University Transportation Research Center - Region 2

Final Report

Prototype Development of the Open Mode Integrated Transportation System (OMITS)

Performing Organization: Columbia University

March 2013

Sponsor:
Research and Innovative Technology Administration / USDOT (RITA)

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 mostresponsive 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 Authorityand 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: 49111-08-23

Project Date: March 2013

Project Title: Prototype Development of the Open Mode Integrated Transportation System (OMITS)

Principal Investigator:

Dr. Huiming Yin
Assistant Professor
Department of Civil Engineering and
Engineering Mechanics
Columbia University
Email: yin@civil.columbia.edu

Performing Organization: Columbia University

Sponsor:
Research and Innovative Technology Administration /
USDOT (RITA)

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

Mailing Address:

University Transportation Reserch 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
Dr. Claire McKnight - Civil Engineering
Dr. Neville A. Parker - Civil Engineering

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
Dr. Mark A. Turnquist - Civil Engineering

Hofstra University
Dr. Jean-Paul Rodrigue - Global Studies and Geography

New Jersey Institute of Technology
Dr. Steven Chien, Civil Engineering
Dr. Priscilla P. Nelson - Geotechnical Engineering

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

Polytechnic Institute of NYU
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, & Society/Public Policy

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

Rutgers University
Dr. Robert Noland - Planning and Public Policy
Dr. Kaan Ozbay - 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. Michael Shenoda - 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)
New Jersey Institute of Technology (NJIT)
New York University (NYU)
Polytechnic Institute of NYU (Poly)
Rensselaer Polytechnic Institute (RPI)
Rochester Institute of Technology (RIT)
Rowan University (Rowan)
Rutgers University (Rutgers)
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 Distin*guished Professor of Civil Engineering, The City College of New York

Dr. Claire McKnight: *Assistant Director for Education and Training; Associate Professor of Civil Engineering, 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 New Initiatives and Assistant Professor of Civil Engineerin*g

Nadia Aslam: *Assistant Director for Technology Transfer*

Dr. Anil Yazici: *Post-doc/ Senior Researcher*

Nathalie Martinez: *Research Associate*

REGION II
UNIVERSITY TRANSPORTATION RESEARCH CENTER

Final Report

Prototype Development of the Open Mode Integrated Transportation System (OMITS)

Prepared by

Principal Investigator

Dr. Huiming Yin
Assistant Professor
Department of Civil Engineering and Engineering Mechanics
Columbia University
Email: yin@civil.columbia.edu

April 2013

COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2.Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Prototype Development of the Open Mode Integrated Transportation System		5. Report Date March 12, 2013 6. Performing Organization Code
7. Author(s) Huiming Yin, P.E., PhD Assistant Professor, Columbia University		8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Civil Engineering and Engineering Mechanics Columbia University 500 West 120th Street New York, NY 100027		10. Work Unit No. 11. Contract or Grant No. 49111-08-23
12. Sponsoring Agency Name and Address University Transportation Research Center City College of New York-Marshak 910 160 Convent Avenue NewYork, NY 10031		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report presents an overview of the Open Mode Integrated Transportation System (OMITS), introduces its key components and algorithms in the recent development and implementation, and demonstrates the working mechanism of dynamic transit service. The OMITS has been designed to integrate the availability of multiple transit modes into the ridesharing service to provide riders and drivers flexible, efficient, and reliable transportation services, through dynamic matching and routing algorithms and emerging information communication and data mining and fusion technologies. The OMITS App, which is run on a smart phone (iPhone or Android), has been developed for customers to communicate with the OMITS server, detect roadway traffic conditions, and receive driving directions. Using the multimodal travel system, the OMITS integrates multimodal transit options including the information of time-dependent arc weights, namely travel time, and switching delays and provides the time-dependent multimodal shortest path using the Dijkstra's algorithm under the FIFO condition. The OMITS also applying Dijkstra's algorithm on social network calculation, to find out the best matching for users. The OMITS system provides an optimized ridesharing and transit service based on spontaneous transportation demands and service availability.

17. Key Words		18. Distribution Statement	
Dynamic transit service Ridesharing service Smart phone APP Multimodal travel system		(Present in TRB conference)	
19. Security Classif (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	12 pages	$6000

Form DOT F 1700.7 (8-69)

Disclaimer

Prototype Development of the Open Mode Integrated Transportation System (OMITS)

Abstract

This report presents an overview of the Open Mode Integrated Transportation System (OMITS), introduces its key components and algorithms in the recent development and implementation, and demonstrates the working mechanism of dynamic transit service. The OMITS has been designed to integrate the availability of multiple transit modes into the ridesharing service to provide riders and drivers flexible, efficient, and reliable transportation services, through dynamic matching and routing algorithms and emerging information communication and data mining and fusion technologies. The OMITS App, which is run on a smart phone (iPhone or Android), has been developed for customers to communicate with the OMITS server, detect roadway traffic conditions, and receive driving directions. Using the multimodal travel system, the OMITS integrates multimodal transit options including the information of time-dependent arc weights, namely travel time, and switching delays and provides the time-dependent multimodal shortest path using the Dijkstra's algorithm under the FIFO condition. The OMITS also applies Dijkstra's algorithm on social network calculation, to find out the best matching for users. The OMITS system provides an optimized ridesharing and transit service based on spontaneous transportation demands and service availability.

Key words: Dynamic transit service; Ridesharing service; Smart phone APP; Multimodal travel system

1. Research background

Traffic congestion has imposed tight constraints on economic growth, national security, and mobility in metropolitan areas. With a marked increase in population and the number of private cars, traffic has become a severe problem for most people living in the U.S. Drivers waste time and money standing idle in traffic. Gasoline consumption and greenhouse gas emissions are at unnecessarily and unsustainably high levels and could be reduced significantly with only modest improvements in traffic.[1-3] The problem is especially dire in major metropolitan areas of the U.S.A. where roadway use drastically exceeds design capacity. The problem is further exacerbated by the exceedingly high use of single occupancy vehicles. As urban areas must contend with increasing traffic congestion transportation delays, volatile gas prices, vehicle emissions and security threats, sustainability of the transportation system has drawn significant attention from researchers and practitioners alike.[1, 2]

The fundamental solution can be made from two sides: 1) to improve the ridership of passenger carrying vehicles and thus reduce the number of cars on the road, and; 2) to optimize the routing and planning of the trips and thus reduce travel time for each trip.

The development of wireless communications, Internet services, global positioning systems (GPS), geographic information systems (GIS), and large-scale database systems creates us an exciting opportunity to integrate our transportation system for higher levels of efficiency and sustainability.[4-7] On the Internet, we can find the static schedule of buses and trains and trace real-time traffic information on major roads. Using cellular phones and GPS, we can communicate with each other about routing and traffic conditions. Carpool matching systems have attracted a lot of attention.[8] All of these technologies can be used to develop a dynamic transit system, so that the riders can easily find the optimal transit approach, thereby creating a virtual system that can serve the public in a more reliable, efficient, and flexible way. When the transition between different transit modes can be seamlessly integrated and placed in the hands of passengers, more riders will be attracted to a public transit system.

2. Introduction of OMITS

The Open Mode Integrated Transportation System (OMITS) has been proposed in 2009.[5] The success of this system essentially relies on effective information communication, accurate prediction of traffic conditions, and comprehensive understanding of transit customer behavior and traffic flow dynamics. Using the OMITS App, which is run on a smart phone including iPhone or Android, customers can communicate with the OMITS server, detect roadway traffic conditions, and receive driving directions.

With the aid of traffic prediction model, the system can analyze the historic and real-time traffic data, from which the optimal routing direction and ridesharing group can be recommended. The Open Mode Integrated Transportation System (OMITS), which has been developed in cooperation of Columbia University and NDJ Sustainable Engineering LLC, uses emerging information and communication technologies, such as smart phones, Internet services, GPS/GIS, and data mining and fusion technologies, to improve ridership of vehicles and optimize operation of transportation system.
In this part, we will introduce OMITS from six parts, including architecture, component, Agent Based Modeling and Simulation system (ABMS), Data structure, Working mechanism, and User interface.

2.1 The architecture

This system is designed to integrate the availability of multiple transit modes, including carpool, vanpool, bus, and train, and to use dynamic matching and routing algorithms to provide flexible, efficient transit services. **FIGURE 1** illustrates the information communication framework of OMITS. The OMITS server collects transportation demands from riders and matches them with the available services. It also probes the traffic information of road sections through vehicles and simulates the traffic conditions for route direction. The user entities of the OMITS include the follows:
1. *Public commuters or riders* can obtain the ridesharing service integrated with the public transit service at the lowest cost in terms of time or fare.
2. *Private car or van owners* can provide dynamic carpooling or vanpooling service and receive routing service based on traffic situation.
3. *General members* can access the OMITS database for the real-time roadway traffic condition and trip planning.

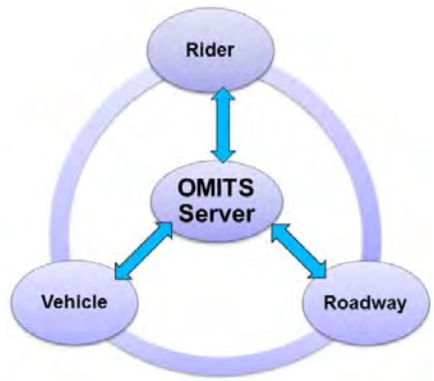


Figure 1 The information communication framework of the OMITS

2.2 The Subsystems

The OMITS system forms a sustainable information infrastructure for communication within and between the mobile/Internet network, the roadway network, and the users' social network. It manipulates the speed gap between different types of the network: information communication through cellular phones and the Internet is tremendously higher than that of vehicles on roadway, which is much faster than that of the social networking. Using the integrated information communication platform of the OMITS system, the time and spatial limits of traditional transportation system can be overcome by high speed of information communication and data fusion through smart phone and the Internet.

The OMITS server performs the information communication and transportation management through the following three modules as illustrated in **FIGURE 2**:[5]

The User Operation System provides the interface for users through smart phone app or the Internet interface. The OMITS App has been developed for iPhone and Android Phone, available for free installation. All drivers are required to use OMITS App for the transit service to provide real-time location and speed of the vehicles.

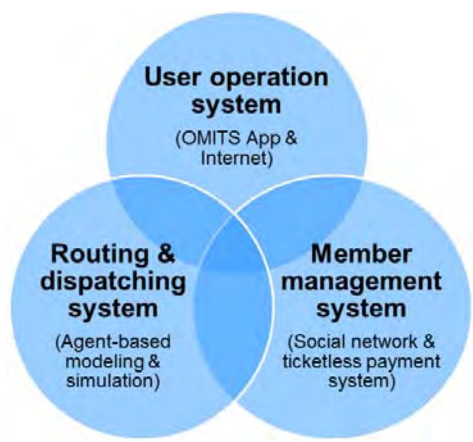


Figure 2 Three subsystems of OMITS for transportation operation and management

The Routing and Dispatching System, which keeps running in the background, provides the optimal route for drivers and matches a driver and riders. Using the data of real-time and historic speed on each road section collected by OMITS vehicles, we predict the travel time of the section in future through traffic flow, which are used for short-term and long-term traffic prediction, respectively.

The Member Management System provides service such as member registration, billing and payment, data reporting and complaint handling. Social network among the member will also be taken into account, so that carpooling among strangers will be avoided. With the clear record in OMITS, no ticket other than the confirmation through the OMITS App is needed at the point of boarding. The payment flow within the OMITS users, both drivers and riders, will go through a monthly bill.

2.3 Agent Based Modeling and Simulation system

Because transportation demand and transit service availability vary greatly over spatial and time domains depending on the real-time traffic condition, which results from roadway capacity and traveler decisions, it is difficult to find the best solution for each participator of this system. Moreover, because the traffic condition changes promptly with time, a good solution for the current situation could become a poor solution soon thereafter. Agent based modeling and simulation (ABMS) will provide an excellent method to mimic the highway traveling environment, allowing predictions of traffic condition based on historic data and stochastic process, thereby providing information for an optimal travel decision. The Background Routing and Dispatching System of the OMITS system is organized ABMS. The architecture of the ABMS is purposely tailored in accordance with the framework of OMITS, so that it can be seamlessly integrated into the computer program and database structure. It will provide a platform for a variety of future extensions and applications. **FIGURE 3** illustrates the architecture of the ABMS for OMITS, which includes three levels elaborated as follows.

In the first level, three types of *environmental agents* form the primary elements for highway traveling environment: 1) *Vehicle* agent is the most active agent. Its drivers can decide driving direction and their driving behavior has significant influence on traffic condition. 2) *Rider* agent can choose the travel routes and modes and affect the number of vehicles on the road. Communication between riders and drivers will also have an impact on traffic condition. 3) *Roadway* agent will provide the roadway speed in time domain for a specific highway section, communicate with driver agents, and provide information to traffic flow.

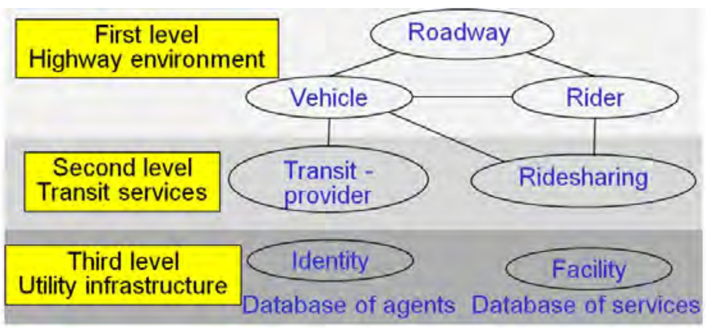


Figure 3 Architecture of agent-based modeling and simulation

In the second level, two types of *service agents* will organize the three environmental agents: 1) *Transit-provider* agent will own a number of buses, vans, and taxi. They will provide dispatching and scheduling services for both drivers and riders. 2) *Ridesharing* agent will be in charge of communication among drivers and riders and set up frequent ride sharing pairs or groups. Combining currently available functions of mobile applications, OMITS App will collect traffic data for roadway agents, communicate with a transit management server, and provide driving directions and matching information for drivers.

In the third level, two types of *utility agents* will perform database management and information acquisition. 1) *Identity* agent will maintain a registry of all environmental agents and their attributes. It provides data support for service agents. For example, when a service agent requests the occupation of a rider agent with her/his ID number, the identity agent will find it from its database timely. 2) *Facility* agent will maintain a list of services that the service agents can provide. For example, when a rider agent requests a taxi service in a region, the facility agent will provide available information. The database of utility agents will be updated with real-time data. Various algorithms, such as traffic flow modeling and prediction, statistical analysis, and data screening and mining, will be used to assure and promote the quality of data.

2.4 Data structure

FIGURE 4 illustrates the entity-relationship (ER) diagram of the OMITS system for the design and development of its database. Starting at the bottom, the road network is made of RoadSections, which are the Links on the map including specific speed limit and historic, current and predicted travel time data. The

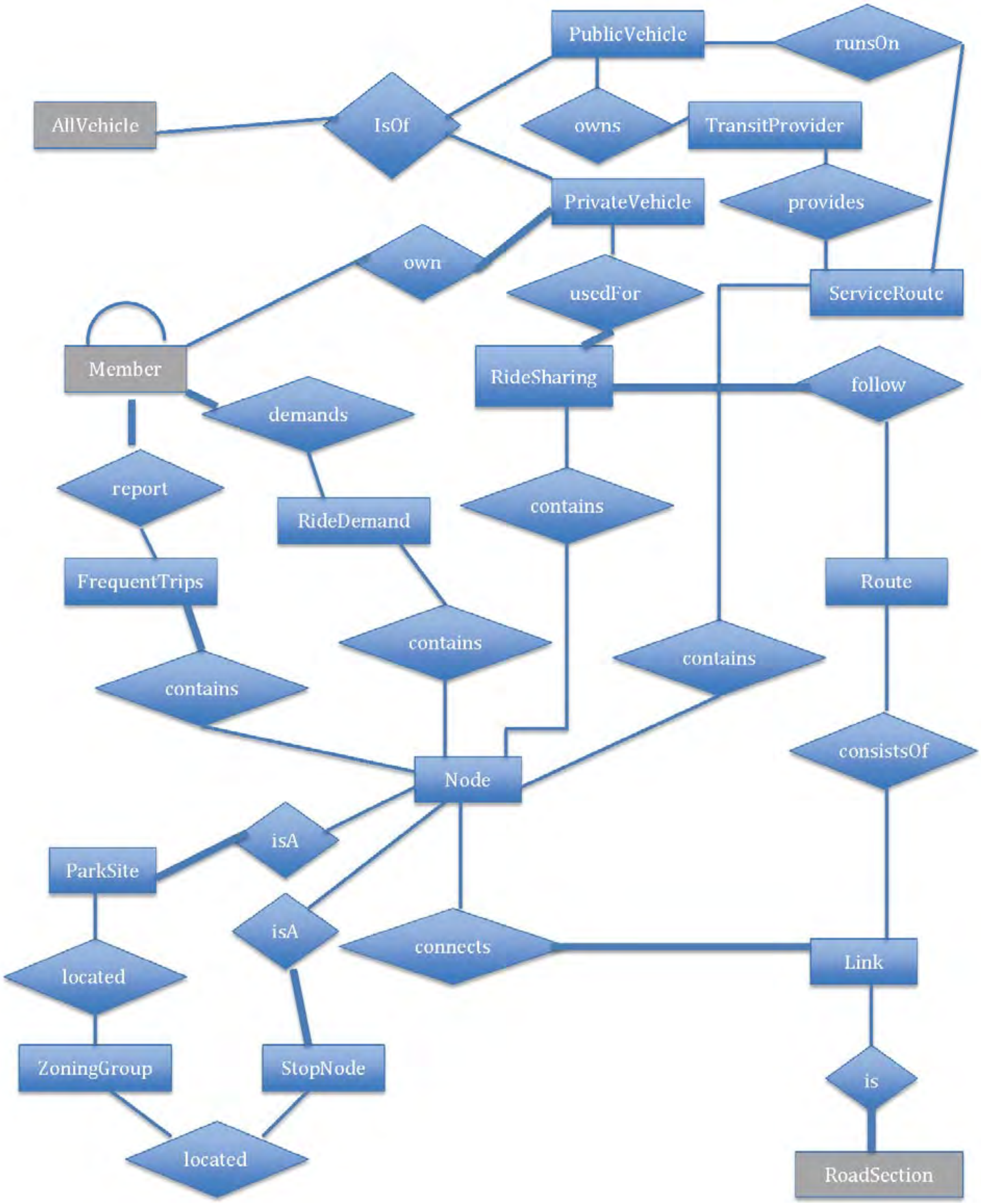


Figure 4 Entity-relationship (ER) diagram of OMITS

Link connects two Nodes, which can be either StopNode or ParkSite associated with a ZoningGroup, which facilitates node grouping. An adjacency list is provided for each Node, which forms the road network. A Route for RideSharing typically consists of multiple Links. A Member of OMITS may own a PrivateVehicle to serve as an OMITS driver or simply present as a rider. FrequentTrips are also reported for each member for easy input of service request. When a member demands a RideDemand, it will match with RideSharing and ServiceRoute containing the related Nodes. Besides PrivateVehicle, AllVehicle also lists the types of PublicVehicle, which are owned by different TransitProviders and serve for different ServiceRoute.

2.5 Working mechanism

The working mechanism is illustrated in **FIGURE 5**. The OMITS system starts its operation at the point when a request is received from a member, either a driver or a rider, who stands for a vehicle agent and a rider agent, respectively. Once a match between riders and a driver is generated, the rider agent can locate vehicle agent through the OMITS App. Multiple riders may be picked up or dropped off at different locations. The OMITS server will record the service information and report it in monthly bills.

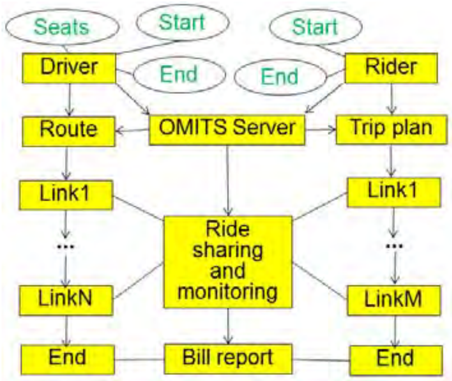


Figure 5 Flow chart of OMITS

2.6 User interface

Using the OMITS App in **FIGURE 6** together with the public transit databases, the OMITS system integrates carpooling and vanpooling into the public transit systems for dynamic transit services to the public. The social network among users has been recorded through membership invitation and registration. To match a ride between a driver and riders, their social relationship and route information (both service time and location) will be considered, so that friends and colleagues will have more chance to share rides, so as to alleviate the nervousness and hesitation of drivers to provide ridesharing service. The OMITS can find a ride for rider requests with a lower cost and higher reliability, so that it is a more preferable choice for users.

FIGURE 6(a) shows the OMITS App's user interface of user profile for member management. We can update the profile as needed. **Trip TAB** is used to request or provide a riding service. The user can type departure and destination addresses manually in **Figure 6(b)**. If the user is to repeat a frequent route, the most frequent trips are shown in a descent order of trip frequency. Each trip item contains the departure time, departure address and destination address as **Figure 6(c)**. Once a ridersharing service is produced, the driver can see the rider's information in **Figure 6(d)** in **Ride TAB**. **Route TAB** will show the current vehicle location and driving direction to pick-up and drop-off riders as **FIGURE 6(e)**. The **Info TAB** provides some common information for public transit providers, OMITS contact and emergency information.

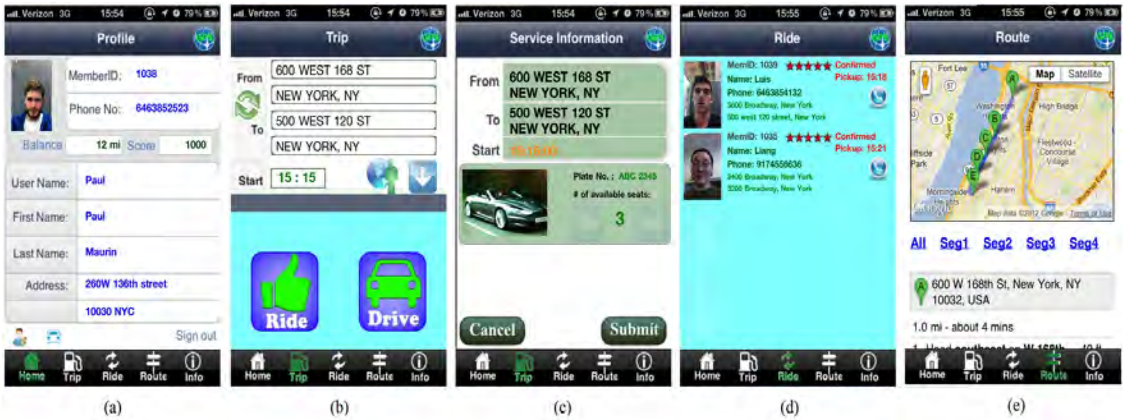


Figure 6 Interface of OMITS App on smart phones: (a) member management, (b) new service request (c) service information, (d) rider information for rider sharing, and (e) dynamic route direction and pick-up sites

3. Algorithm of OMITS

3.1 Roadway network data structure dynamic routing method

Within the OMITS system, the existing public transit service can still be handled with the static data integrated with traffic prediction data. A new feature is to integrate the carpool service into the existing available services. The drive routing and rideshare grouping should be provided under the dynamic traffic condition. Given a starting point and the destination, if the speed or travel time on each road section is given, the drive direction can be obtained by the Dijkstra's algorithm, which is based on the open shortest path first protocol.[10]

For example, **FIGURE 7** provides a simple road network with the shortest travel time for each road section under free flow condition. A driver starts at A toward E. Using the Dijkstra's algorithm, we can find the shortest path and travel time is A → E → F; T=45+45=90.

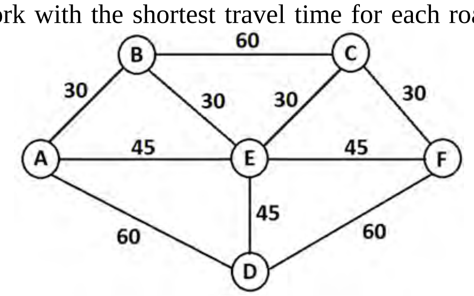


Figure 6 Simple road network with shortest travel time for each road section

However, in actual traffic situation, the travel time in each road section may change asynchronously, which still satisfies the FIFO condition, i.e. for two riders, who start at t_1 and t_2 ($t_1 < t_2$) and take T_1 and T_2 to travel through the same road section, there exists a condition $t_1 + T_1 < t_2 + T_2$ or $(T_2 - T_1) / (t_2 - t_1) > -1$. Through traffic prediction, we can obtain the travel time for each road section at a certain starting time. For demonstration, the traffic data for the road

Table 1 The dynamic travel time for each road section at a specific start time

Time	T(A-B;t)	T(A-E;t)	T(A-D;t)	T(B-E;t)	T(B-C;t)	T(C-E;t)	T(C-F;t)	T(D-E;t)	T(D-F;t)	T(E-F;t)
6:00:00 AM	30	45	60	30	60	30	30	45	60	45
6:10:00 AM	30	40	50	30	70	30	30	45	80	60
6:20:00 AM	30	50	40	30	70	30	30	45	80	90
6:30:00 AM	30	60	40	30	70	30	30	45	80	90
6:40:00 AM	30	60	40	30	70	30	30	45	80	180
6:50:00 AM	30	60	40	30	70	30	40	45	80	180
7:00:00 AM	40	90	40	30	70	40	40	45	100	180
7:10:00 AM	40	90	40	40	70	40	40	45	110	180
7:20:00 AM	40	90	40	40	70	40	40	45	110	180
7:30:00 AM	60	100	40	40	70	40	40	45	110	175
7:40:00 AM	60	120	40	40	70	40	40	45	110	170
7:50:00 AM	60	115	40	40	70	40	40	45	110	165
8:00:00 AM	60	115	40	40	70	35	40	45	110	160
8:10:00 AM	60	110	40	40	80	35	40	45	110	155
8:20:00 AM	60	105	40	40	80	35	40	45	110	150
8:30:00 AM	55	100	40	35	80	35	40	45	110	145
8:40:00 AM	55	100	40	35	80	30	40	45	110	140
8:50:00 AM	50	95	40	35	80	30	40	45	110	135
9:00:00 AM	50	140	40	35	90	30	35	45	110	130
9:10:00 AM	45	135	40	30	90	30	35	45	110	125
9:20:00 AM	45	130	40	30	100	30	30	45	110	120
9:30:00 AM	40	130	40	30	100	30	30	45	110	115
9:40:00 AM	30	125	40	30	100	30	30	45	110	110
9:50:00 AM	30	120	40	30	100	30	30	45	100	105
10:00:00 AM	30	115	40	30	100	30	30	45	90	100

network in **FIGURE 7** are provided in **Table 1**, which satisfy the FIFO condition. The Dijkstra's algorithm obviously cannot be directly used for dynamic routing. However, under the FIFO condition, a minor modification of the Dijkstra's algorithm will make it applicable to find the shortest path at the same complexity level. The main difference between the modified and traditional Dijkstra's algorithm is that the modified algorithm uses dynamical weight (in the OMITS is traveling time) based on transportation prediction. Using the data in **Table 1** for a driver starting at A toward E at 6:00AM, the modified Dijkstra's algorithm in the OMITS system is applied. The shortest path will be of A → E → C → F instead of A → E → F in static Dijstra's algorithm, and the shortest travel time is 115 minutes.

In general, the nodes used in the algorithm are much more than those of the shortest path. However, the Dijkstra's algorithm does not need to go over all notes in the map - once the destination node has been marked visited, then stop. The modified Dijkstra's algorithm exhibits the same computational complexity as the traditional one. The FIFO condition will guarantee that the obtained solution is indeed the shortest path because the later start one for any local point will impossibly make an earlier arrival at the destination.

However, if the start time is flexible, the total travel time on the road can be much different. For example, if the driver starts at 6:30AM, 7:00AM, or 7:30AM, the shortest paths (travel time) can be obtained in the same fashion, which are A → B → C → F (140 min), A → D → F (150 min), and A → D → E → C → F (145 min), respectively. Using this method, we can provide recommendation for drivers to choose a better start time for traffic control and mitigation.

Once the route is found for a driver, we list it as an available transit service. Traditional transportation assignment can be used to dynamically match riders to private cars and public transit vehicles in the uniform fashion.

3.2 Social network Algorithm

In OMITS the social relationship network is as important as Roadway network. All the ridesharing is based on the social network. As we know, social relationship network is limited by one person's working, entertainment, and living etc. As a result, the relationship between two different groups is relatively weak. FIGURE 8 and TABLE 2 shows one example of the social network between department of engineering and teach colleges school facilities. In the left circle, the Engineering school facilities know each other very well, but between the two group of people, there is only one direct connection between A and G. This social phenomenal limits the OMITS user size.

To avoid this situation, we introduce the road-network shortest route concept to social network. For example, In FIGURE 8 and TABLE 2 each connection between two persons has a weight. The bigger weight means this kind of relationship is harder to extend than the smaller weight. In OMITS, we apply Dijkstra algorithm in social network to provide the shortest relationship between two person, and minimize the sum of weight values in one carpooling vehicle. As a result, instead of direct relationship between two person, OMITS applies the shortest relationship chain. In this example, the relationship connection between D and H is D-E(Coworker), E-A(Coworker), A-G(Neighbor), and G-H(Friend). This information of the relationship chain will be showed on smartphone of each rider and driver. The improved social relationship network system will reduce the opportunity to be a "stranger" between two persons, and also enforce the relationship after each ridesharing service.

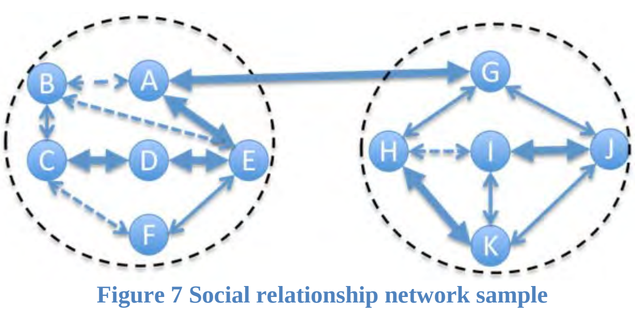


Figure 7 Social relationship network sample

Table 1 Weights of Social relationship network at different relationship

Relationship	Weight	Symbol
Neighbor	1	⟷
Coworker	1	⟷
Friend	2	⟷
Ride-sharer	3	⇠ ⇢

4. Summary and conclusions

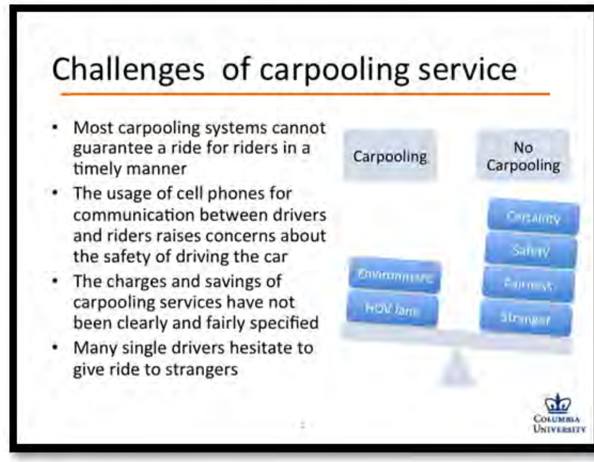
The prototype of the OMITS system has been developed and tested in the laboratory and the Columbia campus, which has been able to successfully provided service to our members through the Internet (http://www.ndjse.com/account.php), iPhone and Android smart phones. The work has been reported in the TRB conference 2013 - H.M. Yin, L. Wang, P. Maurin, H.Xu, 2013, Dynamic transit service through the open mode integrated transportation system. Transportation Research Board 92th Annual Meeting, January 13-17, Washington DC. The work mechanism has been fully demonstrated and the advantages of the OMITS to traditional transportation system are envisioned. The research results will be implemented by NDJ Sustainable Engineering Ltd. through the agreement between it and Columbia Technology Ventures. Our long-term goal is to implement the system and provide the dynamic transit service to the public. A new project, which was launched recently, will include the features of social network into the membership management system and thus improve the transit experience of riders and speed up the matching process as limiting the search scope with users' social relationship. This project will provide a baseline for a lot of transportation systems for transit service, traffic forecast, and transportation system planning.

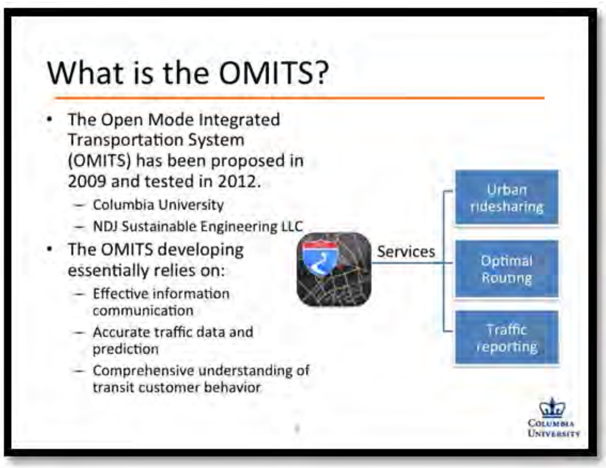
REFERENCES:

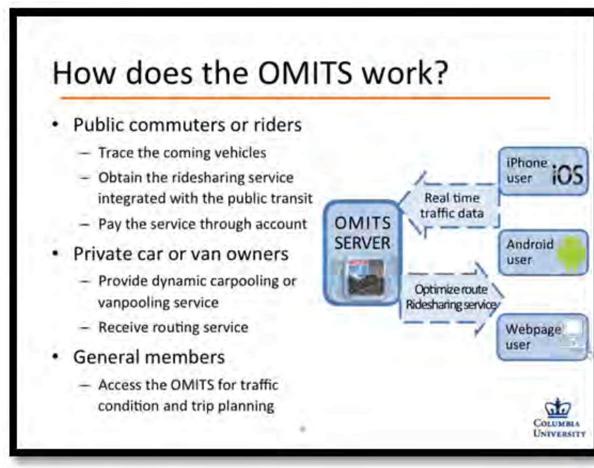
1. Kennedy, C.A., *A comparison of the sustainability of public and private transportation systems: Study of the Greater Toronto Area.* Transportation (Dordrecht), 2002. **29**(4): p. 459-493.
2. Shiftan, Y., *Scenario building as a tool for planning a sustainable transportation system.* Transportation research. Part D, Transport and environment, 2003. **8**(5): p. 323-342.
3. von Blottnitz, H., *A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective.* Journal of cleaner production, 2007. **15**(7): p. 607-619.
4. Dailey, D., *Seattle smart traveler: dynamic ridematching on the World Wide Web.* Transportation research. Part C, Emerging technologies, 1999. **7**(1): p. 17-32.
5. Yin, H.M., A.M. Saleh, M.D. Shields, *Design and payoff prediction for the open mode integrated transit system*, in. *Transportation Research Board 90th Annual Meeting*. 2011: Washington DC.
6. Bajwa, S.I., E. Chung, and M. Kuwahara. *Performance evaluation of an adaptive travel time prediction model*. in *Intelligent Transportation Systems, 2005. Proceedings. 2005 IEEE*. 2005.
7. Unnikrishnan, A., *Integrated Traffic Simulation-Statistical Analysis Framework for Online Prediction of Freeway Travel Time.* Transportation Research Record, 2007. **2039**(-1): p. 24-31.
8. Price, B., *Computerized Carpool System. Computers and People.* Computers and Poeple, 1974: p. 45-45.
9. Liu, K. and X. Fei, *Dynamic short-term traffic flow forecasting for congested freeway.* 2006.
10. Dijkstra, E.W., *A note on two problems in connexion with graphs.* Numerische Mathematik 1959. **1**: p. 269–271.

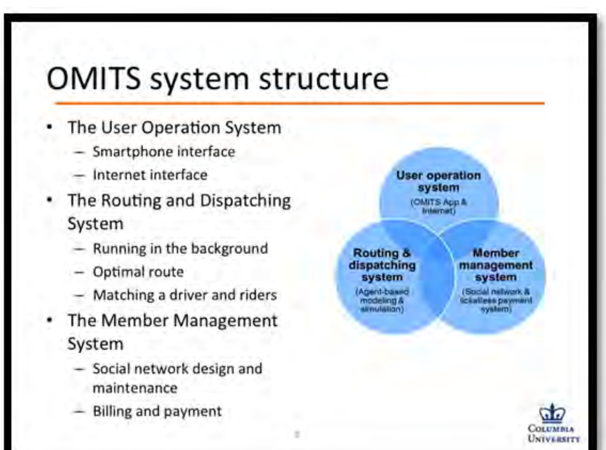
Appendix. Presentation at TRB conference

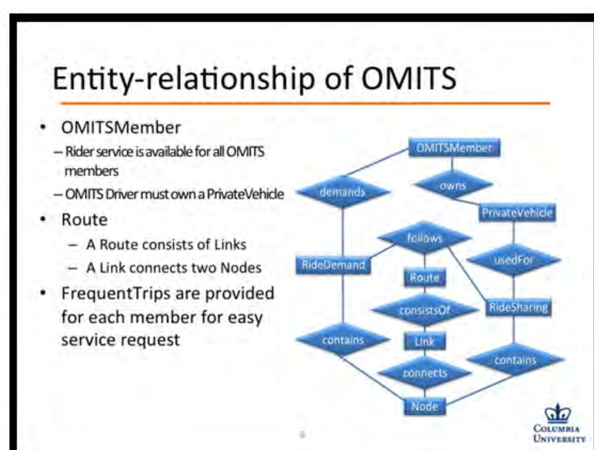
The project of OMITS is invited to join at Transportation Research Board (TRB) 92nd Annual conference at Washington DC, and present at the Innovations in Carsharing Operations meeting. The following pictures are the sliders presented in the conference.





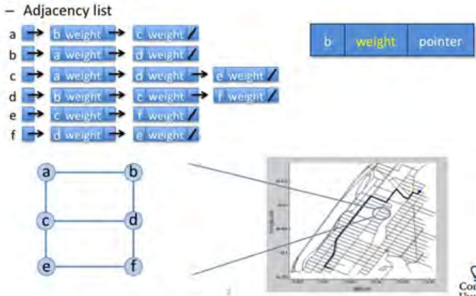






Roadway network data structure

- Roadway network
  - Adjacency list



Dynamic shortest routing algorithm

function Dynamic Dijkstra (*Graph, source, destination*):

. . .

timeCost[v]=timeCost[u]+ timeCost_between(u,v,timeCost[u]) ;

//the time cost between u and v is depend on the departure time. In OMITS dynamic map system, the dynamic edge weight will be listed in the table.//

. . .

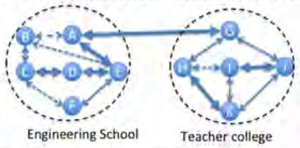
b	weight	pointer

The weight is time-depend value

Departure time	Time cost between u,v
6:00	3 min
6:10	3 min
6:20	4 min
6:30	6 min
6:40	8 min
...	...

Social network-based grouping

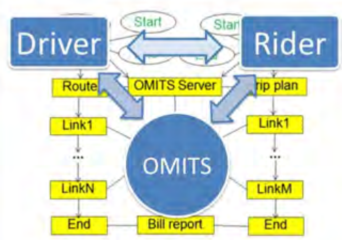
- There is no difference between Social network and Roadway network



Relationship	Weight	Symbol
Neighbor	1	
Coworker	1	
Friend	2	
Ride-sharer	3	

- Appling Dijkstra Algorithm in social network
  - The shortest relationship between two person
  - Minimizing the sum of weight values in one carpooling vehicle
- Reducing the opportunity to be a "stranger"
- Enforcing the relationship after each ridesharing service

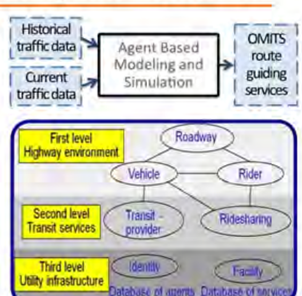
Urban ridesharing service



- Urban Ridesharing Service for the daily commute
- Automatically and Rapidly

Agent Based Modeling and Simulation

- Traffic prediction based on Historical and Current traffic data.
- Three levels of Agent Based Modeling and Simulation system
  - Sharing data and results between levels
  - More effective for large amount of requirements
  - Reducing repetitious Calculation work



Communication through smartphones

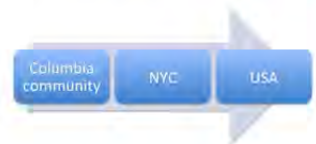
- The OMITS App has been developed for iPhone and Android Phone
  - Communicate with the OMITS server
  - Receive driving directions
  - Submit service requirement
- Detecting roadway traffic conditions
  - Large coverage
  - Real-world spatial distribution
  - No extra construction fee

Who cares?

- City resident
  - Providing efficient and safe carpooling service
  - Reducing travel time for each trip
  - Reducing transport costs
- Governmental agencies
  - Providing organized and detailed traffic data
  - Improving transit operating efficiencies by reducing number of cars
  - Increasing transit ridership of public transit system
  - Cutting down oil consumption for nation energy safety
  - Improving urban environment

What is the next?

- R&D
  - Optimize system structure
  - Improve algorithm
  - Data communication
  - Social network
- Operation
  - Optimize system
  - Transit service
  - Information service
- Scale up
  - User number
  - Database
  - Algorithm



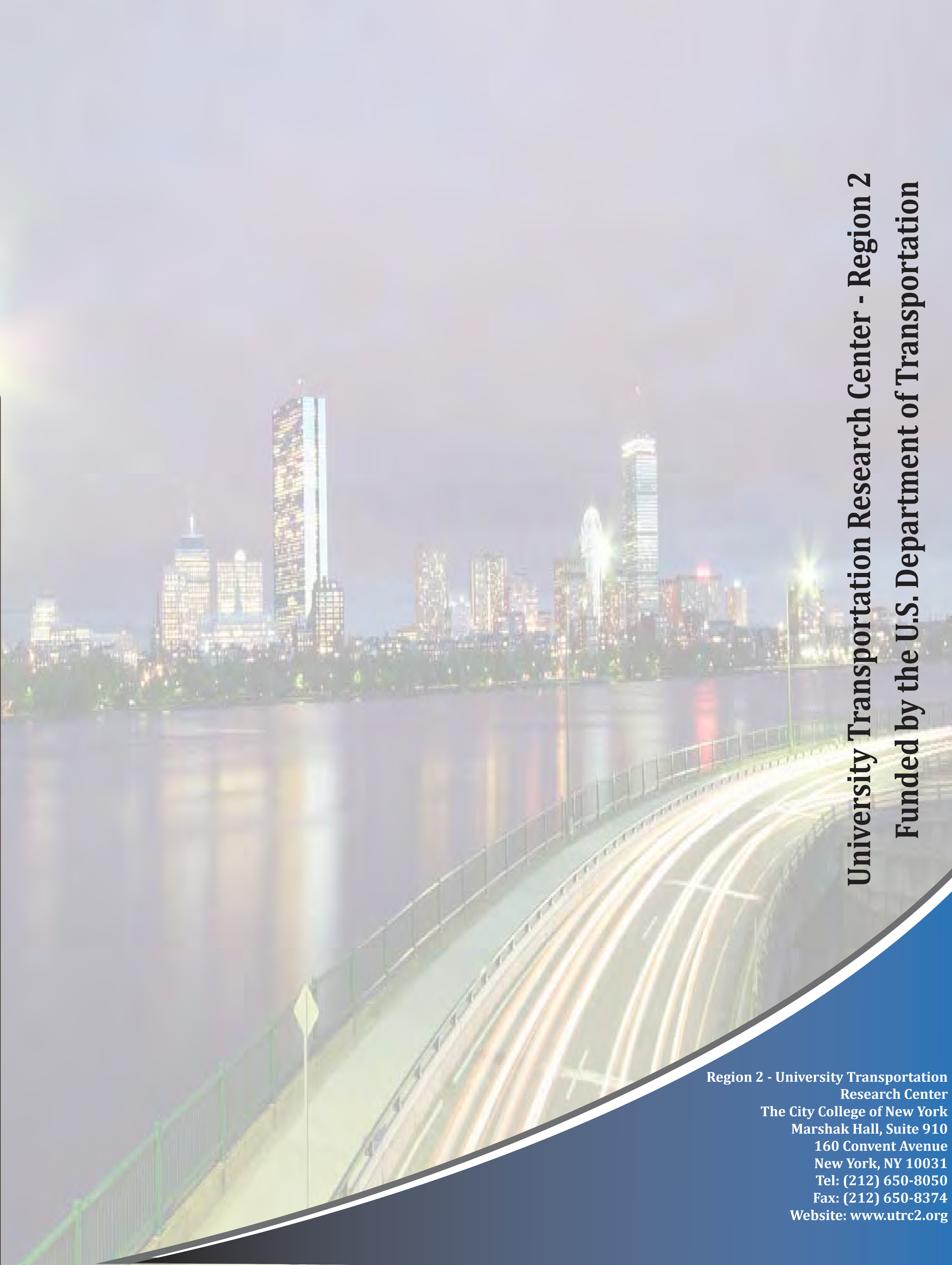
About us

- Cooperation project of Columbia University and NDJ Sustainable Engineering LLC.
- This work has been sponsored by the DOT-UTRC Region II and the RISE Fund of Columbia University
- OMITS webpage: http://www.ndjse.com/omits.php

Dynamic Transit Service through the Open Mode Integrated Transportation System

Welcome to join OMITS

http://www.ndjse.com/omits.php
lw2451@columbia.edu



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