: A Case Study of Second Avenue Subway, NYC.

Dapeng Zhang¹, Xiaokun Wang²

ABSTRACT

An attractive topic in transportation practice is transit ridership estimation. Reliable estimates are beneficial for facility designs, vehicle operations, as well as financial and labor managements. Traditional ridership estimation approaches mainly rely on regression models considering subway fare, population, and employment distribution in surrounding areas. Consideration about ridership’s spatial dependency is largely lacking in these models. This paper recognizes the spatial effect by estimating the ridership of the new Second Avenue Subway in New York City using a Network Kriging method. Network distance, instead of Euclidean distance, is used to reflect the fact that subway stations are only connected by subway tunnels. ArcGIS helps to calculate the network distance and delineate neighborhood as Thiessen Polygons around subway stations. Results show that the new service will effectively relieve the traffic burden on the currently crowded subway lines.

KEYWORDS: Network distance; Kriging; Spatial econometrics; Transit ridership; GIS application

¹ Graduate Student, Department of Civil and Environmental Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180. E-mail: zhanad9@rpi.edu
² Assistant Professor, Department of Civil and Environmental Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180.
INTRODUCTION

Reliable transit ridership estimation is important for passengers, transit companies, and public agencies. With reliable estimation, passengers can make confident decisions on their travel paths, modes, and departure time. Transit companies can assign proper capacity, make reasonable service schedules, and operate economically. Public agencies can propose cost-effective transportation investments, manage financial and labor force, and enhance sustainable city developments.

Most existing studies estimate transit ridership as part of travel demand modeling using four-step methods (Horowitz, 1984) or activity-based models (Hildebrand, 2003). The four step method predicts traffic patterns at an aggregate level while activity-based models predict individual travel behavior at disaggregate level. Both approaches are within the general framework of travel demand modeling, where transit ridership is treated as demand of a specific transportation mode. Although behavior consistent, estimating transit ridership as part of the overall travel demand has high data requirement. An alternative approach is to use regression models to build direct connections between ridership and a set of factors whose information can be easily obtained. These factors often include local demographic features, economic indexes, and geographic information, etc. Regression models present a quick and convenient alternative for ridership estimation. Current regression models tend to assume that the ridership estimates are independent across stations. However, a lot of the uncontrolled factors, such as crime rates in the neighborhood and conditions of sidewalk may influence ridership, causing strong correlation between ridership estimates of nearby stations. The correlation weakens as the distance between stations get longer. There should be a way to fully recognize and utilize such spatial interdependency pattern instead of simply treating the unobservables as white noise.

In light of the deficiency of current regression models, this paper uses a Network Kriging model to estimate transit ridership. Kriging models are often used to estimate unknown variables using known variables at nearby locations. A standard Kriging estimator is a weighted average of known variables where weights are determined by distance. A universal Kriging method can further consider the “shift” caused by local conditions. For ridership estimation, this means ridership at new stations can be estimated based on local factors and current ridership at existing stations. Furthermore, network distance, instead of Euclidean distance, is used to determine weights as it reflects the fact that subway stations are connected via subway tunnels. The distance is calculated in ArcGIS network analysis module. This paper will estimate the subway ridership of a new subway line, the Second Avenue Subway, in New York City using Network Kriging model. The locality of each station on Manhattan is delineated by Thiessen polygons, executed in ArcGIS. Thus, features of stations’ geographical locations and network connectivity are captured in the model, resulting in more reliable ridership estimates.

The next section reviews current literature on transit ridership estimation and Kriging models. Data is then described and the model specification is discussed. Finally results are presented and analyzed, followed by conclusions.
LITERATURE REVIEW

Transit Ridership Estimation

The most commonly used methods of transit ridership estimation in practice include professional judgment, contrasts with similar routes, service elasticities analysis (Litman, 2004), travel demand modeling, and econometric and regression models (Boyle, 2006). Among them, the first three methods are primarily used for assessing route or service changes, while travel demand modeling is commonly used for new services. Although the travel demand modeling has been popular for decades in ridership estimation, it is not a handy method in practice and the resolutions are often too coarse to capture the subtle changes in the built-in environment characteristics near transit stops (Cervero, 2006a). Econometric and regression models, on the other hand, are less costly to use (Marshall and Grady, 2006) and they can establish the relationship between a variety of influential factors and transit ridership. Linear regression models appeared in a large amount of literature to examine the effects of various influential factors on transit ridership. (Gomez-Ibanez, 1996; Hendrickson, 1986; Kain, 1997; Kitamura, 1989; Kuby et al., 2004; Taylor et al., 2003; Wang and Skinner, 1984). Besides the transit system operation conditions, influential factors examined include regional geography, metropolitan economy, population characteristics, and auto/highway system characteristics, etc. (Taylor et al., 2009) The magnitudes of their effects are found to differ significantly in different case studies and should be analyzed on a case by case basis. More advanced econometric models have also been used to accommodate the nonlinear nature of the ridership data generating process. For example, whether or not people choose to ride transit can be treated as a binary choice, and binary logit models are suitable in such cases (Baum-Snow and Kahn, 2000; Syed and Khan, 2000). Koppelman (1983) developed a simplified form of multinomial logit model to predict ridership shift in response to service changes. Abdel-Aty (2001) used an ordered probit model to explain the likelihood of using transit based on a stated preference survey. Cervero (2006b) established nested logit models to explain the relationship between rail location and commute choices in order to evaluate the effectiveness of transit oriented development in California. As transit ridership essentially reflects equilibrium between demand and supply, some studies also use structural equation models to address the potential endogeneity (Peng et al., 1997; Taylor et al., 2009). Another frequently used method is the time series models, which can formulate the trend of ridership and make prediction using previous time periods’ data (Kain and Liu, 1999; Kyte et al., 1988).

All the aforementioned studies focus on the effects of controlled factors and time trend, while few attempt to reduce estimation errors by considering the spatial dependency of transit ridership, which is an important feature underlying the transit system. In the general field of transit research, a few studies have considered spatial dependency using spatial econometric methods. For example, Goetzke (2008) applied a spatial autoregressive logit model to formulate transit use in New York City. Kim and Zhang (2005) investigated the interaction between land price and transit use in Seoul using spatial autoregressive model, spatial error model, and spatial autocorrelation model. These models presume that dependent variables or error terms are correlated among observations. By assuming the spatial patterns, models’ explanatory power normally increases. Another method with spatial consideration is the geographically weighted regression (GWR). Chow et al. (2006) developed a GWR model to improve the accuracy of ridership estimation using data of Broward County, Florida. Cardozo et al. (2012) also used a GWR model in a Madrid metro ridership analysis and concluded that GWR model had a better fit. GWR models allow for specifications of local spatial effects and capture the geographic heterogeneity of influential factors’ effects.
These models with spatial considerations still lack the ability to forecast values at locations that are new in the system. In light of the remarkable forecast ability of Kriging models, this paper will develop a Kriging model to investigate and predict transit ridership, which has not yet been used in existing transit ridership literature.

**Kriging Models**

Kriging in geo-statistics is synonymous with “optimally predicting” in space, using observations with known values at nearby locations (Cressie, 1990). This method has been applied in a variety of research fields and derived to many sophisticated formats. For instance, Odeh et al. (1995) used a heterotopic cokriging and a regression-Kriging to predict soil properties. Goovaerts (2000) presented Kriging models for the spatial prediction of rainfall. Lefohn et al. (1987) used Kriging technique to predict seasonal mean ozone concentrations for estimating crop losses. There are also literatures incorporating Kriging in the transportation field. Briggs et al. (2000) modeled spatial patterns of traffic related air pollution, using Kriging method to generate accurate, high-resolution air pollution maps. Braxmeier et al. (2009) used Kriging methods to forecast the traffic on a road network in Berlin, Germany. Wang and Kockelman (2009) applied a Kriging model to predict annual average daily traffic using Texas highway count data. Given the strong predictive power of Kriging method for forecasting spatially distributed data, this paper also adopts a Kriging model to forecast transit ridership.

Standard Kriging inference for spatially distributed variables is based on the relationship between distance and variability, which is called a semivariogram in Kriging profession. Various theoretical semivariogram have been proposed, and Dale Zimmerman and Bridget Zimmerman (1991) did a comprehensive comparison of those functions. Laslett (1994) also compared the choice of theoretical semivariogram functions and concluded that the precision of prediction is based on the real data. Typical application of Kriging relies on Euclidean distance, assuming spatial dependency over the continuous space. However, Euclidean distance may not be appropriate for certain occasions. For example, Hoef et al. (2006) developed a Kriging model that uses flow volume and stream distance in a research for predicting stream flows at unmeasured locations. Wang and Kockelman (2009) estimated annual average daily traffic using highway network distance measurement. The reason for using non-Euclidean distance is that locations are not related in Euclidean space, but through a certain intermediary. For example, the stream flow is related through rivers and traffic count is related through high ways. This paper investigates ridership on subway stations, which are related through subway tunnels.

**DATA DESCRIPTION**

The case study of this research is the proposed Second Avenue Subway line in the New York City (NYC) subway system.

The NYC subway is one of the oldest, most extensive, and busiest rapid rail systems in the world with an annual ridership of 1.665 billion in 2012 (MTA, 2012a). Stations are located throughout the boroughs of Manhattan, Brooklyn, Queens, and Bronx, and are mostly open 24 hours a day (MTA, 2012b). Manhattan, the study area, has a dense subway network with 20 lines. As shown in the left map on Figure 1, the service on Upper East Side of Manhattan is sparse, which is served only by Lexington avenue lines (MTA, 2003). Lexington avenue lines also work as the major transportation between Manhattan and Bronx. Moreover, Upper East Side has a high
transportation demand because it is one of the most affluent neighborhoods in the City with many diplomatic missions, museums, hotels, and shopping centers. Currently, people have to suffer from the crowded service at stations along the Upper East Side. To relieve the traffic burden, the Metropolitan Transportation Authority (MTA) revealed a set of construction projects, including the one for the Second Avenue Subway from 125th street to Hanover Square (Bennett, 2009).

Figure 1 Current Manhattan Subway Map and Potential Second Avenue Subway Map (MTA, 2013a)

As proposed in 2006, the Second Avenue Subway construction consists of four phases (MTA, 2013b): the first phase is scheduled to complete and open to public at the end of 2016 (Donohue, 2013), aiming to split the flows on the most crowded segments of Lexington Avenue lines (96th street to 63rd street). Upon the accomplishment of the first phase, the current Q trains will be
rerouted to serve Upper East Side and be connected with the current Broadway lines via existing 63rd Street line. A new designation of T train will serve the entire length of second avenue line, sharing tracks and stations with Q trains at the Upper East Side (Reeves, 2006). The plan of routes and stations are shown in the right side map on figure 1 and the list of new stations is shown in Table 1.

### Table 1 List of New Stations (MTA, 2013b)

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
<th>Transfers</th>
</tr>
</thead>
<tbody>
<tr>
<td>125th Street</td>
<td>125th St and Lexington Ave</td>
<td>4 5 6 trains, M60 bus to LaGuardia Airport, Metro-North Railroad at Harlem - 125th Street</td>
</tr>
<tr>
<td>116th Street</td>
<td>116th St and 2 Ave</td>
<td></td>
</tr>
<tr>
<td>106th Street</td>
<td>106th St and 2 Ave</td>
<td></td>
</tr>
<tr>
<td>96th Street</td>
<td>96th St and 2 Ave</td>
<td></td>
</tr>
<tr>
<td>86th Street</td>
<td>86th St and 2 Ave</td>
<td></td>
</tr>
<tr>
<td>72nd Street</td>
<td>72nd St and 2 Ave</td>
<td></td>
</tr>
<tr>
<td>55th Street</td>
<td>55th St and 2 Ave</td>
<td>6 E M trains</td>
</tr>
<tr>
<td>42nd Street</td>
<td>42nd St and 2 Ave</td>
<td>4 5 6 7 S trains, Metro-North Railroad &amp; Long Island Rail Road</td>
</tr>
<tr>
<td>34th Street</td>
<td>34th St and 2 Ave</td>
<td></td>
</tr>
<tr>
<td>23rd Street</td>
<td>23rd St and 2 Ave</td>
<td></td>
</tr>
<tr>
<td>14th Street</td>
<td>14th St and 2 Ave</td>
<td>L train</td>
</tr>
<tr>
<td>Houston Street</td>
<td>Houston St and 2 Ave</td>
<td>F train</td>
</tr>
<tr>
<td>Grand Street</td>
<td>Grand St and 2 Ave</td>
<td>B D trains</td>
</tr>
<tr>
<td>Chatham Square</td>
<td>Worth St and Chatham Square</td>
<td></td>
</tr>
<tr>
<td>Seaport</td>
<td>Fulton St and Water St</td>
<td></td>
</tr>
<tr>
<td>Hanover Square</td>
<td>Water St and Hanover Square</td>
<td>Pier 11</td>
</tr>
</tbody>
</table>

The goal of this paper is to estimate ridership at these proposed stations using easily obtainable data and considering the spatial dependency. More specifically, the focus will be the forecast of average weekday ridership as stations in Manhattan are much busier in weekdays than weekends and holidays. Supporting information mainly comes from four sources: ridership at existing stations provided by MTA (2013c), demographic information in the surrounding neighborhoods derived from the American Community Survey (ACS) (U.S. Census Bureau, 2010a), employment information provided by County Business Patterns (CBP) (U.S. Census Bureau, 2010b), and information regarding built environment derived from the Primary Land Use Tax Lot Output (PLUTO) (NYC Department of Planning, 2010).

### Ridership Information

Ridership information on existing lines is collected by MTA via the MetroCard ticket system. The average ridership data is provided on MTA’s website (MTA, 2013c). The ridership consists of all passengers who enter the subway system, including those transferring from buses, but not those transferring from other subway lines. It should be noted that ridership at some stations are
counted together as they are internally connected to facilitate transfer. In the NYC subway system, there are two pairs of such stations. One is the 14th Street - 6 Avenue station and the 14th Street - 7 Avenue station; the other is the Time Square-42nd Street station and the Port Authority-42nd Street station. In these cases, ridership of individual station is allocated based on the number of tracks in each station. Such processing leads to ridership data for 117 individual stations in Manhattan.

**Neighborhood Information**

Ridership at a station can also be influenced by the characteristics of the neighborhood surrounding it. Most existing studies define “neighborhood” as the zone within certain walkable distance from the station; and 0.25 miles is often used as the industry standard (Sallis, 2008). As a result, neighborhoods are delineated by circles around stations. However, the Manhattan subway stations are so densely located that these circles overlap substantially. In such cases, Thiessen Polygons can be created to represent neighborhoods. Thiessen polygons are generated by (1) drawing inerratic circles around each station; (2) creating bisector lines by connecting the points where circles intersect; and (3) connecting the bisector lines. Essentially, Thiessen Polygon avoids neighborhood overlapping by allocating a location to its nearest station. In a study of Madrid Metro network, Gutiérrez, Cardozo (2011) created Thiessen Polygons to represent neighborhoods around metro stations, and results are satisfactory. This study generates Thiessen Polygons based on locations of subway stations and the boundary of Manhattan, implying that the entire island is assumed to be served by the subway system. Such assumption is justifiable as most of these polygons are within the circles of 0.25 mile radius. Some locations (e.g., along the edge) have longer distance from the stations, but not exceeding 1 mile. Taking into account the condition of walking facilities in Manhattan, such distance is still considered walkable. Figure 2 shows the neighborhoods generated with Thiessen Polygon.
Figure 2 Thiessen Polygons for Manhattan Subway Stations

The Thiessen Polygons are then spatially aligned with the ACS data (in census tract level), CBP data (at ZIP code level), and the Primary Land Use Tax Lot Output (PLUTO) data, generating variables indicating neighborhood characteristics. Table 2 lists their descriptions and summary statistics. Variables \( \ln_{\text{pop}}, \ln_{\text{gender}}, \) and \( \ln_{\text{inc}} \) are derived from the ACS. \( \ln_{\text{emp}} \) is derived from the CBP. \( \ln_{\text{retail}} \) and \( \ln_{\text{storage}} \) originate from PLUTO. Variables \( \ln_{\text{ridership}}, \ln_{\text{pop}}, \ln_{\text{emp}}, \ln_{\text{retail}}, \) and \( \ln_{\text{storage}} \) are in the form of natural logarithm as they have large values and their distributions are right-skewed. Besides, a log transformed model offers convenient interpretation as the estimated coefficients can be directly interpreted as elasticity. The variable \( \text{attract} \) is a binary variable, indicating whether the station serves at least one of the most popular attractions (Timeout.com, 2013). The variable \( \text{line} \) indicates the number of subway lines serving a station. The variable \( \text{othermode} \) is an indicator variable, showing the connectivity to other modes of transportation.
Table 2 Summary Statistics of Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Definitions</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent Variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln_ridership</td>
<td>logarithm of average weekday ridership in persons</td>
<td>9.70</td>
<td>0.89</td>
<td>7.58</td>
<td>11.88</td>
</tr>
<tr>
<td>Independent Variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln_pop</td>
<td>logarithm of population in persons</td>
<td>8.46</td>
<td>1.16</td>
<td>4.75</td>
<td>10.60</td>
</tr>
<tr>
<td>gender</td>
<td>ratio of male to female</td>
<td>0.94</td>
<td>0.19</td>
<td>0.48</td>
<td>2.15</td>
</tr>
<tr>
<td>ln_income</td>
<td>logarithm of residents' income in dollar</td>
<td>11.10</td>
<td>0.57</td>
<td>9.14</td>
<td>12.23</td>
</tr>
<tr>
<td>ln_emp</td>
<td>logarithm of employment in persons</td>
<td>9.01</td>
<td>1.16</td>
<td>6.27</td>
<td>11.53</td>
</tr>
<tr>
<td>ln_retail</td>
<td>logarithm of retail area in square miles</td>
<td>13.43</td>
<td>0.92</td>
<td>11.44</td>
<td>15.23</td>
</tr>
<tr>
<td>ln_storage</td>
<td>logarithm of storage area in square miles</td>
<td>11.41</td>
<td>2.36</td>
<td>6.87</td>
<td>15.84</td>
</tr>
<tr>
<td>attract</td>
<td>indicator variable: 1, if there are top 20 NYC attractions; 0, if not</td>
<td>0.16</td>
<td>0.37</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>line</td>
<td>number of subway lines</td>
<td>2.19</td>
<td>1.61</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>othermode</td>
<td>indicator variable: 1, if available to transfer to trunk bus, intercity bus, train, path, and ferry; 0, if not</td>
<td>0.17</td>
<td>0.38</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

The above statistics are derived from variable values for current neighborhoods. When interpolating the ridership on the Second Avenue Subway stations, the neighborhoods will be re-delineated and the above independent variables will be recalculated.

METHODOLOGY

This paper develops a Network Kriging approach to estimate ridership on newly constructed subway stations. At each station, the ridership can be expressed as

\[ Z_s = X_s \beta + e_s \]  

(1)

where \( Z_s \) is the ridership at station \( s \). \( X_s \) is the vector of \( K \) influential factors at station \( s \). \( \beta \) is the corresponding estimable vector of parameters. \( e_s \) is the error term and can be further formulated by a semivariogram function \( \gamma(h) \), where \( h \) is the network distance between any two stations \( s \) and \( s' \).

The commonly used semivariogram functions \( \gamma(h) \) include exponential function, spherical function, and Gaussian function. All functions are monotonically increasing and have maximal values. Such a trend is consistent with the geo-statistic assumption that closer objects tend to have similar performance. Statisticians find that these functions provide similar results in practice (Zimmerman et al., 1998). This paper chooses the exponential function so that

\[ \gamma(h) = \begin{cases} 
  c_0 + c_1 \left[ 1 - \exp \left( \frac{-h}{a} \right) \right] & \text{if } h > 0 \\
  0 & \text{otherwise} 
\end{cases} \]  

(2)
where $c_0$, $c_1$, and $\alpha$ are parameters to be estimated. $c_0$ is called the "nugget effect" (Geoff, 2005), which reflects discontinuity at the semivariogram’s origin, as caused by factors such as sampling error at subway stations. $c_0 + c_1$ is the maximum of $\gamma$, called the "sill", indicating the maximum variance in the error terms between a pair of subway stations. Thus, $c_1$ refers to the "partial sill". $\alpha$ is called the "range", determining the threshold distance between two stations where the variance in the error term stabilizes.

In order to estimate the Kriging model, $Z_s$ is first regressed on $X_s$ to obtain the empirical value of the error. The empirical semivariogram can be then created and fitted to the exponential function in Equation (2), obtaining $c_0$, $c_1$, and $\alpha$. Once the theoretical semivariogram with the estimated $c_0$, $c_1$, and $\alpha$ is derived, it can be used to construct a variance-covariance matrix of the error term $V$ in the form of

$$V_{ss} = c_0 + c_1 - \gamma_{ss}(h)$$

With the updated error term, the $\beta$ is re-estimated using a feasible generalized least square (GLS) method. Such a process is iterated until converge.

The ridership on the Second Avenue Subway stations can be derived by

$$Z_{new} = X_{new} \beta + V_{new,old}^T V_{old,old}^{-1} e_{old}$$

where subscripts $new$ and $old$ indicate the newly-constructed stations and existing ones respectively. Essentially, ridership at a new station is predicted as the summation of local neighborhood influence (captured by the variables characterizing the neighborhood) and contribution of unobserved factors (captured by the interpolated error term based on estimation residuals at existing stations). The second component in Equation (4) can be considered as the main contribution that distinguishes this study from previous ones: instead of assuming unobserved factors as white noise and treating them as nuisance, they are fully utilized to improve the prediction by considering the spatial dependency. The estimation and forecasting processes are coded in MATLAB.

MODEL VALIDATION

This section validates the reliability Network Kriging models on ridership estimation. Current ridership data on 15 randomly selected stations in current subway network are set to be unmeasured. The unmeasured stations are estimated from other ridership data by three models, linear regression, Kriging with Euclidean distance, and Network Kriging. Then, the estimation accuracy can be indicated by comparing the actual data and estimated values.

Statistics Mean Squared Error (MSE) and Percent Squared Error (%SE) measure the difference between the estimated ridership ($Z_{est}$) and the observed ridership $Z_{obs}$. $n$ is the number of randomly selected stations where ridership counts need to be estimated.

$$MSE = \frac{\sum (Z_{est} - Z_{obs})^2}{n}$$
%SE = \frac{MSE}{\sum Z_{obs}}

The validation results are shown in Table 3. Both measures indicate that Network Kriging has better estimation on the unmeasured ridership and linear regression model has the largest bias. That is, the Network Kriging model has a little improvement on estimation accuracy and should be appropriate for the Second Avenue Subway ridership estimation.

Table 3 Validation Results of Three Models

<table>
<thead>
<tr>
<th></th>
<th>Linear Regression</th>
<th>Kriging with Euclidean Dist</th>
<th>Network Kriging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Squared Error</td>
<td>12.03</td>
<td>11.99</td>
<td>11.97</td>
</tr>
<tr>
<td>% Square Error</td>
<td>19.94%</td>
<td>19.88%</td>
<td>19.84%</td>
</tr>
</tbody>
</table>

RESULTS ANALYSIS

The Network Kriging method is then applied to the ridership data over the entire Manhattan subway network. As shown in Table 4, the values of coefficient estimates are close in all models. This is expected as Ordinary Least Square (OLS) and Generalized Least Square (GLS) both produce unbiased estimators. Unbiased estimators for the same parameter set should be very close to each other. However, the t-statistics in both Kriging models are much larger than those in the linear regression. In other words, the efficiency of estimation is much better with the Kriging models. The Network Kriging method produces estimates with narrower confidence intervals thus more reliable forecasting results for the Second Avenue Subway ridership.
Table 4 Results of the Three Models

<table>
<thead>
<tr>
<th>Variables</th>
<th>Linear Regression</th>
<th>UK with Euclidean Dist</th>
<th>UK with Network Dist</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coef.</td>
<td>t-stat</td>
<td>Coef.</td>
</tr>
<tr>
<td>ln_pop</td>
<td>0.103</td>
<td>2.22</td>
<td>0.104</td>
</tr>
<tr>
<td>gender</td>
<td>0.263</td>
<td>0.97</td>
<td>0.280</td>
</tr>
<tr>
<td>ln_income</td>
<td>0.252</td>
<td>2.82</td>
<td>0.253</td>
</tr>
<tr>
<td>ln_emp</td>
<td>0.168</td>
<td>2.98</td>
<td>0.172</td>
</tr>
<tr>
<td>ln_retail</td>
<td>0.299</td>
<td>3.66</td>
<td>0.297</td>
</tr>
<tr>
<td>ln_storage</td>
<td>-0.054</td>
<td>-2.24</td>
<td>-0.055</td>
</tr>
<tr>
<td>attract</td>
<td>0.315</td>
<td>2.41</td>
<td>0.301</td>
</tr>
<tr>
<td>line</td>
<td>0.240</td>
<td>7.95</td>
<td>0.240</td>
</tr>
<tr>
<td>othermode</td>
<td>0.248</td>
<td>2.12</td>
<td>0.247</td>
</tr>
<tr>
<td>constant</td>
<td>0.258</td>
<td>0.23</td>
<td>0.224</td>
</tr>
<tr>
<td>c0</td>
<td>0.083</td>
<td>5.04</td>
<td>0.047</td>
</tr>
<tr>
<td>c1</td>
<td>0.003</td>
<td>0.78</td>
<td>0.025</td>
</tr>
<tr>
<td>a</td>
<td>0.901</td>
<td>42.21</td>
<td>0.899</td>
</tr>
</tbody>
</table>

These estimates also provide interesting insights into the subway ridership problem.

The coefficient of population is 0.103, indicating that population has a positive effect on subway ridership. A 1% increase of population in the surrounding neighborhood is associated with 0.103% increase of the ridership at the subway station. Male to female ratio is estimated to be positively related to ridership: an additional 0.01 of the gender ratio is associated with 0.270% more ridership. This estimate implies that men tend to generate more subway trips than women do. Wealthier neighborhoods tend to generate more subway ridership, as indicated by the positive coefficient of ln_income. Every 1% increase in the neighborhood’s average household income is associated with 0.252% increase in the ridership. This finding is consistent with most previous studies where income is found to be positively related to the travel frequency.

Many people working in Manhattan rely on subway to commute from Queens, Brooklyn and Bronx to their workplaces. As a result, employment contributes significantly to subway ridership. Stations serving areas with high employment densities are often crowded. It is estimated that a station’s ridership will increase by 0.168% if the number of employments in the surrounding neighborhood increases by 1%. Manhattan is also well known for its commerce and shops generate large travel demand, as captured by the variable ln_retail. It is estimated that ridership at a subway station will be 0.299% higher with 1% additional retail area. In contrast, storage areas do not attract passengers. Ridership decreases by 0.054% if the storage area increases 1%.

Besides local residents and workers, a large portion of NYC subway riders are tourists. Tourists visiting New York City often find subway as the most convenient transportation mode. Millions of tourists come to the City every year, contributing to the subway ridership. Therefore, stations serving scenic spots tend to have higher ridership. The coefficient of attract is 0.314, indicating the ridership at these stations are 31.4% higher than those not serving any tourism attractions.

The subway ridership is not only influenced by surrounding neighborhood’s travel demand, but also quality of supplies. Some stations more attractive to riders because they are served by both
local and express subway lines, or both east-west and south-north lines. In order to reflect the impact of "supply," the effect of number of lines is evaluated. Results suggest that ridership is 23.9% higher when there is one additional subway line serving a certain station.

The NYC subway is also the main connector of NYC’s various transportation terminals. In New York City and surroundings, there are three international airports, one national train hub, several regional train stations, and multiple inter-city bus terminals. Passengers may use the subway system to transfer from one to another, contributing to the subway ridership. The estimate of other mode shows that ridership at stations serving major transportation terminals are 24.9% higher.

The parameters in the semivariogram are estimated simultaneously with the coefficients of independent variables. The "nugget effect" $c_0$ is 0.047, which is caused by the measurement error or the short scale variability. The "partial sill" $c_1$ is 0.025, indicating the variance does not improve much when the network distance increases. The "sill" $c_0 + c_1$ is thus 0.072, indicating the maximum variability of regression error terms is low. The reason may be that the exogenous independent variables have captured most variance. When checking the R-square statistics of the Network Kriging model, more than 99% of the variability of ridership is explained by the independent variables. The "range" parameter is 0.899, indicating that the variability stabilizes when the network distance between two stations is longer than 0.899 miles. In other words, 0.899 miles is the threshold to see whether there is an increasing variability.

The ridership at the Second Avenue Subway stations can thus be interpolated using the estimated coefficients. The independent variables of the new stations are calculated by new Thiessen Polygons which are delineated based on the planned station locations. The before and after ridership are shown in Table 5. Four of the Second Avenue Subway stations use the existing stations and the others are new stations. The ridership changes at the four stations mainly result from the re-delineation of the covered area. Comparison of the results from Network Kriging and those from linear regression shows some differences. For example, the ridership at the 125th station is 39,900 by linear regression, but 32,219 by Network Kriging. The lower ridership estimated by Network Kriging may be due to the consideration of nearby stations (116th station, 110th station, and etc.) which have low ridership as Kriging assumes that the error variability is low for close objects.

Table 5 also lists the before-after ridership on parallel Lexington Avenue stations. Ridership of most existing stations decreases. The main reason is that the Second Avenue Subway covers part of area that is currently covered by Lexington Avenue lines. In other words, the Lexington lines ridership is split to the Second Avenue Subway. This is one of the most important targets of constructing the Second Avenue Subway. When the new lines are open to public, Lexington Avenue lines will not be crowded as it is today and mainly serve as the connection between Manhattan and Bronx.

The total ridership in the NYC subway system before and after the launching of Second Avenue Subway service is then calculated, as presented in Table 6. The increased ridership is 40,570 per weekday, which is 1.5% of the current ridership. In the long term, this number is likely to increase as more residents and business are attracted by the new subway service.
### Table 5: Ridership on Second Avenue Subway stations and Parallel Lexington stations

<table>
<thead>
<tr>
<th>Station on Second Avenue Subway</th>
<th>Current Ridership</th>
<th>Estimated Ridership by Linear Regression</th>
<th>Estimated Ridership by Kriging with Network Dist</th>
<th>Parallel Lexington Avenue Stations</th>
<th>Current Ridership</th>
<th>Estimated Ridership by Linear Regression</th>
<th>Estimated Ridership by Kriging with Network Dist</th>
</tr>
</thead>
<tbody>
<tr>
<td>125th Street</td>
<td>27,990</td>
<td>39,900</td>
<td>32,219</td>
<td>125th Street</td>
<td>27,990</td>
<td>39,900</td>
<td>32,219</td>
</tr>
<tr>
<td>116th Street</td>
<td>New</td>
<td>13,017</td>
<td>8,336</td>
<td>116th Street</td>
<td>15,655</td>
<td>7,556</td>
<td>8,336</td>
</tr>
<tr>
<td>106th Street</td>
<td>New</td>
<td>15,192</td>
<td>9,568</td>
<td>110th Street</td>
<td>15,630</td>
<td>8,954</td>
<td>9,568</td>
</tr>
<tr>
<td>96th Street</td>
<td>New</td>
<td>18,941</td>
<td>10,165</td>
<td>103rd Street</td>
<td>15,210</td>
<td>9,176</td>
<td>10,165</td>
</tr>
<tr>
<td>86th Street</td>
<td>New</td>
<td>44,338</td>
<td>19,411</td>
<td>96th Street</td>
<td>24,870</td>
<td>18,904</td>
<td>19,411</td>
</tr>
<tr>
<td>72nd Street</td>
<td>New</td>
<td>54,776</td>
<td>55,880</td>
<td>86th Street</td>
<td>60,965</td>
<td>60,272</td>
<td>55,880</td>
</tr>
<tr>
<td>55th Street</td>
<td>New</td>
<td>45,748</td>
<td>28,752</td>
<td>77th Street</td>
<td>35,579</td>
<td>29,498</td>
<td>28,752</td>
</tr>
<tr>
<td>42nd Street</td>
<td>New</td>
<td>37,813</td>
<td>17,996</td>
<td>68th Street / Hunter College</td>
<td>34,984</td>
<td>21,244</td>
<td>17,996</td>
</tr>
<tr>
<td>34th Street</td>
<td>New</td>
<td>23,723</td>
<td>58,201</td>
<td>59th Street</td>
<td>63,138</td>
<td>79,255</td>
<td>58,201</td>
</tr>
<tr>
<td>23rd Street</td>
<td>New</td>
<td>22,241</td>
<td>44,313</td>
<td>51st Street</td>
<td>62,774</td>
<td>40,862</td>
<td>34,431</td>
</tr>
<tr>
<td>14th Street</td>
<td>6,123</td>
<td>28,441</td>
<td>55,407</td>
<td>42nd Street / Grand Central</td>
<td>144,350</td>
<td>133,415</td>
<td>93,920</td>
</tr>
<tr>
<td>Houston Street</td>
<td>17,090</td>
<td>24,328</td>
<td>15,020</td>
<td>33rd Street</td>
<td>30,497</td>
<td>23,667</td>
<td>31,357</td>
</tr>
<tr>
<td>Grand Street</td>
<td>23,304</td>
<td>15,994</td>
<td>12,690</td>
<td>25th Street</td>
<td>22,274</td>
<td>12,993</td>
<td>17,327</td>
</tr>
<tr>
<td>Chatham Square</td>
<td>New</td>
<td>12,890</td>
<td>16,095</td>
<td>23rd Street</td>
<td>30,929</td>
<td>11,227</td>
<td>12,346</td>
</tr>
<tr>
<td>Seaport</td>
<td>New</td>
<td>14,294</td>
<td>46,670</td>
<td>14th Street / Union Square</td>
<td>106,380</td>
<td>120,183</td>
<td>55,407</td>
</tr>
<tr>
<td>Hanover Square</td>
<td>New</td>
<td>10,600</td>
<td>15,020</td>
<td>Astor Plaza</td>
<td>17,630</td>
<td>15,212</td>
<td>15,020</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bleecker Street</td>
<td>34,191</td>
<td>57,492</td>
<td>44,084</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spring Street</td>
<td>11,132</td>
<td>11,117</td>
<td>8,522</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Canal Street</td>
<td>46,435</td>
<td>98,357</td>
<td>46,770</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Brooklyn Bridge</td>
<td>36,939</td>
<td>23,423</td>
<td>16,095</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fulton Street</td>
<td>64,287</td>
<td>62,977</td>
<td>33,157</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Wall Street</td>
<td>22,551</td>
<td>8,063</td>
<td>9,705</td>
</tr>
</tbody>
</table>
Table 6 Ridership Induced by Second Avenue Subway

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Estimated Total Ridership</td>
<td>2,711,244</td>
</tr>
<tr>
<td>Total Ridership with Second Avenue Subway</td>
<td>2,751,814</td>
</tr>
<tr>
<td>Induced ridership</td>
<td>40,570</td>
</tr>
<tr>
<td>Percentage ridership increase</td>
<td>1.50%</td>
</tr>
</tbody>
</table>

CONCLUSIONS

This paper uses a Network Kriging method to estimate ridership at subway stations, using the Second Avenue Subway in Manhattan as an example.

With this Network Kriging model, independent variables capture the deterministic part of ridership. The stochastic part is fitted by a semivariogram which is an exponential function of distance between two stations. The distance is calculated by the subway network distance instead of the Euclidean distance in standard Kriging because network distance is a more pattern-consistent index in measuring adjacency in a subway network. The fitted semivariogram shows that close stations have less variability and distant stations generally have large variability, but the variability keeps constant beyond 0.899 miles. The reliability of Network Kriging model is first validated by estimating ridership at 15 randomly-selected stations in the current network. Results show that Network Kriging improves the estimation accuracy compared to a standard linear regression model and a Kriging model with Euclidean distance. The ridership along the new Second Avenue Subway and the parallel Lexington Avenue Subway is then estimated. Results show that Second Avenue Subway will serve a considerable number of passengers and the congestion on Lexington lines will be relieved. The total ridership

The Network Kriging model developed and applied in this study improves Kriging model by using network distance instead of Euclidean distance. The methodology is also applicable in other transportation issues that involve measurements of adjacency. Besides, the study of spatial dependency on transit ridership highly contributes to public transportation research, serving as an important reference for future works on transit-oriented cities.
REFERENCES

http://www.mta.info/nyct/subway/howto_sub.htm Accessed July 29
http://www.mta.info/maps/submap.html Accessed July 29
http://www.mta.info/nyct/facts/ridership/ Accessed July 29