University Transportation Research Center - Region 2

Final Report

Social Network Based Dynamic Transit Service through the OMITS System

Performing Organization: Columbia University

February 2014

Sponsor:
University Transportation Research Center - Region 2

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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.

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16. Abstract

The Open Mode Integrated Transportation System (OMITS) 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 agent based modeling and simulation (ABMS), the time and spatial limits of traditional transportation system can be overcome by appropriately integrating new information communication technologies into transportation services.

This project extends OMITS to social network based applications for dynamic transit service, which uses emerging information and communication technologies, including smart phones, Internet services, GPS/GIS, and database, to optimize the transportation system for improved riders' experience and traffic mitigation. With the aid of the social network based OMITS App, the vehicles serve as probes for the real-time speed of the roadway network. The operation 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. The OMITS App, running on an iPhone or Android smart phone, communicates among the OMITS server, riders, and drivers, detecting roadway traffic conditions and providing driving directions. Using traffic prediction model based on the historic and real-time traffic data, the system provides the optimal routing direction and recommend ridesharing group.

In addition, the recent theoretical research on traffic accident detection, which is a fundamental component of ABMS, has been introduced. The new method focuses on the special tendencies at the downstream and upstream traffic flow in a traffic incident. The improved GIS spatial autocorrelation algorithm is introduced into the new traffic incident detection method.

As a case study, the OMITS system has been proposed to serve the Columbia University community through the campus bus system. CU-OMITS is designed for Columbia University Bus Line – Medical Center to Fort Lee. It includes the services of reservation, bus real-time supervision and bus security management. The Vehicle Information Service Assistant (VISA) emerges as an indispensable requisite to provide real-time data services between the server and the vehicle. CU-OMITS forms an intelligent, safe and reliable school bus service management platform.

17. Key Words	18. Distribution Statement
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SOCIAL NETWORK BASED DYNAMIC TRANSIT SERVICE THROUGH THE OMITS SYSTEM

Final report

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Executive Summary: The Open Mode Integrated Transportation System (OMITS) 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 agent based modeling and simulation (ABMS), the time and spatial limits of traditional transportation system can be overcome by appropriately integrating new information communication technologies into transportation services.

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Keywords: Social network, dynamic transit service, smart phone, GPS, GIS, agent based modeling and simulation, intelligent transportation system, and traffic incident detection

1. Introduction

Traffic congestion has imposed tight constraints on economic growth, national security, and mobility in metropolitan areas [1,2]. 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 in traffic jams. The problem is especially dire in major metropolitan areas. The traffic demand drastically exceeds design capacity, but at the same time, the rate of single occupancy vehicles is extremely high. Several problems have drawn significant attention from researchers and practitioners, such as increasing traffic congestion, transportation delays, volatile gas prices, vehicle emissions and security threats [3].

The Open Mode Integrated Transportation System (OMITS) provides effective, convenient, dynamic and secure carpooling and vanpooling services for metropolitan areas [1]. The system includes the advantages of a traffic road simulation system, Agent-Based Modeling and Simulation (ABMS), an innovative social network management system and an effective information communication technique. The fundamental technical bases of OMITS are the wireless communications, Internet services, global positioning systems (GPS), geographic information systems (GIS) and large-scale database systems. These technologies create an opportunity to OMITS to integrate our transportation system with higher levels of intelligence, efficiency and sustainability.

OMITS has been proposed in 2009. OMITS has constructed a practical web platform which includes computing, smart phone and data terminals. Using the OMITS App, which is run on a smart phone terminal including iOS or Android, customers can communicate with the OMITS server, detect roadway traffic conditions, and receive driving directions [4, 5]. With the aid of its traffic prediction model, the system can analyze the historic and real-time traffic data; which are utilized in the optimal routing direction and ridesharing group calculations. The success of this system essentially forms the effective information communication, accurate prediction of traffic conditions, and comprehensive understanding of transit customer behavior and traffic flow dynamics.

Transportation demand and transit service availability vary greatly over spatial and time domains depending on the real-time traffic condition, thus, it is difficult to predict the traffic situation in a complex road-net. Moreover, the traffic condition changes promptly with time, so a good solution for the current situation could become a poor solution soon thereafter. As a result, it is hard to find a reliable route instruction for each participator of this system. The goal of ABMS in the OMITS is to mimic the highway traveling environment, allowing predictions of traffic conditions. The ABMS recommendations are based on historic data, stochastic process, and real-time traffic data, thereby it can predict the traffic situation and provide for an optimal travel decision.

ABMS is an advanced modeling approach to simulate the actions and interactions of autonomous agents and their effects on the system. Complex phenomena can be understood as systems of autonomous agents following rules of interactions [6,7]. The models simulate the concurrent operations of multiple agents, with an effort to represent and analyze the presentation of complicated phenomena. The concept has been first proposed by John Von Neumann, agent-based modeling has been applied to a broad range of scientific domains including, but not limited to, biology, ecology, social science and computer science. In a transportation system, an agent often refers to a driver or a traveler. The ABMS approach allows one to recreate and forecast a complex problem beyond the reach of conventional modeling tools. Particularly, this feature allows ABMS to be superior in modeling the following situations [8]: 1) The interactions between agents are complex, nonlinear, discontinuous or discrete; 2) Space is crucial and agents' positions are flexible; 3) Population is heterogeneous and each individual possesses different characteristics; 4) The topology of the interactions is complex; 5) Agents exhibit complex behavior, especially involving learning, interactions and adaptation.

More specifically in transportation systems, complicated traffic networks can be simulated as systems of autonomous drivers/travelers that follow certain rules of route choices. With continuously increasing computer power, agents' behavior can be simulated in large transportation networks and the dynamic feature of transportation systems can be modeled, which is out of range of pure mathematical methods. Different from traditional methods where entities follow a sequence of processes defined from the top-down system perspective, ABMS defines the local behavior rules of each agent from a bottom-up perspective. Upon sufficient understanding of underlying behavior factors, simulation reveals the emerging behavior of a system as a whole. ABMS has been applied across a spectrum of areas in transportation. These applications divide into two methodological paradigms [8]: individual-based models that study personal transportation-related activities and behavior, and system and computational methods (Multi-Agents System) to study a collaborative and reactive transportation system by modeling autonomous decision-making by a collection of subsystem entities called agents.

Individual-based models evolve from activity-based travel demand models and display a similar architecture, which combines travel activities and network loading into a simulation platform. The main application of these individual-based models is simulation-based dynamic traffic assignment (DTA) approach. (e.g. Transportation Analysis and Simulation System (TRANSIMS) [9,10]; Dynamic Network Assignment for the Management of Information to Travelers (DynaMIT) [11]; Dynamic Urban System for Transportation (DynusT) [12]. In today's literature, the individual-based transportation systems have the distinctive feature of integrating three components: multidimensional activity decisions, route choices and micro-simulation.

Multi-Agents System (MAS) is featured as a powerful computing technology where the existing distribution allows for breaking down the complex system into multiple subsystems. The subsystems interact with each other under certain local patterns to achieve an expected global goal. MAS has been applied to a variety of traffic and transportation problems [13,14]. The main applications of MAS are modeling and simulation [15-17], traffic control [18-20], traffic management frameworks [18,20,21], dynamic routing [21,23] and congestion management [24].

Traffic congestion can be broadly classified as recurrent or non-recurrent based on its relation with daily variation of traffic demand [25]. The former one is caused by the unbalance between traffic demand and road network capacity. The latter one, non-recurrent traffic congestion, results from traffic incidents such as accidents, vehicle breakdowns or any other incident that impedes the normal flow of traffic. Comparing with recurrent traffic congestion, the non-recurrent traffic congestion has more effects on the accuracy of short time traffic prediction and also citizen's daily lives.

Effective detection of traffic incidents is of extreme importance for maintaining a higher level of service for road users. First, car accidents are a leading cause of death in the city [26]. A real-time and active incident detection can save lives by decreasing the time required for information to reach emergency responders [27,28]. Second, through the geographic messaging service (GMS) system, the traffic incident information such as location, affect region and period, etc. can be informed to drivers by Short Messaging Service (SMS) and Multimedia Messaging Service (MMS)[25,29]. Then some of the drivers will choose the alternative road to reduce the impact area and the duration caused by traffic incident.

Traffic Incident Detective Systems (IDS) use a variety of technologies to detect incidents so that bottlenecks created by incidents can be cleared quickly and appropriate alternative measures can be implemented. Based on the Operational Mode of IDS, there are two main modes of IDS, witness detection IDS mode, and automatic IDS mode [30]. The witness mode framework is illustrated in Figure 1. When a traffic incident happens, witnesses may send the incident information to the traffic management center by voice, short message and picture. The center confirms the location and the nature of the traffic incident, and organizes the rescue schemes and releases information to road users to avoid secondary accidents. Although the witnesses' mode has been used in a lot of cities, there are many disadvantages, such as low Detection Rate (DR), high False Alarm Rate (FAR) and long average delay time between the real time of the traffic incident and the detection time [31].

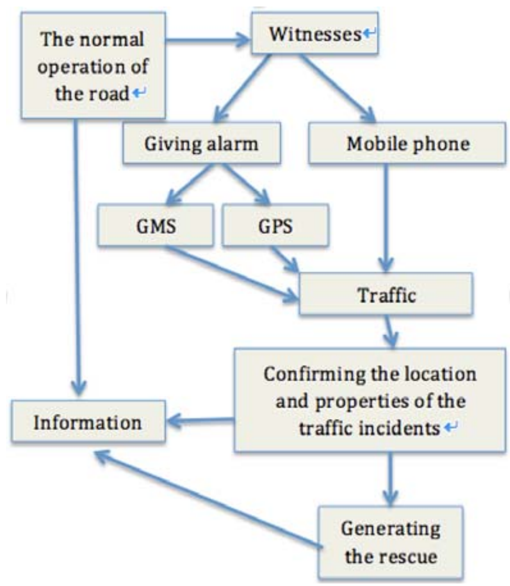


Figure 1 Witness detection mode framework

Compared with the witnesses detection mode, the automatic traffic incident detection mode framework is much more effective. The structure is illustrated in Figure 2 [30]. The traffic sensor will detect the traffic incident signals, and submit to the database. Computers reorganize and analyze the signals in GIS platform. All the determined traffic incident information will be sent to the Traffic Message Channel (TMC) automatically. There are lots of traffic sensors used in the IDS. Based on the taxonomy of traffic sensor types, IDS could also be separated into several subsystems, including loop detector, radar, video, license plate readers, radio-frequency identification transponders, Bluetooth, wireless sensors, and GPS. The aim of this section is to provide an algorithm that applies GPS in smartphones to detect and locate traffic accidents. Smartphone operating systems such as the iOS and Google Android have become common and their usage is rapidly increasing. This large and growing base of smartphone users presents a significant opportunity to extend the reach of the effective IDS detective tool.

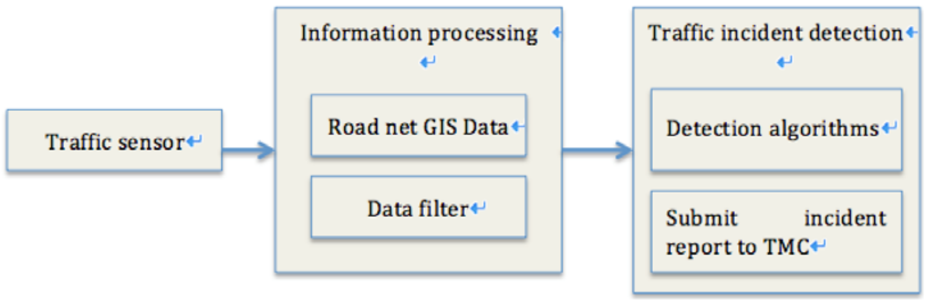


Figure 2 Automatic traffic incident detection mode framework

Current IDS research work focuses on three parts: the first is the traffic jam and waiting line generation simulation [32,33]; the second is traffic incident automatic report system construction [28]; and the last one is multi-mode sensors and relevant systems [26,27]. Almost all of the IDS studies focus on the incident location and upstream road section, but ignore the incident's affect on the normal traffic situation.

This project fits well with UTRC's Research Focus Areas 1 and 3. Using emerging communication technologies, we can understand and improve multi-modal transportation safety and sustainability. Through the collaboration with NDJ Sustainable Engineering LLC, this project will provide reliable, safe, efficient, and economic transit service to the public and produce broader positive impacts on gasoline use, greenhouse gas emissions, city parking, and traffic congestion in the New York Metropolitan area. It can be extended to other areas of the U.S. and other transportation services.

2. Research objectives

This Faculty Initiated Research Project introduces the social network feature into a small scale prototype system of the OMITS in the New York City metropolitan area and investigates a traffic incident detecting mechanism with the following technical objectives:

1) Document the design and implementation of a social network based OMITS software package.
2) Develop automatic traffic incident detection methods with traffic data for OMITS

3) Explore the scalability of the OMITS system and future applications

To achieve the research objectives, the research team has conducted theoretical studies on traffic incident detection and worked with the Columbia Transportation Office to apply the OMITS system for seat reservation and school bus management. The next section analyzes the spatial phenomena and characters of traffic incident, and provides an improved GIS spatial analysis method for IDS. Then the current research and development of CU-OMITS will be reported.

3. Traffic incident detection method

3.1 Different traffic situations on upstream and downstream sections

Upstream and downstream sections of one incident location have different phenomena. Figure 3 demonstrates a typical traffic incident. After one incident, the capacity of the incident location decreases suddenly. As a result, the traffic flow through the incident location is restricted. The traffic jam and waiting line occur at the upstream side of the incident location, while at the downstream section, the traffic flows from the upstream side decrease after the incident. So the downstream traffic situation and service level are "better". Figure 3 demonstrates the different effects by incident at upstream and downstream sections.

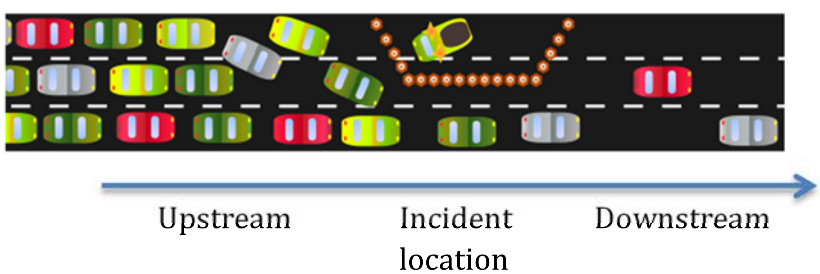


Figure 2 A typical traffic incident

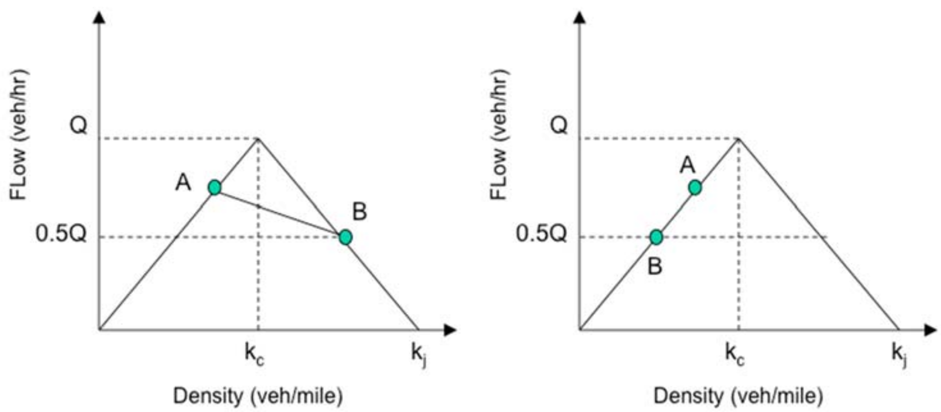


Figure 4 Flow-density relationship. upstream road section(Left), downstream road section(Right)

Figure 4 describes a relationship between traffic density and flow on a road section of highway with two lanes in one direction. The peak capacity of flow is Q vehicles per hour, corresponding to a density of k_c vehicles per mile. The maximum value of density is k_j vehicles per mile. Now, suppose that at a certain location on a highway, one of the two lanes is blocked by a traffic accident. The maximum capacity is decreased to 0.5Q, since only one lane of the two is available. Assume the traffic occupancy before the accident is point A, and after the traffic accident is point B. Figure 4(left) shows the changes caused by the incident in the upstream section. Theoretically when the traffic flow is lower than 0.5Q, the traffic accident has limited effect on traffic flow if we ignore the effect of speed decrease by vehicles lane changing. But if the traffic flow before the incident is higher than 0.5Q that is the road maximum capability, the density will increase to point B and the length of traffic waiting line will also increase by time. Figure 4(right) presents the changes in the downstream section caused by the traffic incident. Because the maximum flow capability in the downstream section is still Q. Because after the incident, the maximum traffic flow from the upstream section will drop to 0.5Q, the traffic density of the downstream section will decrease to the density value of point B.

We also notice that different traffic situations will have different results after the traffic accident. For example, one accident happens at midnight. Although part of the lane is blocked, the traffic incident does not affect traffic flow. This kind of traffic situation is described as point A’ in Figure 5. The traffic flow is much lower than the max capability even when the traffic incident blocks one lane. The traffic flow in the upstream and downstream sections changes little in this kind of situation.

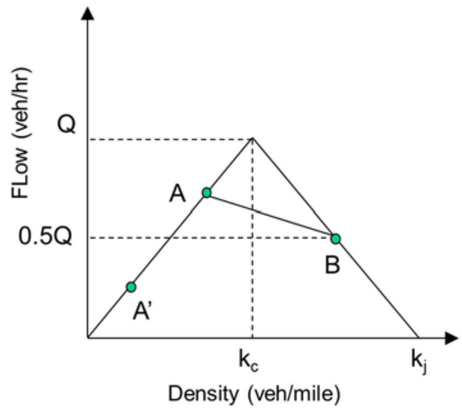


Figure 5 Flow and density relationship

In conclusion, the traffic incident will change the traffic situation, especially when the traffic flow is high. At the upstream section, the traffic situation tends to be worse after the incident, while it will be better at the downstream section. Consider the Tobler's first law of geography [37]: Everything is related to others in the network, but the effects from the neighborhood are stronger than those from the distance. So before an incident happens, the traffic situations of the upstream and downstream sections should not have a significant difference. Table 1 lists the traffic situations of equilibrium at the upstream and downstream sections. US and DS represent upstream and downstream sections. "H" and "L" describe traffic situation. H means the traffic demand is close or over the capability of the road section, and "L" means the traffic demand is much lower than road capability. The last two columns in Table 1 describe the situation of point A' in Figure 5. Theoretically, the probability of the situation that US: H->H DS: H->H exists, but it is beyond the scope of this work as the traffic totally stands still, and the traffic flow decreases to zero. Notice that the "H" and "L" have only qualitative meanings to describe traffic situations. The next section will introduce a digital geographic platform and algorithms to obtain the quantitative results, which can be used in in a practical road-network system.

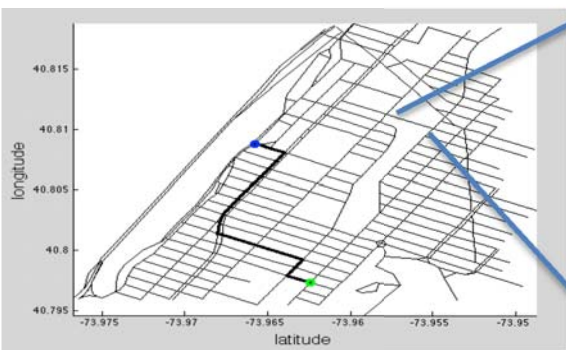
Table 1 Traffic situation changes at upstream and downstream sections

	US	DS	US	DS	US	DS
Before	H	H	L	L	L	L
After	H	L	H	L	L	L

3.2 Digital geographic platform

A digital geographic system of traffic has three platforms: road-net, road section and point [28]. The main characteristics and relationships among them are shown in Figure 6. The road-network belongs to the macro scale analysis, which is usually applied in traffic planning or city planning research. The point level analysis is also called as Cellular Automation Method [34].

Traffic Incident Detection works on the road section level. The parameters of the traffic situation are time dependent, so in the database, an extra dimension space is required to store the traffic situation data.



#	Name	Type
1	laneID	int(11)
2	latitude_1	double
3	longitude_1	double
4	latitude_2	double
5	longitude_2	double
6	maxSpeed_F	int(3)
7	maxSpeed_T	int(3)
8	direction	int(1)
9	numberOfLane_F	int(2)
10	numberOfLane_T	int(2)

#	Name
1	NODEID
2	NODENAME
3	LNG
4	LAT
5	STREETADDRESS
6	CITY
7	STATE
8	ZIPCODE

Figure 3 Digital geographic platform and hierarchy for traffic incident detection

3.3 Traffic data and parameters

As it is well known, traffic incident will change traffic situation. In order to find out the location of the traffic incident, the historical and real-time traffic data are required. Since the traffic incident is a small probability event, the average value of the parameters in the historical data could be used to present the traffic situation without incident. When real-time traffic data is very different from the historical one, we can tell that there is a high probability that a traffic incident happens.

There are a lot of traffic sensors used to collect traffic data, including loop detectors, radar, video, license plate readers, radio-frequency identification transponders, Bluetooth, wireless sensors, and GPS. Different detective sensors generate traffic data of different parameters. Although the parameters have different units and definitions, all of them can describe the traffic situation. With the concept of Spatial Autocorrelation Theory, all parameters are required to transfer into the standard “H” and “L” index system. In the highway traffic incident detective analysis, “H” means the traffic situation in a congested flow, while “L” means the traffic situation in an uncongested flow. In the city traffic incident detective analysis, “H” means the traffic demand is close or over the maximum traffic infrastructure capability, “L” means the traffic demand is much lower than the infrastructure capability [27,35].

Some details of the “H” and “L” index system need to be explained in traffic incident detective analysis. Firstly, based on Spatial Autocorrelation Theory, “H” and “L” are not continuous. When the gap between “H” and “L” is large, the detective sensibility is low, and the accuracy is high, which may result in the ignorance of minor traffic incidents. Secondly, the meaning of “H” and “L” should be adjusted with different road-network systems, different sensibility requirements and different traffic parameters.

There are four traffic parameters used the most in city traffic incident detection analysis:

3.3.1 Occupancy

Occupancy of a sensor is the fraction of time when the detection zone of a sensor is occupied by vehicles during the testing period. Inductive loops, magnetometers, microwave radars and video detection systems provide this measurement. In the case of radars and video, it is possible to configure multiple detection zones (of variable sizes) and measure traffic occupancies simultaneously.

3.3.2 Volume

Volume is defined as the total number of vehicles that pass over the detection zone of the sensor during a chosen interval of time. Inductive loops, magnetometers, microwave radars and video detection systems provide direct measurement of volume counts. Annual average daily traffic (AADT) is a measurement used primarily in transportation planning and transportation engineering. It is the total volume of vehicle traffic of a highway or road for a year divided by 365 days. Sometime the AADT could provide each hour’s traffic volume on each road section.

3.3.3 Speed

Detectors are also deployed to measure point speeds of vehicles as they pass the detection zone of the sensors. Dual inductive loops/magnetometers, separated by a known distance, are commonly deployed to measure speeds indirectly by noting the activation times of each detector. Video detection systems also employ loop emulation to measure speeds, but new systems are also capable of tracking vehicles. Microwave radars, based on Doppler principle, can directly measure vehicle speeds. GPS on the smartphone could provide real time point speed.

3.3.4 Waiting time on signalized intersection

This data presents the average waiting time on each intersection. Lane design and also the turning rates etc.， although the parameter is affected by the traffic light phase intervals. which could reflect the traffic situation on the road. Portable GPS devices, such as the smartphone, could track each car’s behavior and contribute waiting time on signalized intersection data.

3.4 Weight matrix

In spatial analysis, one of the fundamental works is to obtain space relationship. A Spatial Weights Matrix is defined to describe the spatial neighborhood structure. Based on the first law of Spatial Geographic Theory, the spatial weights matrix is a radiation weight matrix, which means all the directions of the neighbors have equal weights. For example, in Figure 7, the neighbors of 4 are 1, 5 and 7 whose weights are the same. However, the effects caused by the traffic incident are different on upstream and downstream sections. So an improved weight matrix is required in the traffic incident detective analysis.

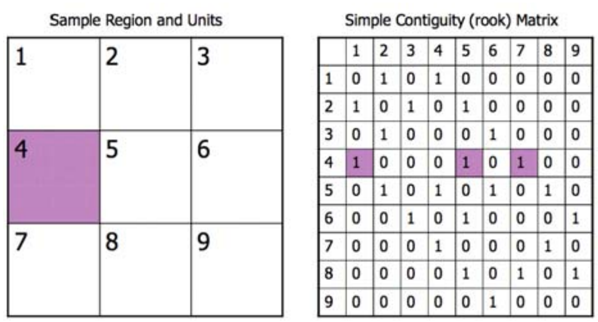


Figure 7 Spatial weight matrix example

To apply to the spatial analysis in the traffic incident detective analysis, upstream and downstream weight matrices are introduced. For highway, the upstream and downstream weight matrices are presented in Tables 2 and 3 respectively for the road sections shown in Figure 8. The values in the tables describe the spatial relationship. For example, Table 3, the third row’s value at section 4 and 5 are 0.5, which illustrates that sections 4 and 5 are the upstream section of the section 3. In this example, the two neighboring sections are considered as the neighbor upstream/downstream sections. The weight depends on the average length. In a fine meshed highway, more neighboring sections could be considered.

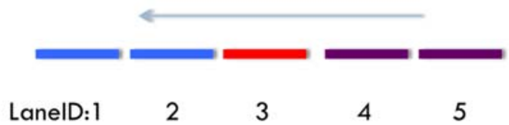


Figure 8 Highway road sections

Table 2 Upstream spatial weight matrix

Lane ID	1	2	3	4	5
1	0	0.5	0.5	0	0
2	0	0	0.5	0.5	0
3	0	0	0	0.5	0.5
4	0	0	0	0	0.5
5	0	0	0	0	0

Table 3 Downstream spatial weight matrix

Lane ID	1	2	3	4	5
1	0	0	0	0	0
2	0.5	0	0	0	0
3	0.5	0.5	0	0	0
4	0	0.5	0.5	0	0
5	0	0	0.5	0.5	0

In the city road-network, the situation is more complex. The values in the upstream and downstream weight matrices describe not only the spatial relationship, but also the distribution of traffic flow. For example, there are two intersections in a city road network in Figure 9. The arrows show the directions of traffic flow. If one lane has two directions, each direction has an individual lane ID. Assuming that the horizontal lane 9, 4, 1 is the main artery. So turning rate from the vertical direction to the main artery is 0.25, whereas that from the main artery to the vertical direction is 0.07. The traffic flow is on the main artery is 5 times of the vertical direction. One neighboring section is considered. The upstream and downstream weight matrixes are presented in Table 4 and Table 5. Take row 4 in the upstream weight matrix for example. The values of lane sections 6, 8, and 9 are 0.05, 0.05 and 0.90, respectively, which means the upstream traffic flow of lane 4 comes from lane 6, 8 and 9, and the flow contributions for lane 4 are 5%, 5% and 90%.

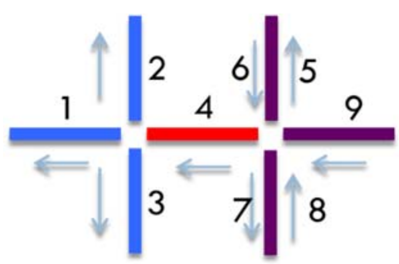


Figure 9 Road network with two intersections

Table 4 Upstream weight matrix

Lane ID	1	2	3	4	5	6	7	8	9
1	0	0	0	1	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0
3	0	0	0	1	0	0	0	0	0
4	0	0	0	0	0	0.05	0	0.05	0.90
5	0	0	0	0	0	0	0	0.59	0.41
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0.59	0	0	0.41
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0

Table 5 Downstream weight matrix

Lane ID	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0.86	0.07	0.07	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0.25	0	0	0.75	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0.25	0.75	0	0	0	0
9	0	0	0	0.86	0.07	0	0.07	0	0

3.5 Local Indicator of Spatial Association

Local Indicator of Spatial Association (LISA) is applied in this traffic accident analysis. Based on L. Anselin’s description, LISA could be any statistic that satisfies the following two standards: (a) the LISA for each observation gives an indication of the extent of significant spatial clustering of similar values around that observation; and (b) the sum of LISAs for all observation is proportional to a global indicator of spatial association [42].

In the traffic accident analysis, traffic situation parameters will switch to “H” and “L” index. Although the parameters of traffic situation are different, all of them can describe traffic situation properly and independently. By reasonably defining a criterion of switching them into “H” or “L” index, the system can meet the first standard of LISA. This traffic incident analysis system also satisfies the second LISA standard, since the upstream and downstream have very clear spatial definition. Although the “spatial” meaning has a slight difference between traditional spatial and traffic accident detective analysis, LISA is eligible for traffic incident analysis.

The general term of LISA is defined as

$$L_i = f(x_i, x_{J_i}) \tag{1}$$

Where f is a function, x_i is the values at region i, and x_{J_i} is the value observed in the neighborhood J_i of region i.

L_i should be such that it is possible to infer the statistical significance of the pattern of spatial association at region i [38,42]. More formally, the requires the operationalization of a statement such as

$$Prob[|L_i| > \delta] \leq \alpha \tag{2}$$

where δ is the critical value, and α is a chosen significance or pseudo significance level.

The Local Moran's I is the most general LISA expression in spatial analysis [38,41]. The purpose of Local Moran's I is identifying the significant cluster or significant dispersion region at a significance level. And the definition is given by

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^{n} \omega_{i,j}(x_j - \bar{X}) \tag{3}$$

where x_i is an attribute for region i, $\bar{X}$ is the mean of the corresponding attribute, $\omega_{i,j}$ is the spatial weight between region i and j and

$$S_i^2 = \frac{\sum_{j=1, j \neq i}^{n} \omega_{i,j}(x_j - \bar{X})}{n-1} \tag{4}$$

where n denotes the total number of features

The value range I_i is from -1 to $+1$. A positive value for I_i indicates that the region i has neighboring regions with similarly attribute values. If I_i is very close to 1 and x_i much larger than $\bar{X}$, we consider region i is a statistically significant cluster of a high value (noted as H-H); Contrarily, if I_i is very close to 1 and x_i is much smaller than $\bar{X}$, we consider region i is a statistically significant cluster of a low value (noted as L-L). Similarly, a negative value for I_i indicates that this region i has neighboring regions with dissimilar values. If I_i is very close to -1 and x_i much larger than $\bar{X}$, we consider region i is a statistically significant dispersion of a high value (noted as H-L); and if I_i is very close to -1 and x_i is much smaller than $\bar{X}$, we consider region i is a statistically significant dispersion of a low value (noted as L-H).

In general spatial research, LISA helps researcher to overall understand the interest attribute distribution of all regions, and finds the significant cluster and significant dispersion region. However in traffic incident analysis, researchers want to find the location of traffic incident. In other words, comparing with the traffic parameters distributions, identifying the special phenomenal of traffic parameter changing is more important. As a result, the traffic incident detective method employs the traditional spatial Autocorrelation method concept but not the Local Moran's I directly. Based on the analysis of characteristics of traffic flow, research should generate a reasonable criterion for traffic parameters switching to LISA cluster index. When the criterion has a large gap between "H" and "L" physical meaning, which indicates that the significant value α in Equation 2 is large and the detective sensibility is low.

Considering two groups of traffic data (historical and real-time traffic parameters) and two weight matrixes are required to compare, there are four result values for each road section. Two of them describe traffic situation without incident, and two of them present the real-time traffic situation. Table 6 lists all the possible traffic situations, where the UW and DW mean the upstream weigh matrix result and downstream weigh matrix values. If the situation without incident is H-H (UW) and H-L (DW), this method does not work. But this scenario is very rare, because traffic situation is usually continuous in the real life.

Table 6 Traffic incident location characteristics

	UW	DW	UW	DW	UW	DW	UW	DW
No accident	H-H	H-H	H-L	H-H	H-H	H-L	H-L	H-L
Accident	H-H	H-L	H-H	H-L	H-H	H-L	H-H	H-L
	UW	DW	UW	DW	UW	DW	UW	DW
No accident	L-H	L-H	L-L	L-H	L-H	L-L	L-L	L-L
Accident	H-H	H-L	H-H	H-L	H-H	H-L	H-H	H-L

If there is not enough real-time traffic data near the incident location, we can analyze the potential region of incident location. If the traffic situation is worse or tends to demonstrate congestion symptoms, the potential traffic incident locates at the downstream side. If the traffic situation is better, the potential traffic incident locates at the upstream side. With the support of other detective devices, we can find out the exact incident location on the potential region.

3.6 Experiment

3.6.1 Introduction

The experiment location is Broadway 125th street to 108th street, with the direction from South to North, Manhattan. The total length is 1.0 mile. There are 19 intersections on this research road-network. The typical intersection is 6 lanes on the Broadway and 2 lanes on the streets. The basic information of the road-network is showed in Figure 10.

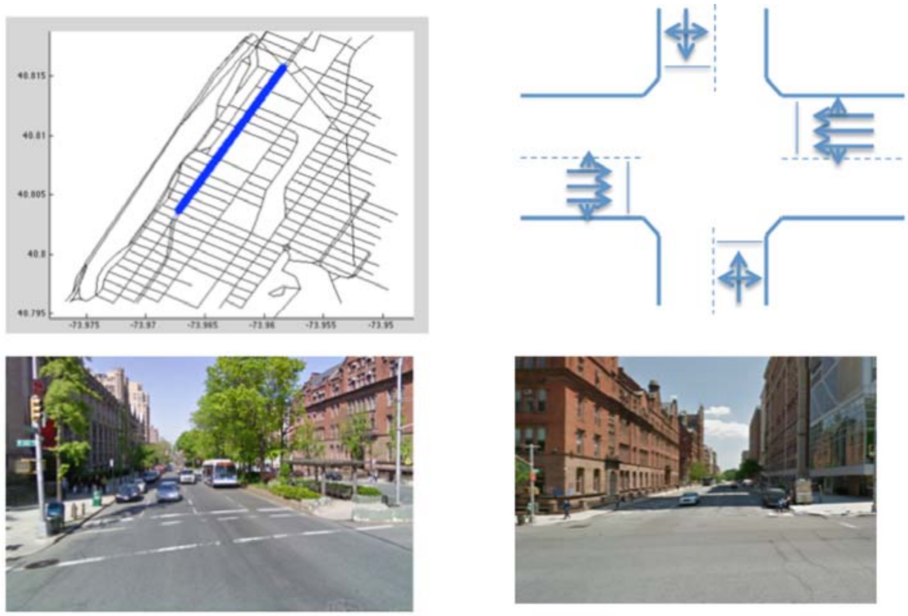


Figure 4 Experimental road information (top-left) research road's position in city road network; (top-right) typical intersection on the experimental road; (bottom-left) Broadway road photo; (bottom-right) street road

To calculate the capacity on this intersection, the following assumptions are used: The proportion of vehicle types is 2:8 (bus and freight vehicle ： passenger vehicle). The traffic light period is $T_c = 90$ seconds, the green signal phase on the Broadway is $t_g = 45$ seconds. Left turning rate is $\beta = 15\%$. Wasting time during the green signal phase $t_0 = 2.3$ seconds, which includes the driver's reaction time, acceleration time etc.

Each straight lane capacity is:

$$C_s = \frac{3600}{T_c} \times \left(\frac{t_g - t_0}{2.65} + 1\right) \times 0.9 = 616(pcu/h) \quad (5)$$

where pcu denotes passenger car unit. It is a vehicle unit used for expressing the impact of a mode of transport on traffic variables (such as headway, speed, density). For example, a car, a taxi and a pick up equals 1.0 pcu ; a bus and a truck equals to 3.0 to 8.0, based on the characteristics of the vehicle, such as size, acceleration, minimum turning radius, etc. Large value of pcu means this type of vehicle has more impact for traffic flow than small pcu value vehicle [39,40].

Because there is no special lane for the right and left turns, the left turning lane capacity is

$$C_{SL} = C_S\left(1 - \frac{\beta}{2}\right) = 616 \times (1 - 0.15/2) = 570(pcu/h) \quad (6)$$

The Broadway direction capacity (one direction) is

$$2 \times C_s + C_{SL} = 2 \times 616 + 570 = 1802(pcu/h) \qquad (7)$$

3.6.2 Data analysis

Annual Average Daily Traffic (AADT) is traffic situation without incident. The criteria for AADT transferring into "H" and "L" index are showed in Table 7. For the experimental road, the traffic volume is about 349 vehicles per hour.

Table 7 Traffic situation without incident criteria

	Criteria	Reason
H	> 1186	If traffic accident blocks one lane, traffic jam will happen
L	< 570	Even two lanes are blocked, still fine

An iPhone application is developed to collect the real-time traffic data. The interface is showed in Figure 11. The application can record users longitude, latitude, speed, and time information and store them in a database. The parameter of waiting time on intersection is used in this example. When the speed is lower than 1.5 mile per hour, waiting time begins. The "H" and "L" criteria for the real-time traffic situation are showed in Table 8.

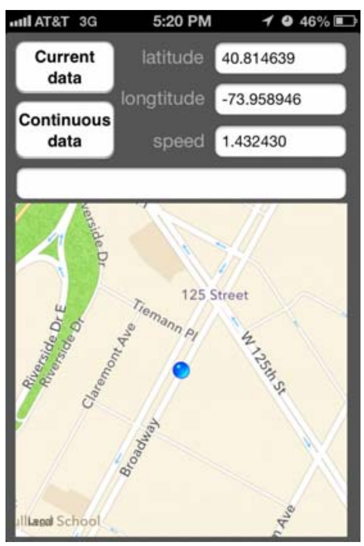


Figure 11 iPhone GPS collection APP interface

Table 2 Real-time traffic situation data criteria

	Criteria	Reason
H	Waiting time over 120 second	One traffic signal loop is less than 90 second, so driver has to wait the second green light.
L	Waiting time less than 90 second	The waiting time less than one green signal period

3.6.3 Experimental result

At the 16th road section occurred a traffic incident, the waiting line covers 3 road sections. The waiting time recorded by iPhone is shown in Figure 12. The traffic situation without incident (AADT) LISA result is showed in table 9(right), the current traffic situation (Waiting time) LISA index result showed in table 9(left). The traffic accident detective result showed in table 9(middle), which means the road section 16 is the location of traffic incident. As a result, five groups of numbers in the green cells contribute to determine the incident location.

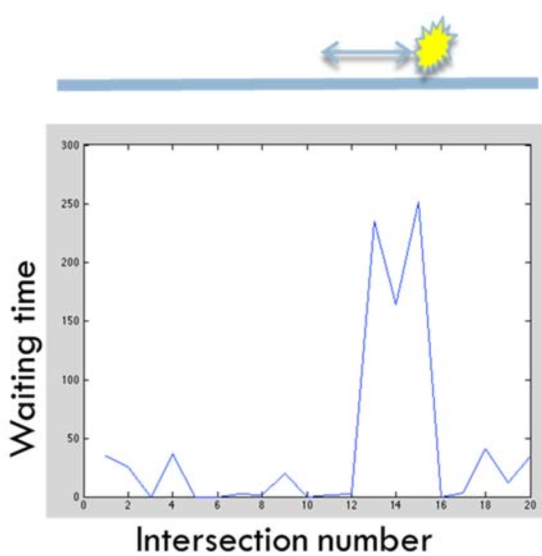


Figure 5 (Top) Traffic incident location and waiting line, (Bottom) Waiting time on each road sections

Table 3 Real-time traffic LISA value(Left); Real-time traffic LISA result(Middle); traffic situation without incident LISA result(Right)

	UW	DW
35	0	25
25	35	36
0	60	36
36	25	0
0	36	2
0	36	3
2	0	21
1	2	20
20	3	1
0	21	3
1	20	237
2	1	399
235	3	415
164	237	251
251	399	3
0	415	44
3	251	53
41	3	47
12	44	53
35	53	

	UW	DW
low	low	low
low	low	low
low	low	low
low	low	low
low	low	low
low	low	low
low	low	low
low	low	low
low	low	low
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high	low	high
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low	low	low

	UW	DW
low		low
low	low	low
low	low	low
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low	low	low
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low	low	low
low	low	

Traffic incident detection is an important part in traffic research. Accurate and real-time traffic incident location with an effective informer system could reduce the effects caused by the incident. The new traffic incident detective method introduced in this article finds out the traffic incident location through the analysis of upstream and downstream sections, which means all the changes of traffic situations around the incident location can help to confirm the location where the incident happens.

4. OMITS Application: CU-OMITS

CU-OMITS has been designed for Columbia University school bus service system, which is based on the OMITS. At this stage, the CU-OMITS is tailored for Columbia University Bus Line – Medical Center to Fort Lee. It includes the services of reservation, bus real-time supervision and bus security management. The Vehicle Information Service Assistant (VISA) emerges as an indispensable requisite to provide real-time data services between the server and the vehicle.

Compared with other private and public transportation, school bus requires higher safety standard, punctuality rate. However, there are a lot of problems on campus bus service. Common people are waiting in a long line at rush hours but there are not enough seats for all the riders. Some passengers who cannot get on bus will have to find alternative ways for transportation. Another problem is the bus cannot accurately operate on schedule, in the low service level of NYC traffic. When a bus is late by a traffic jam, riders cannot check the bus status – whether the bus has problem or is stuck in traffic, how long time they have to wait to get on bus, and when they can arrive at their destinations?

4.1 Architecture of the CU-OMITS

We design the CU-OMITS school bus service system to solve such problems. The way it works including data communication mechanics and Entity-Relationships of CU-OMITS are presented below.

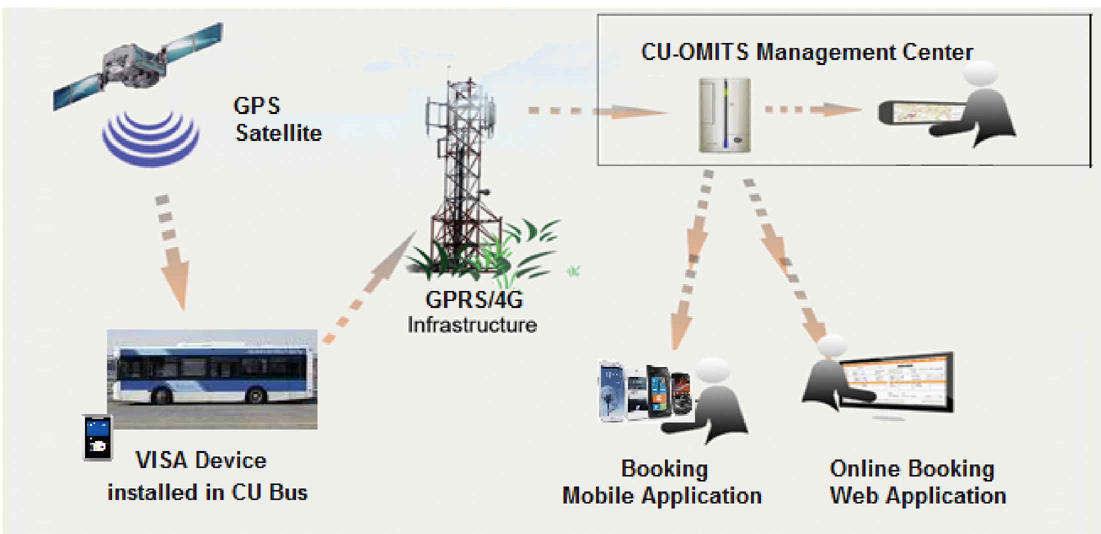

Figure 13 Data communication in CU-OMITS

Figure 13 presents the CU-OMITS data communication mechanism. Based on the CU-OMITS design, a Vehicle Information Service Assistant (VISA) is installed in each school bus. The VISA is able to collect and update the school bus real-time information to CU-OMITS management center through GPRS/4G. CU-OMITS management center will check and track all operating school buses real-time status includes location, speed, voice broadcasts and passenger information. Meanwhile, the management center will provide traffic real-time conditions and optimized routes instructions for bus drivers. The rider can make a reservation, check bus current location and receive bus arrival time report through smart phones or computers. All the data of vehicles and passengers are stored in the CU-

OMITS database. These data are significantly important for bus management and supervision.

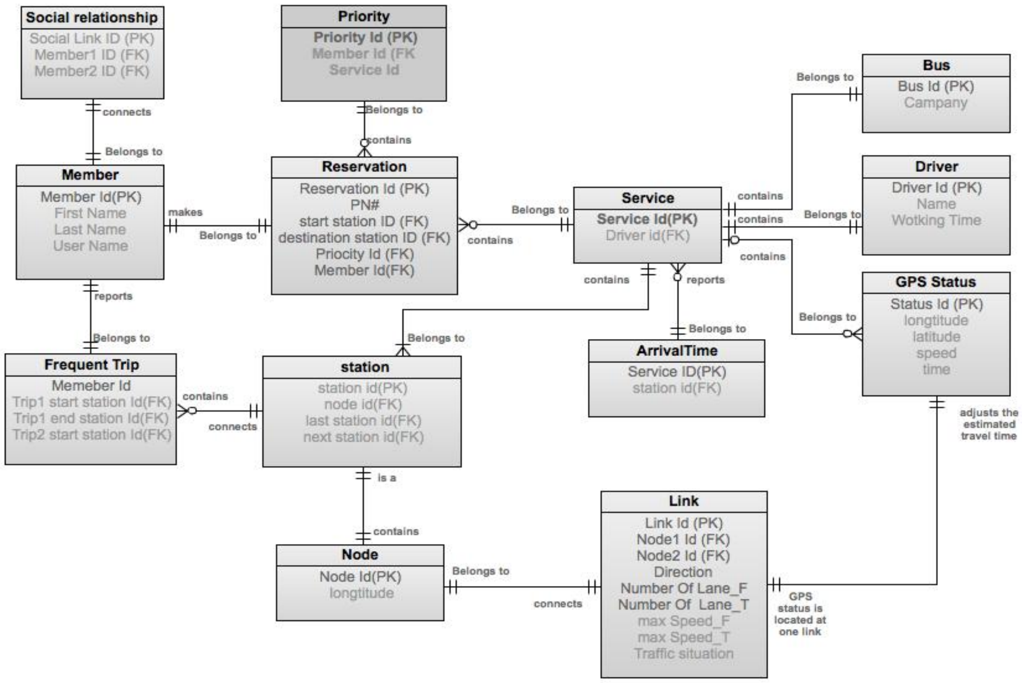

Figure 14 Entity Relationship Diagram of CU-OMITS

Figure 14 illustrates the entity-relationship (ER) diagram of the CU-OMITS system for the design and development of its database. Typically, the road network consists of multiple links. The information of each link is stored in the Table Link including specific speed limit and historic, current and predicted travel time data. The Table Link is directly connected to the ABMS. The traffic situation predictions calculated by ABMS are uploaded into the table instantaneously. At the same time, real-time traffic situation from a Table Link obtained by ABMS will calibrate traffic prediction results. Each item in the Table Link connects two nodes, whose information is stored in the Table Node, which includes node's geographic information and basic traffic character, such as turning restrictions, traffic light phases, etc. The Table Node and Table Link construct the fundamental map and traffic situation data of the OMITS system.

To fulfill the CU-OMITS for different school bus service requirements, there are four key components in this database, which include riders, social relationships, bus services and reservations. All the riders information is stored in the Table Member, including rider's personal basic information and status in school. The Table Frequent Trip belongs to Table Member, and collects each rider's travel records. Social relationship as a special feature of OMITS, which use dynamic Dijkstra Algorithm [36] in social network, and try to construct the best travel experience for all riders. In the Table Social relationship, every two riders' relationships are stored in this table (more information is introduced in the next section). School bus services information is stored in Table Service. Notices that in Table Service, every school service at bus timetable are stored in the Table Service separately. Which means two bus services operate at different time, even if they follow the same school bus service route, should be separately stored in Table Service. Table Service owns Table Bus, Table Driver, Table Stations, Table ArrivalTime and Table GPS Status. When a bus service begins to operate, the GPS device in VISA on the bus starts to upload school bus real-time status to Table GPS Status. The organized real-time GPS data are uploaded into relevant links in Table Link. Then, ABMS can calculate and calibrate the values in Table ArrivelTime. In CU-OMITS, school bus seats are limited, and riders are required to reserve a seat before aboard. All the reservations information is stored in the Table Reservation, which belongs to the Table Member, and contains to The Table Service. The Priority Table belongs to Table Reservation, and keeps the information of reservation rules and restricts.

In this project, only school bus will be considered but significantly larger data will be used. The existing data structure will be tailored for MTA bus time data and will be used in design and implementation.

4.2 Social network-based grouping

To construct friendly and trustable social network for ridesharing, OMITS applies the innovative social network-based grouping method. This method uses dynamic Dijkstra Algorithm [36] in social network to find out the best match between riders and drivers. A small region prototype of social network-based grouping has been tested.

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 15 and table 6 is one example of the social network between School of Engineering and Teachers College 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 Table 10, 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 people, 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.

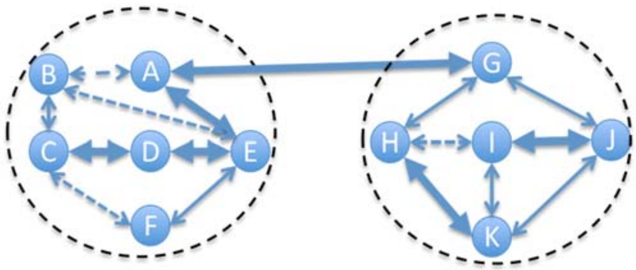

Figure 15 Social relationship network sample

Table 10 Weights of Social relationship network at different relationship

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

4.3 Vehicle Information Service Assistant (VISA)

VISA emerges as an indispensable requisite to provide real-time data services between the server and the vehicle in CU-OMITS. VISA is also a kind of Telematics device, besides its vehicle tracking and wireless data communication services. Figure 16 is a demo of VISA devices.

Figure 16 A demo of VISA

VISA has embedded smart card reader; it's easily to read the rider's Columbia University campus card ID number. By the customization setting, the device can provide voice alert or lighting tips once it successful identifies the rider.

VISA device is triggered to download the passengers booking data from the remote server automatically once the vehicle is turned on.

Once the VISA device gets the booking data from the remote server, it will help the driver to identify all the passengers with the confirmed ID list. By reading the rider's campus card and comparing his or her ID with the white list, VISA would provide voice alert to tell the driver whether the rider is in the white list. Once the In-List passenger is identified, it will pop the voice message to tell the passenger's seat number. If there has space allow more passengers besides the white list to take the bus, the VISA device would give these passengers left available seat numbers. Once the vehicle status changes from stop to running, the VISA device would be triggered to upload the on board passengers data to the remote server since the first stop.

VISA has three LED lights to show the status for its power supply, online communication and the passengers ID verification while it's working. It helps the driver knows the status of the device. Voice alert is triggered while the VISA is identifying passengers' ID card. Verification success or failure will generate different kind of alert voice.

While the VISA is working, its TFT screen will show the related text to the driver. It would help driver and passengers to understand what's happening during the VISA is processing the data. Generally it will display current bus schedule, time, available seat, on board passenger ID or name, white list, etc.

The VISA device supports driver to make voice broadcasts to the all passengers or booked riders. It can record the driver's voice, store it in the local, upload it to the server and send to the rider's handheld device (ex. Smart Phone) through the Internet.

VISA has embedded GPS receiver with wireless communication module to communicate with backed server. It provides a way to monitor the location, movements, status and behavior of the vehicle, and its data will periodically transferred to the remote server.

Based on the tracking data and other management information, the vehicle manager or the passenger will know the location of the vehicle, how fast the vehicle is running, the estimate time for each stop in the route and how many seats still available in the bus.

5. Conclusions and Summary

OMITS is designed for a comprehensive and complex transportation service and management system, which includes several theoretical and practical research topics. It could promote a fair environment for competition and operation of multiple transit modes. This faculty initiative project explored the integration of social network features into the OMITS system and the application of CU-OMITS in the Columbia University community. The hardware and software architecture has been designed and investigated. The operational mechanisms have been tested and validated. An improved method of spatial analysis for traffic incident detection has been developed.

However, there still exist several technical and non-technical barriers to implement the system in the actual operation as follows:

- Due to the dynamic nature of the transit system, the speed, capacity, and stability of the system are critical to the success of applications, which is under investigation.
- It is not easy to recruit enough members for the OMITS system for some reasons, which includes policy, privacy, ratio of return to risks, and safety.
- The operation of this system requires extra human resources and facility support, which is not ready for the research team yet.

The team will continue to pursue the collaboration with governmental agencies and industry partners to change the system for better settings for wide applications. More tests and investigation are underway to secure the system.

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