



University Transportation Research Center - Region 2

Final Report



A GIS-Based Performance Measurement System for Assessing Transportation Sustainability and Community Livability

Performing Organization: State University of New York (SUNY)



August 2014



Sponsor:
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the most responsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally. Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council, New York State Department of Transportation, and the New York State Energy and Research Development Authority and others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

Technology Transfer

UTRC's Technology Transfer Program goes beyond what might be considered "traditional" technology transfer activities. Its main objectives are (1) to increase the awareness and level of information concerning transportation issues facing Region 2; (2) to improve the knowledge base and approach to problem solving of the region's transportation workforce, from those operating the systems to those at the most senior level of managing the system; and by doing so, to improve the overall professional capability of the transportation workforce; (3) to stimulate discussion and debate concerning the integration of new technologies into our culture, our work and our transportation systems; (4) to provide the more traditional but extremely important job of disseminating research and project reports, studies, analysis and use of tools to the education, research and practicing community both nationally and internationally; and (5) to provide unbiased information and testimony to decision-makers concerning regional transportation issues consistent with the UTRC theme.

Project No(s):

UTRC/RF Grant No: 49997-28-24, DTRT-12-G-UTC02

Project Date:

August 2014

Project Title:

A GIS-Based Performance Measurement System for Assessing Transportation Sustainability and Community Livability

Project's Website:

<http://www.utrc2.org/research/projects/GIS-based-performance-measurement-system>

Principal Investigator(s):

Dr. Qian Wang, Ph.D.

Assistant Professor

Department of Civil, Structural, and Environmental Engineering

University at Buffalo (SUNY)

Buffalo, NY 14260

Tel: (716) 645-4365

Email: qw6@buffalo.edu

Dr. Le Wang, Ph.D.

Associate Professor

Department of Geography

University at Buffalo (SUNY)

Buffalo, NY 14260

Tel: (716) 645-0474

Email: lewang@buffalo.edu

Performing Organization(s):

State University of New York (SUNY)

Sponsor(s):

University Transportation Research Center (UTRC)

To request a hard copy of our final reports, please send us an email at utrc@utrc2.org

Mailing Address:

University Transportation Research Center

The City College of New York

Marshak Hall, Suite 910

160 Convent Avenue

New York, NY 10031

Tel: 212-650-8051

Fax: 212-650-8374

Web: www.utrc2.org

Board of Directors

The UTRC Board of Directors consists of one or two members from each Consortium school (each school receives two votes regardless of the number of representatives on the board). The Center Director is an ex-officio member of the Board and The Center management team serves as staff to the Board.

City University of New York

Dr. Hongmian Gong - Geography/Hunter College
Dr. Neville A. Parker - Civil Engineering/CCNY

Clarkson University

Dr. Kerop D. Janoyan - Civil Engineering

Columbia University

Dr. Raimondo Betti - Civil Engineering
Dr. Elliott Sclar - Urban and Regional Planning

Cornell University

Dr. Huaizhu (Oliver) Gao - Civil Engineering

Hofstra University

Dr. Jean-Paul Rodrigue - Global Studies and Geography

Manhattan College

Dr. Anirban De - Civil & Environmental Engineering
Dr. Matthew Volovski - Civil & Environmental Engineering

New Jersey Institute of Technology

Dr. Steven I-Jy Chien - Civil Engineering
Dr. Joyoung Lee - Civil & Environmental Engineering

New York University

Dr. Mitchell L. Moss - Urban Policy and Planning
Dr. Rae Zimmerman - Planning and Public Administration

Polytechnic Institute of NYU

Dr. Kaan Ozbay - Civil Engineering
Dr. John C. Falcocchio - Civil Engineering
Dr. Elena Prassas - Civil Engineering

Rensselaer Polytechnic Institute

Dr. José Holguín-Veras - Civil Engineering
Dr. William "Al" Wallace - Systems Engineering

Rochester Institute of Technology

Dr. James Winebrake - Science, Technology and Society/Public Policy
Dr. J. Scott Hawker - Software Engineering

Rowan University

Dr. Yusuf Mehta - Civil Engineering
Dr. Beena Sukumaran - Civil Engineering

State University of New York

Michael M. Fancher - Nanoscience
Dr. Catherine T. Lawson - City & Regional Planning
Dr. Adel W. Sadek - Transportation Systems Engineering
Dr. Shmuel Yahalom - Economics

Stevens Institute of Technology

Dr. Sophia Hassiotis - Civil Engineering
Dr. Thomas H. Wakeman III - Civil Engineering

Syracuse University

Dr. Riyad S. Aboutaha - Civil Engineering
Dr. O. Sam Salem - Construction Engineering and Management

The College of New Jersey

Dr. Thomas M. Brennan Jr - Civil Engineering

University of Puerto Rico - Mayagüez

Dr. Ismael Pagán-Trinidad - Civil Engineering
Dr. Didier M. Valdés-Díaz - Civil Engineering

UTRC Consortium Universities

The following universities/colleges are members of the UTRC consortium.

City University of New York (CUNY)
Clarkson University (Clarkson)
Columbia University (Columbia)
Cornell University (Cornell)
Hofstra University (Hofstra)
Manhattan College (MC)
New Jersey Institute of Technology (NJIT)
New York Institute of Technology (NYIT)
New York University (NYU)
Rensselaer Polytechnic Institute (RPI)
Rochester Institute of Technology (RIT)
Rowan University (Rowan)
State University of New York (SUNY)
Stevens Institute of Technology (Stevens)
Syracuse University (SU)
The College of New Jersey (TCNJ)
University of Puerto Rico - Mayagüez (UPRM)

UTRC Key Staff

Dr. Camille Kamga: *Director, Assistant Professor of Civil Engineering*

Dr. Robert E. Paaswell: *Director Emeritus of UTRC and Distinguished Professor of Civil Engineering, The City College of New York*

Herbert Levinson: *UTRC Icon Mentor, Transportation Consultant and Professor Emeritus of Transportation*

Dr. Ellen Thorson: *Senior Research Fellow, University Transportation Research Center*

Penny Eickemeyer: *Associate Director for Research, UTRC*

Dr. Alison Conway: *Associate Director for Education*

Nadia Aslam: *Assistant Director for Technology Transfer*

Nathalie Martinez: *Research Associate/Budget Analyst*

Tierra Fisher: *Office Assistant*

Bahman Moghimi: *Research Assistant; Ph.D. Student, Transportation Program*

Wei Hao: *Research Fellow*

Andriy Blagay: *Graphic Intern*

1. Report No.		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle A GIS-Based Performance Measurement System for Assessing Transportation Sustainability and Community Livability				5. Report Date August 31, 2014	
				6. Performing Organization Code	
7. Author(s) Qian Wang, Le Wang, Shuai Tang, Jing Hu, Xiao Chen, Wenjie Ji				8. Performing Organization Report No.	
9. Performing Organization Name and Address Department of Civil, Structural and Environmental Engineering University at Buffalo, the State University of New York 231 Ketter Hall, Buffalo, NY 14260-4300				10. Work Unit No.	
				11. Contract or Grant No. 49997-28-24, DTRT-12-G-UTC02	
12. Sponsoring Agency Name and Address US DOT Region 2 University Transportation Research Center City College of New York Marshak Hall, 910 New York, New York 10031				13. Type of Report and Period Covered	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
<p>16. Abstract</p> <p>Sustainability and livability in transportation, as the concepts referring to the capability of transportation systems to maintain the well being of our society, have been widely accepted as the critical principles to improve quality of life and health of communities. The research developed a GIS-based performance measurement system for assessing the roles of transportation in achieving these goals. Using the City of Buffalo, New York as the case study, we collected various data and generated twenty sustainability and livability related performance measures (PMs), including the transportation attributes, land use measures, living condition indicators, and system-wide indices. The analysis on PMs derives several policy implications and suggestions. Lessons and challenges learnt from the PM development process were also summarized to help other relevant initiatives. The PMs, supporting database, case study and findings produced by the research are expected to help a wide range of audience such as policy makers, planners and transportation engineers to gain insights about the sustainability and livability oriented performance measurement.</p> <p>The land use information is found as an important input data for developing such a performance measurement system. However, it is often outdated and not sufficient to support sustainability and livability assessment practices. In this context, we also developed the methods to predict land use classes by taking advantage of frequently updated remote sensing data. We utilized the multinomial logitistic regression, or called multinomial logit (MNL) models, for land use classification, whose great potentials have been overlooked in the field. In addition, we also suggest use transportation related attributes, such as the distances from a parcel of land to the nearest road or intersection, as the ancillary attributes to improve classification performance, in addition to spectral features collected by remote sensing. The MNL models were tested on the land use data collected in the City of Buffalo, New York. The best model achieves an average prediction accuracy of 83.7%. For the residential and commercial parcels, the prediction accuracy reaches up to 94.5%. In addition, the suggested transportation attributes were also found significant in discriminating land use classes.</p>					
17. Key Words sustainability, livability, performance measures, Geographical Information Systems (GIS), land use, remote sensing, multinomial logistic regression, multinomial logit (MNL) models, land use classification, transportation planning, orthoimagery data			18. Distribution Statement		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No of Pages 33	22. Price

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. The contents do not necessarily reflect the official views or policies of the UTRC Region II or the Federal Highway Administration. This report does not constitute a standard, specification or regulation. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

TABLE OF CONTENTS

Introduction.....	1
Research objectives.....	2
Part I: Development of the GIS-Based Performance Measurement System	3
Literature Review.....	3
Sustainability and Livability	3
Performance Measures.....	5
Research Approach	6
Study Case and Data	6
Performance Measure Generation and Analysis.....	8
PM Generation	8
PM Interpretation	14
Challenges and Opportunities in Developing PMs.....	17
Part II: Land Use Classification with Remote Sensing.....	19
Rational of Conducting Land Use Classification with Remote Sensing	19
Literature Review.....	20
Data.....	21
Attributes.....	21
Methodology.....	23
Applicability of MNL to Land Use Classification.....	23
Model Setting for the Study Case	24
Modeling Results	25
Model Prediction Performance	30
conclusions and future work.....	31
Acknowledgements.....	32
References.....	32

INTRODUCTION

Sustainability and livability in transportation, as the concepts referring to the capability of transportation systems to maintain the well being of our society, have been widely accepted as the critical principles to improve quality of life and public health. Different from the traditional objectives that emphasize short-term effects of planning and operation decisions, sustainability and livability emphasize the productiveness and efficiency of transportation systems over time, and pay special attention on the linkages of transportation to economic competitiveness, environmental protection, and social equity. As the recognition of this unique feature, the recent years have witnessed growing interest in incorporating sustainability and livability goals into transportation policy and decision making. For example, countries like the United Kingdom, Sweden, and Canada have been adopting sustainability policies for nearly two decades, to reinforce the positive impact of transportation projects on social and economic development (1, 2, 3, 4). As a follower, the U.S. has developed a couple of guidebooks to address critical issues involved in planning and developing sustainable transportation systems and livable communities (4, 5).

Although a number of principles and guidelines have been suggested, they are often found too ambiguous to be used for decision making processes due to the following issues. The first issue is the lack of performance measures (PMs) to translate abstract principles to quantitative metrics. The state of the practice is still lingering at the stage of developing guidelines and descriptive measures rather than offering technical details regarding how to quantitatively monitor the progress of policies and projects (4, 5, 6). Among the limited studies of exploring PMs, the majority of the suggested PMs fall into the narrow range of transportation service related indicators, and do not show the big picture in the social, economic and environmental contexts (7, 8). Moreover, little attention is paid on the freight transportation related measures on the monitoring of transportation performance changes over time.

Another issue is related to the unavailability of data fusion engines in supporting of such comprehensive assessments. Sustainability and livability focus on the health of transportation systems within a broad context of social, economic and environmental development. Thus, intensive data collection is needed to cover these aspects. Since sustainability and livability are comparative concepts that may vary by scales of areas (e.g., across neighborhoods, regions and states) and time frames (short term versus long run, current generation versus future generations), how to process and update data in spatial and temporal dimensions is another challenge to deal with. As the state of the art, the knowledge is still missing about what types of data should be collected and from which sources they can be found; not mentioning how these data can be processed by space and over time. As the consequence of the aforementioned issues, no such a comprehensive performance measurement system is available, which has the capability of integrating various PMs with relevant data for sustainability and livability oriented decision making.

These issues point out to the genuine need for developing such comprehensive performance measurement systems. As a step to fulfill this need, this research conducted a review to identify relevant data sources and performance measures. By using City of Buffalo in New York State as a case study, this paper demonstrates the process and findings gained from building a GIS-based performance measurement system. As an essential goal, the PMs, supporting database, case study and implications produced by the research are expected to help a wide range of audience such as policy makers, planners and transportation engineers to gain more insights about the PM system development.

This report is organized in the following manner. The second section reviews the sustainability and livability related research. The third section introduces the study area and the data. The fourth section presents the performance measures developed. The fifth section discusses the challenges and opportunities in developing the PM systems. At the end, a summary of the research findings is offered to conclude the research.

RESEARCH OBJECTIVES

The objectives of the proposed research are to:

- 1) Recommend an effective and efficient set of PMs that will help New York State to track the performance of transportation systems under the goals of enhancing quality of life and economic, environmental and social sustainability of our society;
- 2) Archive, fuse, organize and analyze relevant data streams in support of the calculation of PMs; and
- 3) Suggest additional data sources and data-oriented prediction methods for sustainability and livability measurement practices

The PMs, supporting database, case studies and implications produced by this research are expected to help a wide range of audience such as policy makers, planners and transportation engineers to incorporate sustainability and livability objectives into planning and operation practices in New York State.

This report is divided into two parts reflecting the afore-mentioned three objectives of the study. The first part describes the development of the GIS-based performance measurement system for assessing the role of a transportation system in supporting sustainability and livability goals, using the City of Buffalo as a study case. The second part, on the other hand, discusses the importance of land use information in the sustainability and livability measurement and the land use prediction methods that update land use in a timely fashion by taking advantage of remote sensing data.

PART I: DEVELOPMENT OF THE GIS-BASED PERFORMANCE MEASUREMENT SYSTEM

Literature Review

Sustainability and Livability

The concepts of sustainability and livability have been discussed in many research and review articles (9, 10, 3, 4, 11, 12, 13). The following is the authors' summary from a state of the art review. Sustainability and livability are two development goals to be achieved for fostering the long-term well-being of our communities and societies. *Sustainability* is a broad concept that refers to the capability of biological systems to support and adapt to the changing needs of members living in different places in different times. It emphasizes the long-term health and the harmony of three main goals of human activities such as economic competitiveness, environmental protection and social equity. As an organizing principle, *sustainable development* denotes coordinated decision making and actions that efficiently allocate resources to meet the current generation's needs without compromising the quality of life and needs of future generations.

Livability refers to the general well-being of communities and neighborhoods. Different from sustainability, it emphasizes how people feel about their living environments and the role of communities and neighborhoods in supporting human activities. It is narrower in scope and is more subjective since it is conceptually linked with people's opinions towards quality of life, standards of living, happiness, human rights, equity and so on. More specifically, a livable neighborhood should follow at least six principles as defined by FHWA (4), including: 1) provide more transportation choices; 2) promote equitable, affordable housing; 3) enhance economic competitiveness; 4) support existing communities, 5) coordinate policies and leverage investment, and 6) value communities and neighborhoods.

Sustainability and livability deviate from the economic goals used by conventional economics in terms of decision making rules, evaluation measures and measurement units. As shown in Table 1, the economic goals used in conventional economics, such as economic or cost efficiency, are to maximize the production and/or consumption generated by a project or system under the constraint of resource availability. Since the decision making only considers the current time span, there are less control on the resource limit and less consideration on the resource conservation for the future generations. In addition, both objectives and constraints are valued by financial capital or monetary values while the nonmonetary capitals are excluded in general.

On the contrary, sustainability emphasizes resource conservation. If formulated as an optimization problem, it is to minimize the resource consumption under the constraint of meeting the needs for both the current and the future generations. In addition to financial capital, it also considers natural and social capitals. Due to the involvement of nonmonetary capitals such as

natural and social capitals, non-monetary value units or converted monetary value unit are used for assessment. As for livability, it is to maximize people's perceptions about the well-being of the communities or neighborhoods they live, given the limited resources available. Both well-being and resources can be measured as the combination of multiple capitals such as financial, natural and social capitals. Different from sustainability, livability emphasizes more on natural and social capitals. As mentioned before, it is more community or neighborhood oriented and more subjective.

Table 1 Evaluation under Sustainability and Livability versus under Economic Goals

	Economic Efficiency	Sustainability	Livability
Decision making	<i>Max</i> Production or Consumption <i>s.t.</i> Resource <i>Time</i> : Current	<i>Min</i> Resource consumption <i>s.t.</i> Needs <i>Time</i> : Current & Future	<i>Max</i> Well being <i>s.t.</i> Resource <i>Time</i> : Current & Future
Measures	Financial capital	Financial, natural, and social capital	Emphasize on natural and social capital
Unit	Monetary value (\$)	Monetary and/or nonmonetary value	Monetary and/or nonmonetary value

As the recognition of the critical role of transportation systems in supporting the sustainability and livability of our society, many transportation and planning agencies have started to incorporate these principles to transportation related decision making. As they aim at, transportation decisions should be made across the organizational and disciplinary boundaries to promote and support sustainability and livability of broader systems. As defined in the Transportation Planning for Sustainability Guidebook published by the Federal Highway Administration (FHWA) (13), *sustainable transportation* refers to "transportation that contributes to the sustainable development of the community that owns and uses the system". Specifically, sustainable transportation is "safe, high quality, and accessible to all; ecologically sound; economical; and a positive contributor to regional development" (3). As for *livability in transportation*, a frequently cited definition is by the former Secretary of Transportation Ray LaHood: "Livability means being able to take your kids to school, go to work, see a doctor, drop by the grocery or post office, go out to dinner and a movie, and play with your kids at the park—all without having to get in your car." In other words, livability in the context of transportation means mobility, connectivity, accessibility and multiple choices of modes that support people's daily activities.

Performance Measures

Performance measures (PMs) refers to criteria and metrics that quantify the progress of systems or projects toward specific goals or objectives (11). As for sustainability and livability, the relevant PMs are a collective set of measures that clearly indicate the efficiency and effectiveness of a development plan or project in achieving the two goals. PMs are mainly used for description, evaluation, accountability, decision support and communication (11). Some representative studies are reviewed as below.

As for an important component of sustainable development, Miller (14) summarized 45 performance measures used by 25 states in the U.S. for the purpose of assessing transportation and land use coordination. These PMs were classified under seven goals, including: (1) increased transportation options; (2) increased transportation accessibility; (3) improved quality of existing transport options; (4) improved public services or economic growth; (5) protects or manages corridors; (6) aligns state and local efforts; and (7) reduced land consumption. As found from the state DOT based surveys, a majority of the 25 responding states did not explicitly measure transportation land use coordination at the state level. The active PMs are often those that rely on the data traditionally collected by states.

NCHRP Report 708 *A Guidebook for Sustainability Performance Measures for State Department of Transportation and Other Transportation Agencies* developed a comprehensive sustainability PM framework for guiding decision makings at different levels (11). According to the procedure suggested, PMs should be selected based on decision making goals, focus areas, and specific objectives. There are 11 goals suggested for the top level of PM selection, including *safety, basic accessibility, equity/equal mobility, system efficiency, security, prosperity, economic viability, ecosystems, waste generation, resource consumption, and emission and air quality*. Under each goal, six focus areas were suggested, among which are *planning, programming, project development, construction, maintenance and system operations*. Multiple specific objectives are defined for each focus area, under which potential PMs are listed. As indicated by the report, the data availability and the benefits are the main factors that determine the selection and usage of PMs.

Litman (9) conducted a comprehensive review about the evaluation procedures, performance indicators, data sources and examples of various agencies worldwide in assessing sustainable and livable transportation planning. As suggested, assessing sustainability and livability in transportation planning should begin by defining goals, objectives, targets, and outcomes. As found from the PM related reviews, most of agencies tended to group PMs under three dimensions, namely economic, environmental and social values. Standardizing transportation data collection practices is recommended as an important step to enhance the data availability and quality so that both the convenience and comprehensiveness of performance measurement can be achieved.

Research Approach

As shown in Figure 1, the GIS-based performance measurement system is composed of an evaluation database, the sustainability and livability related PMs, and a GIS interface that offers the PM reporting and demonstration. The system has the following features to support decision making. First of all, it concerns multiple dimensions of sustainability objectives such as economic, environmental, social, spatial, and temporal in the context of transportation. Second, it consolidated various data sources, such as transportation, census, land use, environmental, economic data, to form the input database for the PM development. Third, it offers the reporting and visualization functions of PMs on the maps that help reveal changes and communicate ideas.

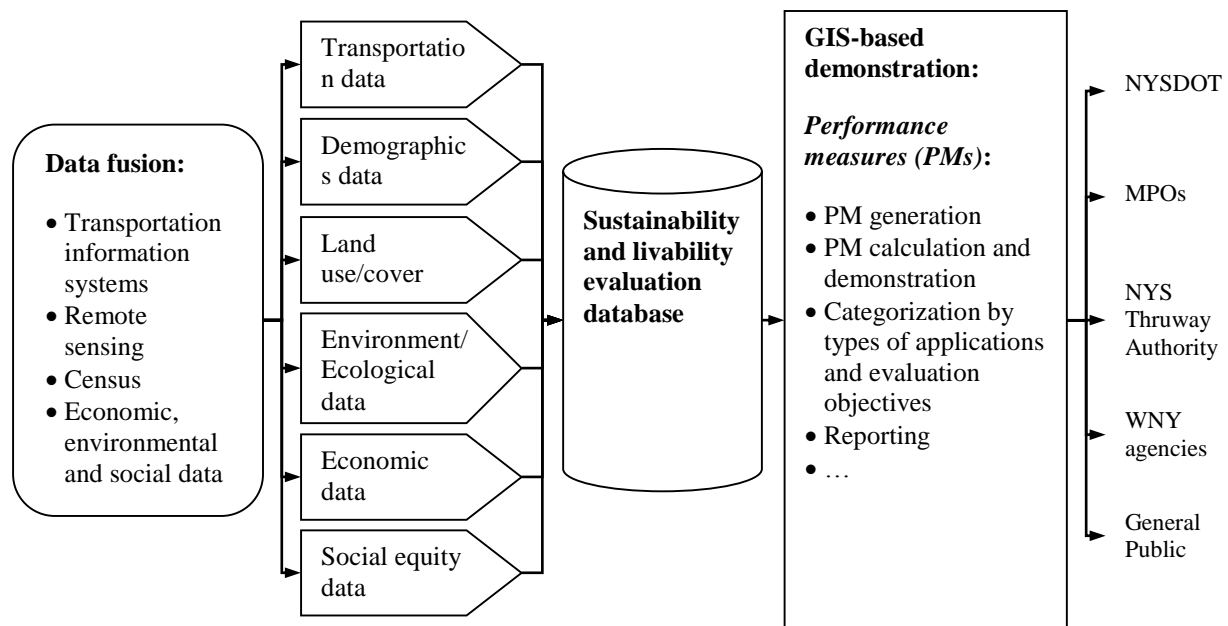


Figure 1 The GIS-based prototype performance measurement system

Study Case and Data

City of Buffalo, New York is selected as the study case to develop a sustainability and livability performance measurement system. The main reason for the selection is that there is more information available for exploring PMs because of the long-term collaborations between University at Buffalo, the State University of New York and the local metropolitan planning organization - the Greater Buffalo-Niagara Regional Transportation Council (GBNRTC). Another reason for the selection is the importance of the City of Buffalo. Buffalo is the second most populous city in the state of New York, after New York City. Located in Western New York on the eastern shores of Lake Erie and at the head of the Niagara River across from Fort Erie, Ontario, Canada, Buffalo is the seat of Erie County and the principal city of the Buffalo-Niagara Falls metropolitan area, the largest in Upstate New York. Buffalo itself has a population

of 261,310 and the Buffalo–Niagara–Cattaraugus Combined Statistical Area is home to 1,215,826 residents (15).

It needs to be noted that the performance measurement system was built with respect to the whole system, rather than a specific project. Our initial thinking was to select a transportation plan or a system-wide project as the measurement subject. However, collecting the project specific data, particularly the before and after data, became a major obstacle. In this context, the performance measurement was performed for the entire City of Buffalo to assess the overall performance of the system.

Various data were collected and fused to build an input database. These data include: (1) transportation data such as traffic counts, travel costs, delays, travel speeds, travel itinerary survey data and mode share collected in different years since 2000; (2) the parcel level tax maps in year 2000 and year 2010, including the shape files of parcel polygons, parcel sizes, land use types, land assessment values and so on; (3) digital Ortho- imagery data in 2011 and airborne LIDAR data in 2009; (4) demographics and socio-economic information such as population, employment and household income obtained from the Census Bureau; and (5) transportation network data including roadway, transit and pedestrian networks.

It needs to mention that remote sensing data is a very important component of the input database. They are more frequently updated than the typical land use maps and geographical information. In addition, they can provide land use information in detailed resolutions such as at the parcel level if being processed by advanced remote sensing techniques and analysis. They also provide transportation related information, particularly for transportation network distributions, densities and so on (16, 17).

Two types of remote sensing data have been explored in this study, including digital Ortho- imagery data and airborne LIDAR data. The Digital Orthoimagery data can be acquired through a free download from the New York State GIS clearing house at <http://www.nysgis.state.ny.us/>. A high density two-return airborne LiDAR data for ERIE County in 2009 has been obtained from the Federal Emergency Management Agency. Eventually, we decided to use the Digital Orthoimagery data because of the higher resolution it provides.

The inconsistency in the geographical and temporal scales has been the major challenge we dealt with during the data processing. Since the data were collected from different sources with different types, they are available at different geographical scales with different spatial boundaries. For example, the travel itinerary survey data were collected at the traffic analysis zone (TAZ) level while the demographic information such as population and employment are available at the census block or census tract level. As for the tax map, the tax related information is available at a more refined resolution, i.e., at the parcel level. Since these geographic units are defined for different purposes, their spatial boundaries are not mutually inclusive, which raised questions such as which geographical scale to be chosen for the data merging purpose and how to translate them from one scale to another. In addition, the data were collected in different years.

We have the travel itinerary survey data collected in year 2000 while the parcel-level tax map and the census information are available for year 2010.

After carefully examining all the data, we decided to choose the census tract as the geographic unit of analysis and year 2010 as the year of analysis, without losing any significant data. All the data have been converted correspondingly to ensure the consistency of analysis.

Performance Measure Generation and Analysis

PM Generation

The literature search provides a long list of candidate PMs that can be used. In this context, the fundamental questions that need to be addressed are: 1) which measures should be generated given the data availability; and 2) among these PMs, which ones are the most effective in assessing sustainability and livability in transportation. The answers to the former are mainly constrained by the data while the latter is to suggest the core set of PMs given the usage and correlations among them.

In addition to the abovementioned research questions, the subject of assessment and the spatial and temporal resolution of analysis should also be configured to help the selection and the calculation of the PMs. It needs to note that the main purposes for building such a PM system are to assess the existing the conditions and to identify the problems and barriers for the entire system (or the entire study area). It's different from the project-oriented performance measurement and thus does not have a specific project focus area (such as planning, project development, or construction) and objectives (e.g., to enhance traffic safety) as suggested by NCHRP Report 708 (11). In this context, the system wide PMs, particularly the ones related to land use and transportation coordination and transportation networks, have been emphasized. In terms of the spatial resolution, as mentioned in the data description section, census tract was selected as the analysis scale since it is the finest scale at which all the data are available. In this context, the PMs calculated at the finer scales (such as at the parcel level or TAZ level) were all aggregated, analyzed and compared at the census tract level. As for the temporal scale, year 2010 was selected as the baseline year for the analysis. In summary, the PM analysis was conducted for the system wide evaluation purposes at the census tract level given the information of the base year 2010.

Twenty PMs were generated at the census tract level, given the transportation, land use and demographic data available for the area (see TABLE 2). These variables are the seventeen census tract based measures such as transportation, land use, and living condition related attributes, and the three system-wide indices obtained from the Texas A&M Transportation Institute Annual Urban Mobility Report (18). In the group of *transportation attributes*, at least one measure was generated for each modal network. Among the roadway network related attributes are street density and intersection density. Transit stop density and transit service frequency are selected to represent the level of service of the transit network. As for the bicycle

network, a popular index, called the bike land completeness index, is used to indicate the coverage and serviceability of bike lanes.

There are eight *land use attributes* generated to assess the characteristics of land use such as density, diversity, and destination accessibility. The population density was calculated for each census tract to identify the areas with high population concentration. Multiple diversity indices were also created, including the population employment mix index, land use balance measure, the ratios of different service lands to residential, and the percent of single-family or two-family residential. Job accessibility is used to represent the accessibility to job-end destinations. These land use related attributes explain how lands, as the main generators of human activities and travel demand, are spatially distributed. Therefore, they are important inputs to understanding land use patterns, travel demand generation, the land use and transportation coordination.

Livability measures were found to be the most difficult to obtain due to the subjective "nature" of them and the lack of relevant survey data. Given the restriction, we generated three *living condition* related attributes, hoping that they may partially reflect the livability of an area. They are the per capita income, the unemployment rate, and the health insurance coverage rate of a census tract. The per capita income represents the available financial resource and the spending power of a person. The unemployment rate is correlated to poverty level, economic recession, and simply unhappiness of being in a neighborhood. Health insurance coverage rate, on the other hand, has been suggested as an important indicator of the healthy lifestyles by many livable city or neighborhood ranking studies. These three attributes, combined, measure the availability of essential resources for maintaining social wellness.

In addition to the seventeen census tract specific PMs, three system-wide indices were obtained from the Texas A&M Transportation Institute Annual Urban Mobility Report (18), including the travel time index denoting the ratio of peak-hour travel time to the free-flow travel time, the total congestion cost in dollars, and the CO₂ emission per commuter estimated from travel delays (TABLE 3). They will be discussed in the following section.

TABLE 2 Sustainability and Livability Performance Measures for City of Buffalo, New York

Category	Performance Measure	Definition	Data Source
Transportation Networks	Street Density	The total centerline distance of streets divided by the area size (km/km ²)*	Census TIGER/Line
	Intersection Density	The number of intersections divided by the area size (intersections/ km ²)	Census TIGER/Line
	Transit Stop Density	The number of transit stops divided by the area size (stops/ km ²)	The General Transit Feed Specification (GTFS)
	Transit Service Frequency	Average transit service time interval (minutes)	The General Transit Feed Specification (GTFS)
	Bike Lane Completeness Index	The total centerline distance of <i>bike lanes</i> divided by the total centerline distance of <i>streets</i>	Greater Buffalo-Niagara Regional Transportation Council (GBNRTC)
Land Use	Population Density	Population divided by the area size (people/km ²)	Census Bureau
	Population Employment Mix Index	$\text{Index} = 1 - \text{abs}\left(\frac{\alpha \times \text{population} - \text{employment}}{\alpha \times \text{population} + \text{employment}}\right),$ <p>where $\alpha = \frac{\text{regional population}}{\text{regional employment}}$ (19)</p> <p><i>population</i> = population in a census tract; <i>employment</i> = employment in the census tract; <i>regional population</i> = total population in the entire area; and <i>regional employment</i> = total employment in the entire area.</p>	Census Bureau, American Community Survey

	Land Use Balance	$balance = \frac{\sum P_i \times \ln P_i }{\ln N}$ <p>P_i =proportion of total land area allocated to each land use class; N =total number of land use categories considered(i.e., residential, commercial, industrial, institutional) (20)</p>	University at Buffalo Regional Institute Parcel
	Commercial2Residential Ratio	Ratio of the commercial land area to the residential land area.	University at Buffalo Regional Institute Parcel
Land Use	Amusement2Residential Ratio	Ratio of the amusement land area to the residential land area	University at Buffalo Regional Institute Parcel
	Institutional2Residential Ratio	Ratio of the institutional land area to the residential land area	University at Buffalo Regional Institute Parcel
	% of single family residential	The area size of single family parcels divided the total area of residential parcels	
	% of two-family residential	The area size of two-family family parcels divided the total area of residential parcels	
	Job Accessibility (21)	$A_{im} = \sum_j O_j C_{ijm}^{-2},$ <p>A_{im} =accessibility at census tract i to potential work census tract j using mode m; O_j =number of jobs at census tract j; and C_{ijm} =cost function to travel between i and j using mode m.</p>	Google Map Routes, American Community Survey

Living Condition	Per Capita Income	Annual income per person (\$)	American Community Survey
	Unemployment Rate	The population unemployed divided by the total population (considering the labor force of 16 years and older)	American Community Survey
	Health Insurance Coverage Rate	Percentage of population with health insurance coverage	American Community Survey
System-Wide Indices	Travel Time index	The ratio of travel time in the peak period to travel time at the free-flow speed from year 2006 to 2011.	Texas A&M Transportation Institute Annual Urban Mobility Report
	Congestion Cost	Monetary value of the total system travel delay for year 2006 through 2011.	Texas A&M Transportation Institute Annual Urban Mobility Report
	CO ₂ per Commuter	Represents the pounds of additional CO ₂ emissions generated by a commuter during a year due to traffic congestion.	Texas A&M Transportation Institute Annual Urban Mobility Report

Notes: * km denotes kilometers.

PM Interpretation

The census tract specific PMs are illustrated by using the GIS maps in FIGURE 2 through FIGURE 4. In terms of the transportation supply, the City has a roadway network that provides a good coverage according to Figure 1.a. The central area on the east side of the downtown (marked by a star) is the best in roadway density while the two census tracts located in the south of the downtown are the worse, although the density level is still acceptable. The transit stop density map shares the similar pattern, with the highest concentration in the central area and the lowest in the south. In contrast, the bicycle network offers a very poor coverage. The complete bike lanes have a low average coverage rate of 18.1% for the entire City. More than 70% of the 79 census tracts have lower than 20% coverage while three census tracts even have near-zero complete bike lanes. This imbalanced supply of different modal networks causes the dominance of autos in the transportation system.

The spatial distribution patterns of land use are demonstrated by the land use related PMs in FIGURE 3. The population density map (Figure 2.a) and the job accessibility map (Figure 2.b) share the similar pattern of the high concentration (or value) in the northern part and the central area of the City. The central area near the downtown has been losing population and job opportunities in the last two decades. Some of the population and job opportunities have been relocated to the outer core area such as the northern part. This is why these outer core census tracts gain higher population density and job accessibility than the central downtown. The land use balance map shows how different land use types are spatially mixed in a census tract (Figure 2.c). Conceptually, the value should range between zero and one. The higher the value, the more balanced or the better mixed the various land types are. The low average values in the City (less than 0.33) indicate the imbalanced land use or the dominance of single land use in neighborhoods. As for individual census tracts specifically, the large parcels in the south of the downtown and several ones in the far north are slightly better, followed by the ones in the central area. This single-land-use development pattern causes the spatial separation of residential areas from commercial land and others, which, furthermore, explain the area's high dependency on autos.

A joint view of these PM maps points out a distinctive area that deserves special attention (marked by a red boundary on the maps). On one hand, blessed by the densely located street blocks and bus stops, the neighborhoods in this area have very good accessibility to retail stores, schools and sidewalks, and are more likely to be walking or bicycle friendly. On the other hand, their population densities and job accessibilities are disproportionately low, leading to the questions of why. This area, as the old neighborhoods of City of Buffalo, was planned and developed in a neo-traditional fashion that embraces dense street blocks and mixed land use. However, due to the economic recession and many other historical reasons, the area has been losing population and job opportunities to the outer core of the City or suburban areas. This is also the area that separates the rich neighborhoods in the northwestern part of the City from the low-income neighborhoods in the east, as confirmed by the per capita income map (Figure 3.a)

and the unemployment rate map (Figure 3.b). Since this area is between, it is mixed with low-income and medium-income households. Therefore, the average income values are low and the unemployment rates are high. It needs to note that the percent of insured residents in the City is high in general, with the lowest value of 78.5% and the highest as 99.7% (Figure 3.c).

Three system-wide performance measures were obtained for year 2006 through 2011 to assess the changes in congestion level and the transportation related CO₂ emissions. There was a significant improvement on transportation performance in year 2008, which brought down the travel time index to 1.15 (denoting 1.15 times of the free-flow speed), CO₂ per commuter to 286 pounds, and the total congestion cost to \$450 million. The values rose a bit in 2009 and remained the same since then.

These PMs, combined, provide some insights regarding the sustainability and livability of the City. Green transportation modes, such as bicycles, are discouraged in the City due to the poor bike lane network offered. The dominance of single-land-use neighborhoods causes the spatial separations of residential land from others, and thus contributes additionally to the low accessibility to green modes (such as walking and bicycling) and the high dependence on autos. In addition, some traditional neighborhoods, which are well planned and designed in terms of land use mix and transportation accessibility, are losing population and jobs to more single-land-use areas. This will lead to longer travel distances, higher dependency on autos, and more transportation pollution issues. Moreover, a spatial separation of low-income and high-income neighborhoods is witnessed in the City, which has been and will continuously be causing social equity related problems.

These findings lead to the following policy implications. First, revitalization of the central downtown area, particularly the area marked on the map, is needed to attract residents and jobs back to take advantages of the nicely planned and smartly built environment in these communities. The gained jobs and increased income in the area are expected to impose positive impact on the adjacent low-income community on its right hand side as well. The improvement plan on sidewalks and bike lanes should also be developed to encourage the use of green modes such as bikes and walking.

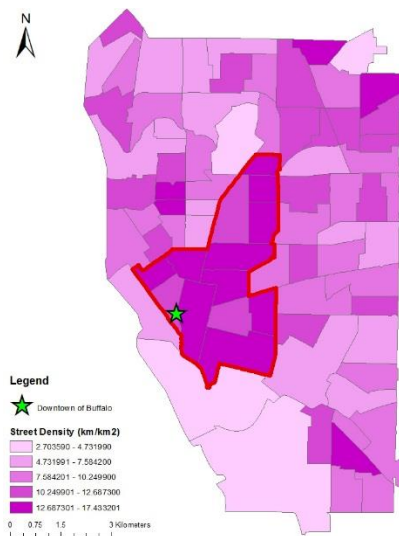


Figure 1.a Street density

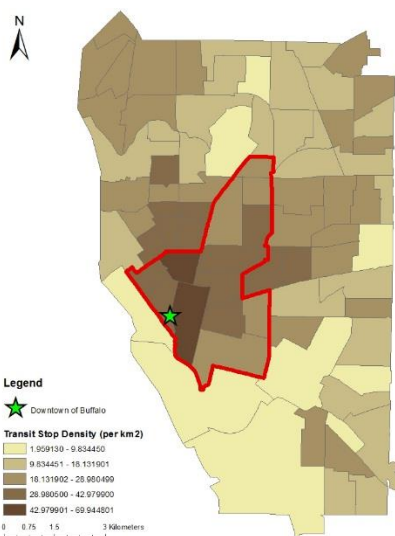


Figure 1.b Transit stop density

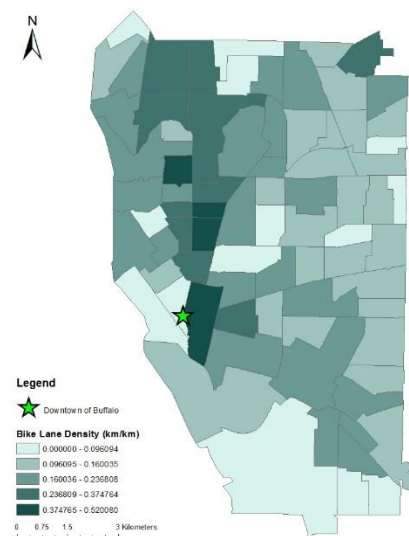


Figure 1.c Bike lane density

FIGURE 2 Transportation related performance measures

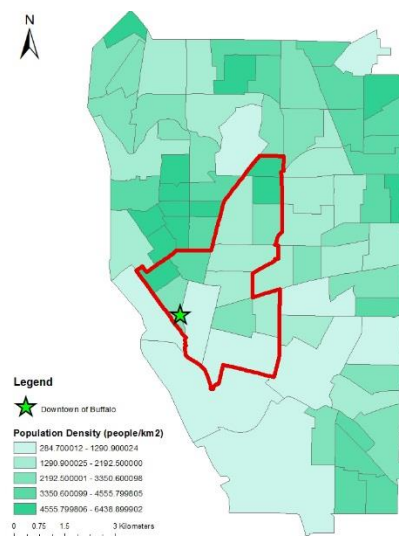


Figure 2.a Population density

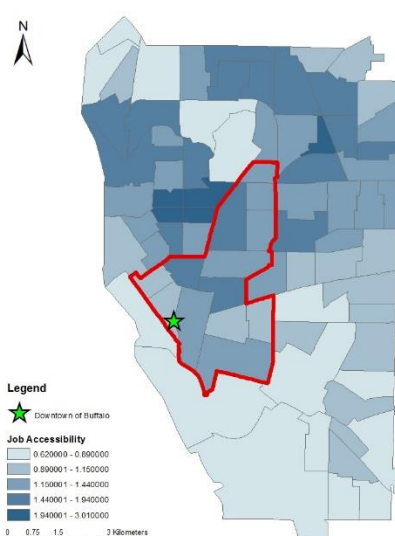


Figure 2.b Job accessibility

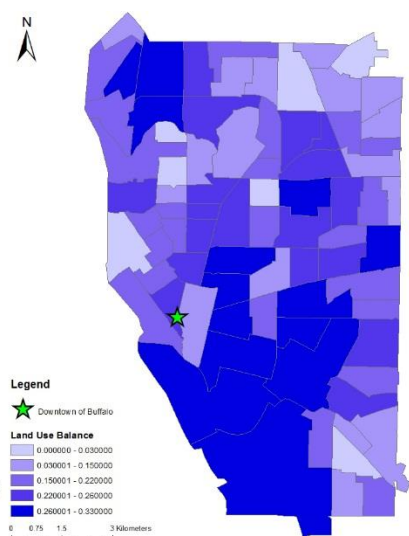


Figure 2.c Land use balance

FIGURE 3 Land use related performance measures

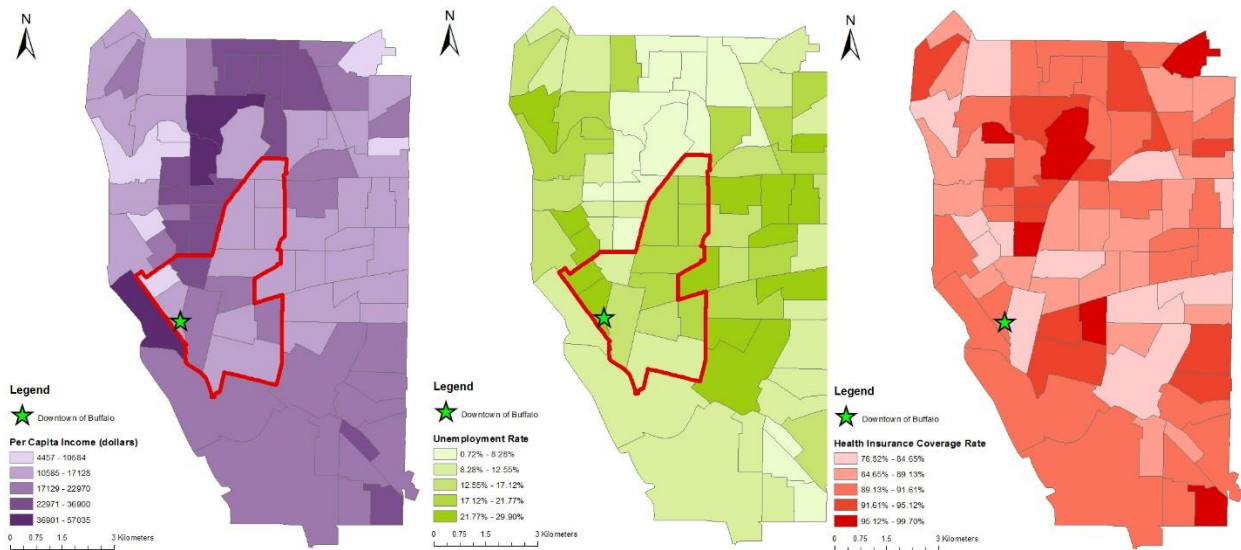


Figure 3.a Per capita income Figure 3.b Unemployment rate Figure 3.c Health insurance coverage rate

FIGURE 4 Living condition related performance measures

TABLE 3 Three City-Wide Performance Measures (Source: the Texas A&M Transportation Institute Annual Urban Mobility Report (18))

Year	Population	Travel Time Index	CO ₂ per commuter (pounds)	Congestion Cost (\$ millions)
2006	274,740	1.22	429	582
2007	272,492	1.20	357	560
2008	271,220	1.15	286	450
2009	270,240	1.17	357	479
2010	261,179	1.17	357	474
2011	260,371	1.17	357	474

Challenges and Opportunities in Developing PMs

The following lessons are learnt from the process of developing the GIS-based sustainability and livability performance measurement system.

The availability of good data is always the first concern. PMs are quantitative measures that require large and diverse data as the input. For sustainability and livability in particular, since they are broad goals that cover all the economic, environmental and social

aspects over space and by time, a large database with sufficient and diverse information is needed to develop desired PMs. Among the data that are found particularly difficult to collect are temporal data that help track the changing patterns of traffic conditions and land use. Taking the land use distribution pattern as an example, we initially planned to collect multi-year land use data to monitor the changing patterns of land use. Unfortunately, we only got access to the land use data of 2010, which leaves the temporal analysis and related PM development impossible.

Data collection and processing is a heavy burden. Even when the data are available, it requires collaborative efforts to obtain them and dedicated time to mine them. For our case, we contacted multiple transportation agencies (local, regional, state, and even national) to acquire data. Due to the issues such as no electronic version, no response, no dedicated staff, or simply confidentiality, many data could not be obtained. Even for the collected data, it took a lot of time to clean and process. Moreover, it is not easy to agree on which geographical scale and temporal resolution the data should be merged to and analyzed on.

Whether this type of performance measurement is suitable for project-based evaluation is a big argument. Conceptually, any transportation project can be evaluated under the sustainability and livability goals. The reality, however, is that it is very difficult to track and distinguish the effects of a project from the effects of others under such a big umbrella of sustainability and livability. It is achievable but requiring dedicated effort and additional work on developing project-specific PMs. Therefore, for our case study, we eventually selected the whole system as an assessment subject.

PM selection and generation are not straightforward as they look like. PMs are objective specific. Therefore, clarifying on the specific assessment objectives is the prerequisite to PM selection. As suggested by the NCHRP Report 708 (11), the decision making goals, focus areas and specific objectives should be clearly defined before PMs can be appropriately selected. In addition, the PM generation is restricted by the type of input data. The more data needed, the less likely a PM can be created. These types of PMs often happen to be significant ones since it is related to multiple characteristics or features of a system.

PM interpretation should be performed or facilitated by professionals or experts who know the system very well. Strong expertise is always needed to interpret the results. To collect the insights, we have sent the PM results to the local metropolitan planning organization and transportation agencies to dig out more insights.

We also identify several opportunities in developing such performance measurement system. In terms of data collection techniques, remote sensing can be used as a reliable source to collect land use information. It can provide land use information at detailed resolutions such as at the parcel or tax lot level if being processed by advanced remote sensing techniques. It can also collect transportation related information such as transportation network distribution. In terms of the PM demonstration, we see great benefits from developing a web-based GIS system to facilitate the customized PM selection and demonstration. We are developing such a system for City of Buffalo, using it as a platform of data consolidation and PM demonstration.

PART II: LAND USE CLASSIFICATION WITH REMOTE SENSING

Rational of Conducting Land Use Classification with Remote Sensing

Land use information is found to be a critical input to develop the sustainability and livability performance measures. Knowledge of the distribution and conditions of residential, commercial, and recreational land among others, as well as information on their changing proportions, is critical to legislation, population and employment estimation, land use and transportation planning, travel demand forecasting, environmental quality assessment, and social equity research. However, the information is often outdated, particularly on the finest parcel or tax lot scale, due to the long lag of the survey-based reporting processes. For example, the transportation agencies in the Chicago metropolitan area are still relying on the 2005 parcel-level land use data for decision making. The updated 2010 parcel-level inventory won't be available until late 2014. The outdated information will cause the inaccurate forecasting of land use and travel demand changes, and thus hamper effective planning and decision making, particularly for fast growing areas.

Remote sensing data has been introduced to fill the gap more from the viewpoint of geographic science and image processing. Most of these studies are done by considering the spectral features mined from remote sensing data and ancillary information such as spatial metrics, topographic features, building elevations, and housing and population densities. Transportation systems and their connections to land use are often overlooked as a potential source of complementary attributes. In addition, the possibility of using multinomial logistic regression, or called multinomial logit (MNL) models, has been overlooked as well. MNL regression has been one of the most popular and sound approaches to estimate discrete responses or categorical outcomes in the disciplines such as econometric, psychology and engineering. It deserves its place in land use classification because of its strong theoretical basis and reliably good performance in dealing with general multiclass problems with discrete outcomes.

In this context, the second part of the research is aimed at testing the applicability of MNL models in land use classification at the finest parcel level with remote sensing data as the input. As another addition to the literature, the research also introduces transportation related attributes, such as the distances of a parcel to the nearest road or intersection, to reflect the impact of transportation systems on land use distribution. Moreover, the attributes of the neighborhood where a parcel is located are also used to provide a spatial context for land use classification. In terms of the methodology, the research is among a very few to apply the MNL approach to land use classification. The new additions in both the method and the complement attributes of transportation and neighborhood lead to the impressive prediction performance. As will be demonstrated in the case study, the average prediction accuracy for the seven land use classes is 83.7%. The accuracy level for the dominant residential parcels can be as high as 94.5%. It is impressive given the facts that the prediction was performed at the finest parcel level; and that no any background information or historical hints about land use, except the spectral features, is used for prediction.

The research and its results are deemed to be useful for both researchers and practitioners. It confirms on remote sensing as a reliable source for land use and land cover prediction in the context of transportation. For transportation planning organizations, the proposed remote sensing data mining techniques and the MNL based land use classification models can be easily adapted to perform the timely updates of land use and land cover for any regions. This adds another venue of data for land use and transportation related planning and decision making.

Literature Review

Remote sensing is an important but underused data source for transportation related research. They are more frequently updated than typical maps and geographical information. In addition, they can provide land use information at the fine parcel or tax lot level if being on high resolution and being processed by advanced image processing techniques. They can also provide transportation information such as transportation networks and pavement conditions (16, 17).

Remote sensing techniques have been proposed to provide primary data for land use and land cover since the mid-1940s. However, the lack of adequate remote sensing data with high spatial resolutions prevented the further exploration until the seminal work of Anderson (22) who defined the hierarchical U.S. Geological Survey land-use/land-cover classification scheme. This scheme involves two sequential levels of classification, including the separation of urban areas and built-up land at the first level (e.g., land cover classes), followed by the identification of multiple discrete urban land use classes at the more detailed second level (e.g., land use classes). The second level is much more difficult to achieve since spectral features are not sufficient to discriminate various land use classes in a complex urban environment.

Following the scheme, a majority of the earlier and continuous work has been focusing on the first level classification at a high thematic resolution, which is the separation of vegetation, bare soil, water, rock, and built-up land cover classes. Various classification methods have been proposed, which can be categorized to parametric and non-parametric methods. Among the parametric methods are the maximum likelihood classifiers (23) and linear discriminant function classifiers (24, 25). On the track of the nonparametric approaches are nearest neighbor based clustering analysis (26), expert systems (27), artificial neural networks (ANN) (28, 29), fuzzy logic classification (30), decision trees (31, 32), and support vector machines (33, 34). The main differences between the two approaches are that the nonparametric methods make no assumption about the distribution of input data and they do not require the estimation of parameters from training data. A very few of the studies in the literature have tried MNL regression, but mainly for land cover classification on a larger geographical scale (35).

Much less research effort is dedicated to the second level of classification, which is the classification of multiple discrete land use types on a fine parcel or tax lot scale. The major challenges come from the availability of remote sensing data with sufficient resolution and the heterogeneity of urban environment. Fine data are often acquired on demand and are expensive to get. In addition, spectral confusion is common among land use classes, particularly in complex

and heterogeneous biophysical environments. Therefore, ancillary data are needed, in addition to spectral responses by remote sensing, to improve the classification performance. The existing studies use spatial metrics, topographic features, building elevations, and housing and population densities as the complement attributes (36). Few of them pays attention on the transportation related attributes.

Data

The remote sensing data used in this study is the digital orthoimagery data collected for the City of Buffalo, New York. They were acquired in a raster format through a free download from the New York State GIS clearing house (37). The images have a high spatial resolution of 1 foot by 1 foot and include four spectral bands of blue, green, red, and near-infrared (NIR). They were mined to get spectral reflectance of each pixel in each color band. The pixel-based information was then processed by Definiens Professional 5.0 to generate spectral features for each parcel, as will be discussed in the following subsection. In addition to the remote sensing data, the parcel boundary information and the transportation network data were also obtained from the University at Buffalo Regional Institute (38) and from the National Highway Planning Network respectively (39).

There are 14,860 parcels used for the model training and testing, located in the downtown Buffalo as shown in FIGURE 5. They represent seven land use types, including residential (49.6% of the parcels), vacant (35.83%), commercial (11.94%), recreation & entertainment (0.24%), community service (1.86%), industrial (0.23%), and public service land (0.20%) as classified and defined by the New York State Office of Real Property Services (40). It needs to be noted that two other typical land use classes, namely agriculture, and wild, forested, conservation lands and public parks, are not available due to the urban setting of the study area.

Attributes

There are 91 attributes generated for each parcel, including the parcel shape properties, spectral features, transportation related variables, vegetation index, and neighborhood related attributes. *Shape properties* illustrate the shape and size of each parcel, such as the area size in pixel square, the depth of the parcel lot in feet, the aspect ratio of length to width, and the compactness denoting the ratio of the parcel polygon area to the area of a circle having the same perimeter. *Spectral features* represent the intensities of pixels in different color bands. Example attributes are the mean and standard deviation of the intensity value of pixels for each color band of red, green, blue or NIR, and the maximum difference among these intensity values, divided by brightness of image. The *vegetation* index denotes the vegetation coverage of a parcel. It is used because it proves to be a significant variable in separating lands with different vegetation coverage (41).

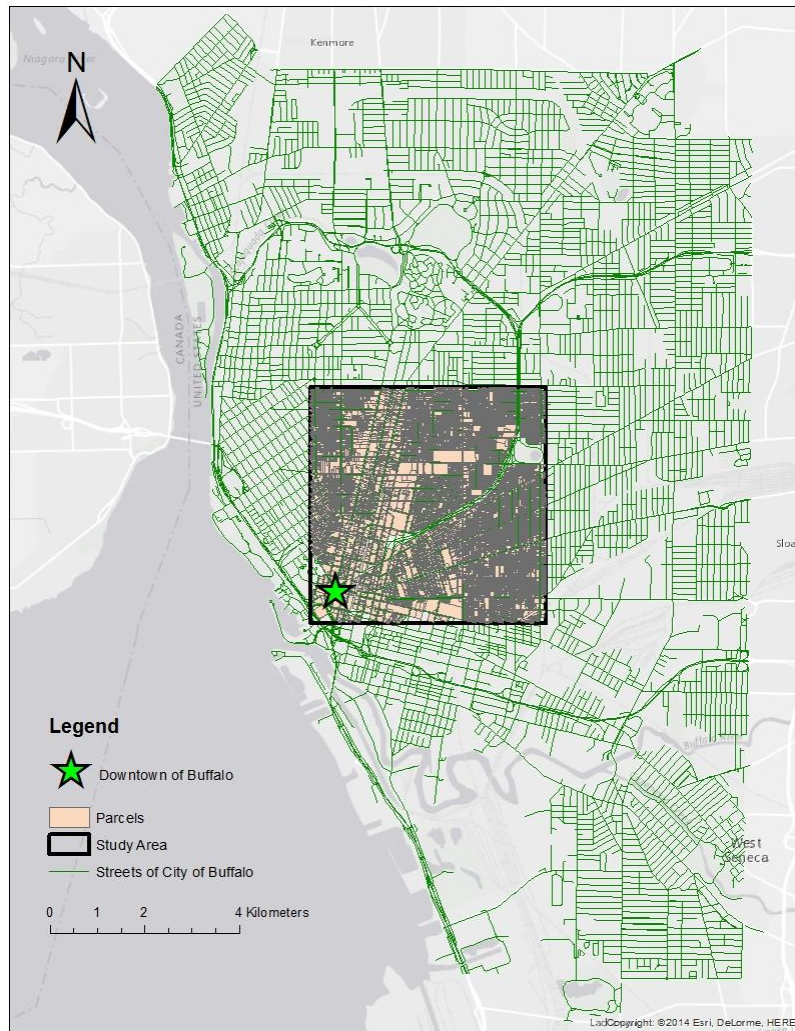


FIGURE 5 Study area in City of Buffalo, New York

The research introduced new variables that reveal the linkage between land use and *transportation*. They are distance based, such as the distance from a parcel to the nearest road or to the nearest intersection. Separate distance measures were created with respect to different types of roads such as primary highways, secondary roads, or local streets. The rationale behind differentiating them is that service lands, such as the ones accommodating commercial and industrial businesses, are very sensitive to travel time, and therefore tend to be closer to high-speed links.

Neighborhood related attributes are basically the mean values and standard deviations of the above mentioned shape, spectral, transportation and vegetation attributes for the neighborhood where a target parcel is centered. The neighborhood of a target parcel is defined as a circular area centered at the parcel with the radius of 150 feet. Any parcels that are within or intersect the circular area are considered as neighboring parcels of the target parcel.

Methodology

There has been a long history of using MNL models to deal with the multiclass problems with discrete outcomes in diverse disciplines such as econometric, psychology and engineering. MNL models are built for the situations in which the categorical class of an event or the discrete choice of a decision maker is affected by a set of observable attributes and the unknown factors. The alternative values for the class or choice response should be discrete and exclusive. They are assumed to be independent from and irrelevant to each other (IIA). To link the discrete response variable to the potential affecting factors, a score function is assigned to each alternative (i) for each event or subject (n). It is configured as a weighted linear combination of the observed attributes (X) plus a random error (ε_{in}) as shown in Equation (1). Attributes X can be subject related or alternative specific. The coefficients (β) denote the marginal effect of a variable on the score of a class. The random error (ε_{in}) in a score function captures missing information and estimation biases. They are assumed to be independently and identically distributed (IID) and follow a Gumbel distribution (42).

$$Score_{in} = (\beta X)_{in} + \varepsilon_{in}, \forall i \quad (1)$$

The scores are converted to class probabilities according to the following logic: the probability of being in class i (P_{in}) is equal to the probability that class i returns the highest score. Given the assumptions of the IID and Gumbel distribution for the error terms (ε_{in}), the probability is transformed to an exponential-based ratio form as shown in Equation (2).

$$P_{in} = Prob(Score_{in} \geq Score_{jn}, j \neq i, j \in \{1, \dots, J\}) = \frac{\exp((\beta X)_{in})}{\sum_{j=1}^J \exp((\beta X)_{jn})}, \forall i \quad (2)$$

Applicability of MNL to Land Use Classification

In comparison with ANN and decision tree methods that have gained wide popularity in land use classification, the MNL method has a much stronger theoretical basis and suffer less from the issue of local minima. The model estimation process and the resulting coefficients also provide an additional layer of information regarding the significance of variables, which is missing from the ANN and decision tree based analysis. The significance of a variable in discriminating land use classes can be sensed through the change of model performance after adding or deleting the variable. Moreover, the estimated coefficients also quantitatively reveal the marginal effects of the variables. An example is the ancillary variable of the distance to the nearest road. Given the coefficient of it estimated by a MNL model, we can easily tell how the probability for a parcel to be residential or industrial varies by its distance to the nearest roadway link. This result can provide additional implication regarding how the improvement of transportation infrastructure

would affect the land use distribution patterns. These quantitative effects are not provided by ANN and decision tree based methods due to the nonparametric "nature" of them.

As it applies to any method, MNL models also have disadvantages. The main disadvantages that have been claimed in the previous applications are the reliance on the assumptions for random errors (e.g., IID) and for the correlations among discrete outcomes (e.g., IIA); and the required expertise in model training and model interpretation. Regarding the former, a variety of multinomial regression models, such as multinomial probit models and mixed logit models, have been offered to relax these assumptions. As for the latter, due to the fact that land use classification for transportation related applications is usually acquired at a relatively long temporal scale (e.g., every year or even longer), the burden of model training and model interpretation should be endurable.

Model Setting for the Study Case

The land use classification situation of particular interest is defined as below. Each parcel in the study area is defined as a *subject* whose seven *alternative land use classes* are residential, vacant, commercial, recreation & entertainment (R&E), community service, industrial, and public service. For each alternative land use class (denoted as alternative i) for each parcel (denoted as parcel n), its score function ($SCORE_{in}$) is built as a weighted linear combination of a set of affecting variables (X) plus a random error (ε_{in}) as shown in Equation (1). Given the score values, the probability for parcel n to be in class i (P_{in}) can be calculated by using Equation (2). Here, as the typical MNL applications do, we assume the IIA for the seven classes, and the IID and the Gumbel distribution for the random errors. The commercially available econometric software, LIMDEP, is used for the model development.

One more note is regarding the "pivot" alternative. For our case, there is no alternative specific attribute that measures the hypothesis of how a residential parcel would look differently if it were used as industrial land instead. In other words, the 91 variables in the data are all parcel-related, and none varies across alternative classes for a parcel. In this special case, an alternative land class has to be chosen as the "pivot" or the base with which other alternatives can be compared. For our study case, the residential land use is selected as the "pivot" alternative because it is one major land use class from which other classes should be discriminated. Therefore, the score function of the residential class only has a constant.

The modeling process involves the two steps of model training and model testing. A half of the 14,860 parcels in the study area are used for the model training as discussed above. The remaining half is used for model validation to verify the prediction performance of the model. The detailed modeling process and model performance are discussed in the following sections.

Modeling Results

Due to the multiple land use classes involved and the large inventory of 91 attributes, many MNL models have been tested by using LIMDEP. The adjusted McFadden R-squared value is used as an indicator of the overall goodness of fit of a model, in addition to the criteria of statistical significance and conceptual validity for the estimated coefficients. The adjusted R-squared value is between 0 and 1 conceptually although most of good models in the transportation literature have the values ranging from 0.1 to 0.5 depending on the sample size and the modeling situations.

The issues of multicollinearity and overfitting were addressed during the modeling process. A pre-diagnosis on the correlation matrix of the 91 variables was performed to prevent the inclusion of highly correlated variables in the models. In addition, variables that contribute little to the improvement of the adjusted McFadden R-squared are eliminated so that less information is needed for model application.

The best model that meets all the above-mentioned criteria and returns the best goodness of fit is shown in **TABLE 4**. The very high value of the adjusted McFadden R-squared (0.48888) indicates the great overall goodness of fit of the model. Fifteen variables are found statistically significant in discriminating the seven land use classes. Each estimated coefficient, in terms of magnitude and sign, indicates how much the score or likelihood of the corresponding land use class will be changed with respect to one unit increase of the corresponding variable and whether the change is positive or negative.

Four *parcel shape properties* are identified as the contributing factors to land use classification, including the area size, depth, aspect index, and compactness ratio of a parcel. The area size is positively and identically related to the last six land use classes, indicating that the increase of area size will identically increase the likelihood for a parcel to be any land use class except residential. As for the depth of a parcel, the effects of it vary by class. The negative sign of the coefficient associated with vacant land implies that the increase in depth will diminish the likelihood for a parcel to be vacant. In contrast, it has the opposite effects on the likelihood of being commercial, recreational & entertainment, or community service land, implying that a parcel expanding more along the depth dimension is more likely to be in one of the three classes. The third variable, the aspect index (denoting the length to width ratio of a parcel) and its coefficients show some interesting findings. As the signs tell, a parcel with a narrower width in comparison with its length is more likely to be vacant land. A low aspect index value, on the opposite, will lower the likelihood for a parcel to be other classes, particularly industrial land. The last significant shape property is the compactness ratio. It is only included in the score functions of vacant and industrial. The two negative coefficients indicate that compact parcels are less likely to be the two classes.

These findings imply distinctive shape patterns exhibited by different land use classes. All the land use classes, except residential, are in favor of large parcels. Vacant land tends to have a “squeezed” rectangular shape that is short on the width edge but long on the length edge.

In contrast, commercial, R&E, and community service land tend to expand on the depth dimension and are more likely to be in the parcels with the lower length to width ratio. In terms of the compactness, vacant and industrial land, particularly the latter, tend to be the least compact among the seven classes. These resulting shape related patterns are consistent with the functionality of these land use classes.

The second category of significant variables is the *spectral attributes* that represent the spatial distribution patterns of spectral pixels in different color bands within a parcel. According to the coefficients, the higher the intensity value in *blue* band, the more likely a parcel to be vacant, commercial, industrial, or public service land. In contrast, a parcel with a higher intensity value of *NIR* band is less likely to be any of the four land types, except public service. Instead, it is more likely to be in the remaining two classes of R&E and community service. The standard deviation of the *NIR* band intensity value has the consistent negative impact on the likelihood of being vacant, commercial, and industrial land. As for the maximum difference among the intensity values of different color bands, the increase of its value will increase the probability for being vacant, commercial or public service land. These findings, in summary, indicate the unique spectral characteristics associated with different land use classes.

There are two significant distance-based *transportation measures*. They are generated by ArcGIS based on the shapefiles of parcel boundaries and transportation networks. The negative coefficients of the distance to the nearest primary or secondary road in the score functions, except for residential and community service, indicate that the farther a parcel is from the fast-speed roads, the less likely it would be vacant, commercial, R&E, industrial, or public service land. The distance to the nearest intersection has negative impact on the likelihoods of being vacant, commercial and community service, but a positive impact on the likelihood of being R&E. These relations indicate the higher sensitivity of these non-residential land classes to transportation accessibility in general. The distinct land class is R&E. On one hand, R&E parcels tend to be close to primary or secondary roads to take advantage of the fast transportation service. On the other hand, they also tend to be away from the locations nearby the intersections to avoid noise and traffic congestion.

The percent of *vegetation* within a parcel is only located in the score function of vacant land. The negative coefficient tells that vacant parcels tend to have less vegetation coverage in comparison with other land use classes.

The last category of significant variables are *neighborhood related attributes*, representing how compactness values, intensities of pixels in blue band and NIR band, and the vegetation percents vary among the neighboring parcels covered by a circle of 150 feet radius centered at the target parcel. Distinct patterns are revealed for vacant and commercial land. Vacant and commercial parcels are more likely to be in the neighborhoods with larger variations in compactness or pixel intensities in blue or NIR band. This implies the mixed environment where the two land use classes tend to be located.

In summary, the best MNL model we found in **TABLE 4** demonstrates an impressive goodness of fit. The estimated coefficients empirically and quantitatively reveal the characteristics of different land use classes in terms of shape, spectral, transportation, vegetation and neighborhood related features.

TABLE 4 Best MNL Model for Land Use Classification

Estimated Coefficients Variables		Score Function of						
		Residential	Vacant Land	Commercial	R&E	Community Service	Industry	Public Service
Constant	0. Alternative-specific constant	12.7988		7.7341	1.7167*	8.9594	15.5265	2.7119*
Shape Properties	1. Area size (pixel square)		0.31E-4	0.31E-4	0.31E-4	0.31E-4	0.31E-4	0.31E-4
	2. Depth of the parcel lot (feet)		-0.0064	0.0085	0.0069	0.0121		
	3. Aspect index as the length to width ratio of the parcel image		0.1118	-0.4718	-0.8389	-1.0943	-1.7421	-1.0103
	4. Compactness ratio of the area of the polygon to the area of a circle having the same perimeter		-2.7045				-8.9963	
Spectral Features	5. Mean intensity value of all pixels in <i>blue</i> band		0.2685	0.1237			0.1622	0.1958
	6. Mean intensity value of all pixels in <i>Near Infrared</i> band		-0.1608	-0.0868	0.0341	0.0108	-0.0911	
	7. Standard deviation of the intensity value of all pixels in <i>Near Infrared</i> band		-0.1612	-0.0396			-0.0909	-0.1224
	8. Maximum difference among red, green, blue, and near infrared band intensity values, divided by brightness		29.9775	7.0368			-4.4840	18.2254

Transport Measures	9. Distance from the centroid of the parcel to the nearest primary or secondary road (feet)		-0.0006	-0.0038	-0.0041		-0.0086	-0.0099
	10. Distance from the centroid of the parcel to the nearest intersection (feet)		-0.0018	-0.0013	0.0055	-0.0030		
Vegetation index	11. Percent of vegetation contained within the parcel image		-0.0581					
Neighborhood Attributes	12. Standard deviation of the compactness values of the parcels in the neighborhood		5.1968	11.7680		10.7029		
	13. Standard deviation of the <i>blue</i> band intensity values of the parcels in the neighborhood		0.1027	0.1231	0.1647			
	14. Standard deviation of the <i>Near Infrared</i> band intensity values of the parcels in the neighborhood		0.1170	0.0259				
	15. Standard deviation of the vegetation ratios of the parcels in the neighborhood		-0.0230	-0.0518		0.0656		0.1193
Summary Statistics	Number of parcels: 7,430 Log likelihood _ constant only: -7,065.6157 Log likelihood _ model: -3,606.706 Adjusted McFadden R-squared: 0.48888							

Note: (1) *The two constants are the only two coefficients that have the p-value greater than 10%; and (2) there is no or little correlation among the selected variables.

Model Prediction Performance

The remaining half of the parcels in the study area is used for model testing. The prediction process consists of score calculation, followed by probability estimation. Given the score functions in TABLE 4 and the values of affecting factors provided in the testing data, the score with respect to each class is calculated for each parcel. The scores are then converted to probabilities by using Equation (2). The class that returns the highest probability is the estimate.

A confusion matrix was generated from the test results to allow a visual inspection on the model performance (see TABLE 5). The rows represent the actual land use classes while the columns denote the predicted classes. The cells contain the counts in each category. As can be seen in, the MNL model did excellent job in discriminating residential land, which is the dominant land class that accounts for 62.1% of the parcels in the testing data. The prediction accuracy is very high as 94.5%. The prediction accuracy for vacant parcels is also satisfactorily high (79.82%). In contrast, the prediction performance is disappointing for commercial, community service and other land classes that have very low shares of parcels. As demonstrated by the testing area (FIGURE 6), commercial and community service parcels are often wrongly predicted as residential or vacant. So are the public service lands.

TABLE 5 Model Performance (Actual Classes versus Predicted Classes)

		Predicted Class							Accuracy
		Resident	Vacant	Commercial	R&E	Community Service	Industry	Public Service	
Actual Class	Resident	4,362	200	45	0	8	0	1	94.50%
	Vacant	369	1,673	51	0	2	1	0	79.82%
	Commercial	341	20	172	0	5	0	0	31.97%
	R&E*	6	2	4	0	0	0	0	0.00%
	Community Service	74	4	51	0	12	0	1	8.45%
	Industry	0	2	8	0	0	0	0	0.00%
	Public Service	7	6	3	0	0	0	0	0.00%

Note: R&E denotes recreation & entertainment.

The unsatisfactory prediction performance for the minority land use classes could be due to the following reasons. First, a lot of commercial and community service establishments in the City of Buffalo are located in house-like properties that are mixed with residential properties. The similarity in appearance, building materials and roof textures make it very difficult to discriminate them based on spectral features. The same confusion has been claimed in other

studies (36). The second reason is that the five classes are so highly underrepresented that insufficient distinct patterns could be captured to discriminate them.

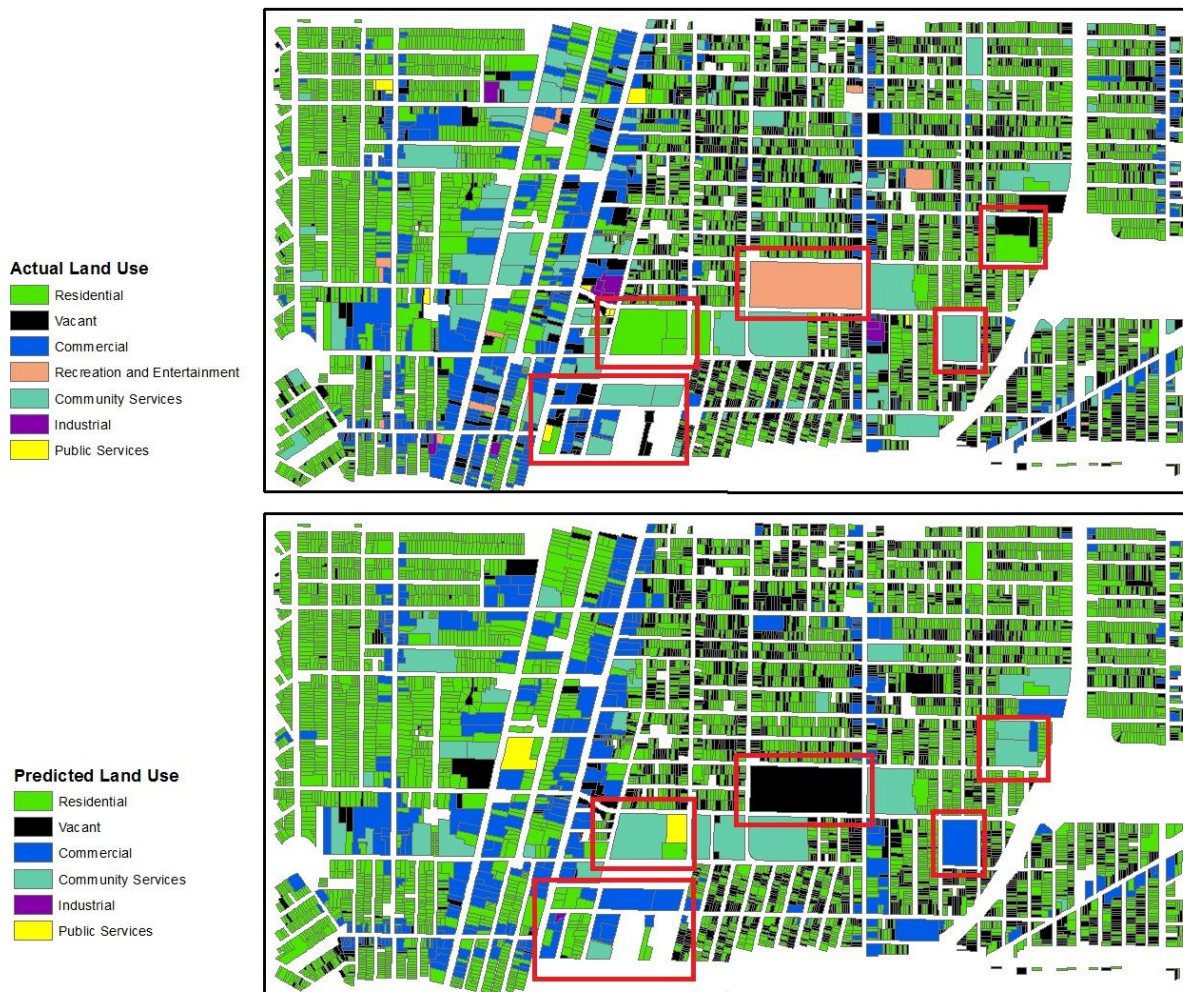


FIGURE 6 Actual land use classes versus predicted classes

CONCLUSIONS AND FUTURE WORK

The research developed a GIS-based performance measurement system to assess the sustainability and livability in transportation, using the City of Buffalo, New York as the case study. Twenty PMs were generated to assess the transportation, land use, living conditions, and congestion level. These PMs were examined and interpreted in the economic, environmental and social context. Several issues were identified, including the insufficient and incomplete bike lanes, high dependency on autos, single-land-use dominated neighborhoods, spatial separation of low-income and high-income houses, and so on. Policy implications were also derived, such as the improvement plan on the bike lane network and the revitalization of the central area to take

advantage of the resources and strength of the existing neighborhoods. The challenges and opportunities encountered during the PM system development were also discussed.

In addition, this research also explores the applicability of remote sensing in supporting land use prediction and updating. Transportation related attributes, such as the distance to the nearest road or intersection, were introduced as the complement variables to improve the land use classification model prediction performance. The best MNL model achieves an average prediction accuracy of 83.7% for the seven classes of land for the case study in City of Buffalo, New York. It works particularly well for the dominant land use classes such as residential and vacant. For the two classes, the prediction accuracy can be as high as 94.5% and 79.82% respectively, which is very impressive given the facts that the classification was performed at the finest parcel level; and that most of attributes used are spectral features mined from remote sensing image data. The low performance for other land use classes was also perceived mainly because of the low sample rates of them and the similarity in spectral features with residential lands.

ACKNOWLEDGEMENTS

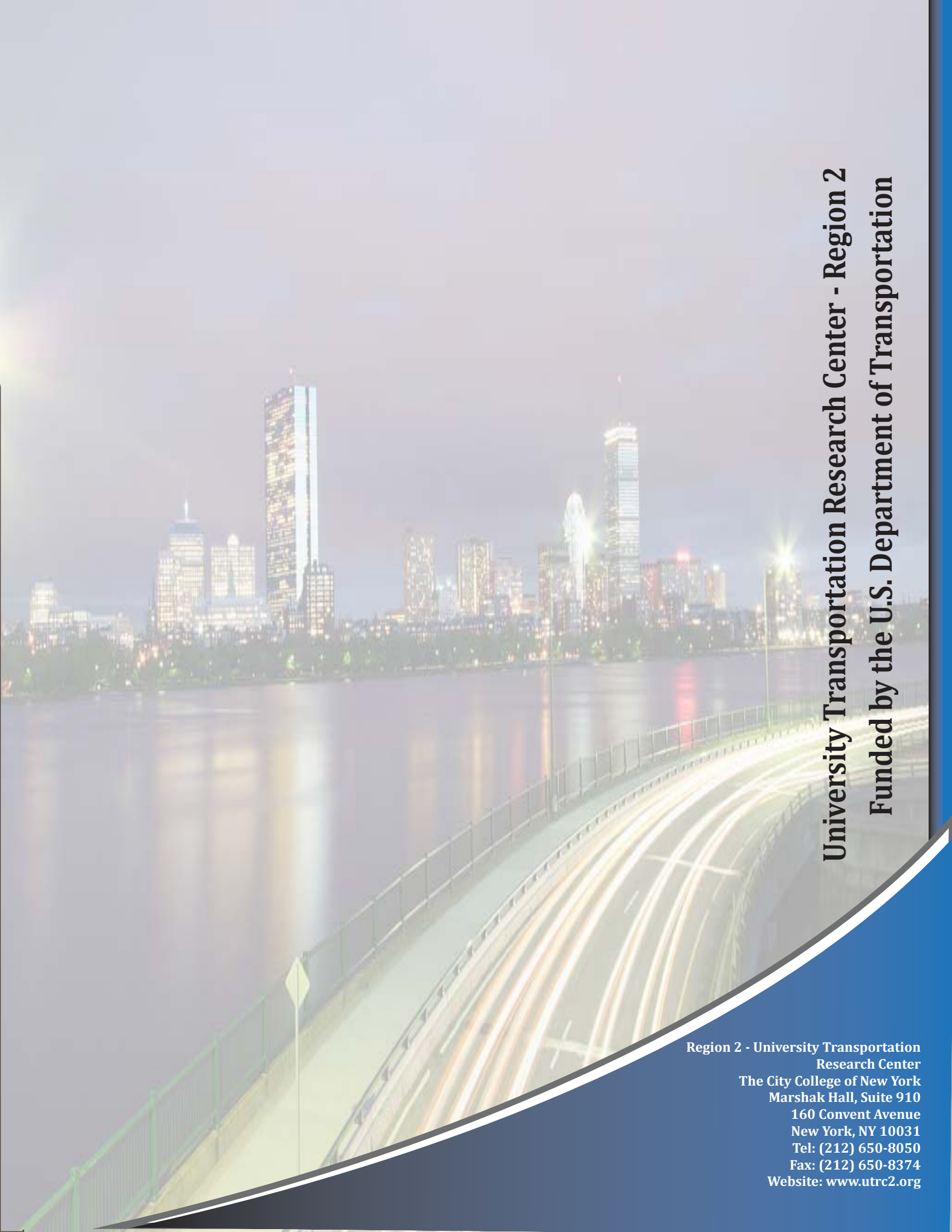
This research is funded by the University Transportation Research Center, Region II through the research project titled "A GIS-Based Performance Measurement System for Assessing Transportation Sustainability and Community Livability".

REFERENCES

1. Brokking, P., Emmelin, L., Engstroem, M. G., Nilsson, J. E., Eriksson, G., & Wikberg, O. An environmentally sustainable transport system in Sweden. A scenario study. 1997.
2. Canada, D. o. F. Advantage Canada: Building a Strong Economy for Canadians: Summary. *Dept. of Finance*, Ottawa, Canada. 2006.
3. FHWA. Sustainable Transportation Practices in Europe. *Federal Highway Administration*. Washington, D.C. 2001.
4. FHWA. Livability in Transportation Guidebook: Planning Approaches that Promote Livability. 2010.
5. FHWA. Transportation Planning for Sustainability Guidebook. Washington, D.C.: U.S. Federal Highway Administration. 2011.
6. FHWA. The Role of FHWA Programs in Livability: State of the Practice Summary. *Federal Highway Administration*. Washington, D.C. 2011.
7. EPA. Guide to Sustainable Transportation Performance Measures. *Environmental Protection Agency*. Washington, D.C. 2011.
8. NCHRP. A Guidebook for Sustainability Performance Measurement for Transportation Agencies. *Transportation Research Board*. Washington, D.C. 2011.
9. Litman, T. Well Measured: Developing Indicators for Sustainable and Livable Transport Planning. *Victoria Transport Policy Institute*. 2013.
10. Litman, T., & Burwell, D. Issues in sustainable transportation. *International Journal of Global Environmental Issues*, 6(4), 2006, pp. 331-347.
11. Zietsman, J., & Ramani, T. A Guidebook for Sustainability Performance Measurement for Transportation Agencies NCHRP Report No. 708. 2011.

12. AASHTO. The Road to Livability: How State Departments of Transportation are Using Road Investments to Improve Community Livability. *American Association of State Highway and Transportation Officials*. 2010.
13. Amekudzi, A., Meyer, M., & Ross, C. Transportation Planning and Sustainability Guidebook. 2011.
14. Miller, J. S. Potential performance measures to assess transportation and land use coordination. Paper presented at the Transportation Research Board 87th Annual Meeting. 2008.
15. Buffalo–Niagara Falls metropolitan are. In Wikipedia, The Free Encyclopedia. http://en.wikipedia.org/wiki/Buffalo%E2%80%93Niagara_Falls_metropolitan_area#Combined_Statistical_Area. Last Access: August 1, 2014.
16. Wu, S., X. Qiu, L. Usery and L. Wang. Using Geometrical, Textural, and Contextual Information of Land Parcels for Classification of Detailed Urban Land Use, *Annals of the Association of American Geographers*, 99(1), 2009, pp. 1-23.
17. Silvan, J., L. Wang, P. Rogerson, C. Wu, T. Feng, B. Kamphaus. Assessing Fine Spatial Resolution Remote Sensing for Small Area Population Estimation, *International Journal of Remote Sensing*, 31(21), 2010, pp. 5605-5634.
18. Schrank, D., Eisele, B., & Lomax, T. TTI's 2012 Urban Mobility Report. *Proceedings of the 2012 Annual Urban Mobility Report*. Texas A&M Transportation Institute, Texas, USA. 2012.
19. USEPA. *Guide to Sustainable Transportation Performance Measures*. 2011.
20. Ramani, T., Zietsman, J., Eisele, W., Rosa, D., Spillane, D., & Bochner, B. *Developing Sustainable Transportation Performance Measures for TXDOT's Strategic Plan: Technical Report*. 2008.
21. Lily Elefteriadou, S. S., Ruth L. Steiner, Patricia C. Tice, Kwangkyun Lim. *Expanded Transportation Performance Measures to Supplement LOS for Growth Management and Transportation Impact Analysis*. Florida Department of Transportation. 2012.
22. Anderson, J. R. A Land Use and Land Cover Classification System for Use with Remote Sensor Data, *US Government Printing Office*. Vol. 964, 1976.
23. DeFries, R. S., & Townshend, J. R. G. NDVI-derived Land Cover Classifications at A Global Scale. *International Journal of Remote Sensing*, 15(17), 1994, pp. 3567-3586.
24. Du, Q. and Chang, C. A Linear Constrained Distance-Based Discriminant Analysis for Hyperspectral Image Classification. *Pattern Recognition*, 34, 2001, pp. 361–373.
25. Du, Q. and Ren, H. Real-time Constrained Linear Discriminant Analysis to Target Detection and Classification in Hyperspectral Imagery. *Pattern Recognition*, 36, 2003, pp.1–12.
26. Richards, J. A. *Remote sensing digital image analysis* (Vol. 3). Berlin et al.: Springer. 1999.
27. Hung, M., & Ridd, M. K. A Subpixel Classifier for Urban Land-Cover Mapping Based on A Maximum-Likelihood Approach and Expert System Rules. *Photogrammetric Engineering and Remote Sensing*, 68(11), 2002, pp. 1173-1180.
28. Atkinson, P. M., & Tatnall, A. R. L. Introduction Neural Networks in Remote Sensing. *International Journal of remote sensing*, 18(4), 1997, pp. 699-709.
29. Kavzoglu, T., & Mather, P. M. The Use of Backpropagating Artificial Neural Networks in Land Cover Classification. *International Journal of Remote Sensing*, 24(23), 2003, pp. 4907-4938.

30. Shalan, M.A., Arora, M.K. and Ghosh, S.K. An Evaluation of Fuzzy Classifications from IRS 1C LISS III Imagery: A Case Study. *International Journal of Remote Sensing*, 24, 2003, pp. 3179-3186.
31. Friedl, M. A., & Brodley, C. E. Decision Tree Classification of Land Cover from Remotely Sensed Data. *Remote Sensing of Environment*, 61(3), 1997, pp. 399-409.
32. Pal, M., & Mather, P. M. An Assessment of the Effectiveness of Decision Tree Methods for Land Cover Classification. *Remote Sensing of Environment*, 86(4), 2003, pp. 554-565.
33. Brown, M., Gunn, S. R., & Lewis, H. G. Support Vector Machines for Optimal Classification and Spectral Unmixing. *Ecological Modelling*, 120(2), 1999, pp. 167-179.
34. Otukey, J. R., & Blaschke, T. Land Cover Change Assessment Using Decision Trees, Support Vector Machines and Maximum Likelihood Classification Algorithms. *International Journal of Applied Earth Observation and Geoinformation*, 12, 2010, pp. 27-31.
35. Xie, C., Huang, B., Claramunt, C., & Chandramouli, C. Spatial Logistic Regression and GIS to Model Rural Urban Land Conversion. In *Proceedings of PROCESSUS Second International Colloquium on the Behavioural Foundations of Integrated Land-use and Transportation Models: Frameworks, Models and Applications*, 2005, pp. 12-15.
36. Lu, D., & Weng, Q. A Survey of Image Classification Methods and Techniques for Improving Classification Performance. *International Journal of Remote Sensing*, 28(5), 2007, pp. 823-870.
37. New York State GIS Clearing House. Remote Sensing Data in New York State. <http://www.nysgis.state.ny.us/>. Accessed: July 28, 2014.
38. University at Buffalo Regional Institute (UBRI). <http://regional-institute.buffalo.edu/>. Accessed: July 28, 2014.
39. Federal Highway Administration (FHWA). National Highway Planning Network. <http://www.fhwa.dot.gov/planning/processes/tools/nhpn/>. Accessed: July 28, 2014.
40. New York State Office of Real Property Services. *The New York State Assessor's Manual*. <http://www.tax.ny.gov/research/property/assess/manuals/assersmanual.htm>. Accessed: July 28, 2014.
41. Franklin, S.E., Connery, D.R. and Williams, J.A. Classification of Alpine Vegetation Using Landsat Thematic Mapper, SPOT HRV and DEM data. *Canadian Journal of Remote Sensing*, 20, 1994, pp. 49-56.
42. Ben-Akiva, M., and S.R. Lerman. *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press, Cambridge, Massachusetts, 2000.

A long-exposure photograph of a city skyline at night, reflected in a body of water. In the foreground, a bridge or highway has light trails from moving vehicles. The sky is dark, and the city lights are bright and colorful.

University Transportation Research Center - Region 2
Funded by the U.S. Department of Transportation

**Region 2 - University Transportation
Research Center**
The City College of New York
Marshak Hall, Suite 910
160 Convent Avenue
New York, NY 10031
Tel: (212) 650-8050
Fax: (212) 650-8374
Website: www.utrc2.org