University Transportation Research Center - Region 2

Final Report

Traffic Prediction Using Wireless Cellular Networks

Performing Organization: New York Institute of Technology

March 2016

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.

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.

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16. Abstract
The major objective of this project is to obtain traffic information from existing wireless infrastructure.
In this project freeway traffic is identified and modeled using data obtained from existing wireless cellular networks. Most of the previous research on freeway traffic control assumes the availability of traffic parameters like vehicle velocity and density. Such data is available only at a few locations on major highways where sensor nodes have been pre-deployed. In practical terms, to build a comprehensive network of sensors for this purpose is prohibitive in terms of the cost involved. However, an existing cellular network of a large wireless provider can be used for collecting traffic parameter information. As mobile devices have become very common, these devices can not only provide traffic parameter data but can also be used to receive real time traffic information using mobile applications. This project uses information obtained from mobile networks to formulate traffic density models.

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Introduction

The control of vehicular traffic to avoid congestion is an ongoing important area of research [1-5]. In most of the literature, the collection of traffic parameters for feedback control is not addressed. It is assumed that the traffic velocity and density (and other parameters, if needed) are available through an array of sensors deployed throughout the length of the highways whose traffic they are intended to control. In practical terms, to build a network of sensors for this purpose is prohibitive in terms of the costs involved.

In this project the collection of traffic parameters is addressed using existing wireless cellular infrastructure. Mobile network providers deploy cell sites along highways to provide seamless coverage while their customers are travelling. As such, the necessary infrastructure already exists on most highways. Mobile devices have become so ubiquitous that we can assume that a majority of the vehicles on the highway have some type of a wireless cellular device. With the advent of third generation (3G) and fourth generation (4G) technology, data usage has grown tremendously, and mobile phones are not only connected to their networks during voice calls, but spend most of the time connected during data sessions, be it active browsing, streaming or accessing background data such as email. As such, using mobile phones for traffic control is relevant and justified.

However, mobile phones do not communicate with the wireless infrastructure (or wireless cell sites) all the time. During the idle state, the devices only observes the network (measuring the signal strength and certain other activities) and do not let the network know of their location except when they cross a location area (LA) and routing area (RA) for GSM and UMTS systems or tracking area (TA) for LTE systems or when it is time for a periodic LA, RA or TA update. These LA's, RA's, and TA's are designed with battery consumption of the mobile user equipment (UE) in mind and are fairly large. Therefore the idle mode UE's cannot be used for parameter collection (except at LA, RA or TA boundaries where all UE's of the network perform a LA, RA or TA update). Furthermore, UE's on highways do not belong to one particular cellular carrier (or wireless service provider). As such, we cannot get a count of all UE's on a highway. Summarizing, the difficulties of using mobile cellular network are

- Idle mode UE's do not communicate with the network.
- UE's on a highway do not belong to a single wireless carrier or service provider. Therefore, an accurate count of UE's present on the highway is not known.

Connected mode UE's (be it a voice call or a data session) on the other hand are communicating with the network. The network knows their location on a cell level and these can be used for estimating the traffic parameters [6]. However, the modeling in [6] considers the total density estimated from the partial density of the connected UE's which is highly unreliable and therefore not usable. Only the measure of velocity from the active users of a particular cell can be considered reliable. In [7] the vehicle density is estimated directly using the partial data set obtained from the users of a particular network. As expected the results are not very accurate.

There are two ways that network providers can measure the velocity of UE's in a cell. One is by measuring the time between handoffs occurring between the two neighboring cells for all connected UE's moving between these two cells. This is a simple method of measuring speed and direction of flow and such measurements can be enabled in a mobile network. The other method is the measurement of speed using the Doppler effect or wavelet transform [8-10]. The Doppler measurements are mostly not collected by mobile service providers. Therefore, we will use the former method of speed measurement. In the absence of handover data from the network providers, we have carried out drive tests, using mobiles in connected mode to obtain this information.

In this project, we will assume that there is at least one or more than one connected UE in a mobile network cell and moving on the highway, which can be considered to be a fair assumption. The average speed of vehicles within the cell is then the average of speed of all the connected UE's within that particular cell. This assumption is justified from observation as at low density a majority of the vehicles travel at speeds close to the speed limit of the highway and at high congestion, most vehicles travel at the same low speed. At medium densities, there may be some variation in the actual speeds of all the vehicles, but given the penetration of UE's, an average of the speeds of connected UE's should provide a reasonable estimate. The average velocity estimate can then be used to predict the vehicle density by choosing an appropriate traffic model that estimates density of vehicles from the average speed.

Significance and Intellectual Merit

Intelligent transportation control has become a very important area for researchers. Every year we lose billions of dollars due to time wasted on congested highways and roads. Control systems theory is increasingly being used to control traffic flow [1-5]. Recently we have been observing a variety of ways in which real time traffic information is being provided to travelers. Examples include electronic signs at specific locations on the roads, GPS's enabled with real time traffic information as well as mobile apps with navigation and traffic information. However the current traffic information obtained from such devices is not completely reliable. Therefore new and better methods for collection of traffic data are needed, which this project aims to address.

Traffic Model Identification

In this section an appropriate model for estimating density will be formulated by modifying the existing traffic models and using data obtained from wireless cellular networks. The data used will be the speed of users connected to the cell obtained during drive testing. In order to represent traffic behavior there are generally two kinds of modeling approaches. One is the microscopic approach, where behavior of each vehicle is taken into consideration. The traffic dynamics are represented by a set of rules or an equation based on the individual vehicle behavior. This type of modeling approach is very detailed but computationally very expensive. The other approach is macroscopic, where the overall average behavior of the traffic flow, over a specified section, is considered. The traffic model is represented in terms of traffic density, average speed and section area. In this type of modeling, the traffic characteristics are modeled like a fluid flow by using continuous parameters such as the concentration $\rho(x,t)$ (traffic density), average speed $v(x,t)$ and flow rate $q(\rho,v)$, all functions of space x and time t.

Figure (1) shows the macroscopic model of the sections of the freeway demarcated according to the cell boundaries, assuming the freeway is divided into N sections based on (N-1) cell towers. Here $\rho_i(t)$ and $v_i(t)$ are the densities of vehicles, and average speed of vehicles in i-th section and $q_i(t)$ is the flow of vehicles leaving the i-th section of the freeway with x_i as its length as dictated by the distance between two consecutive cell sites. A traffic model can then be developed using the relationships between these variables.

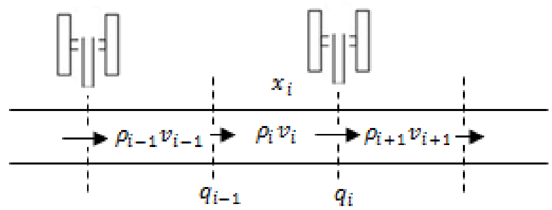

Figure 1. Flow of vehicles on a freeway

The way cell phones interact with towers and therefore give us an estimate of the distance x_i and time t is explained in Figure 2.

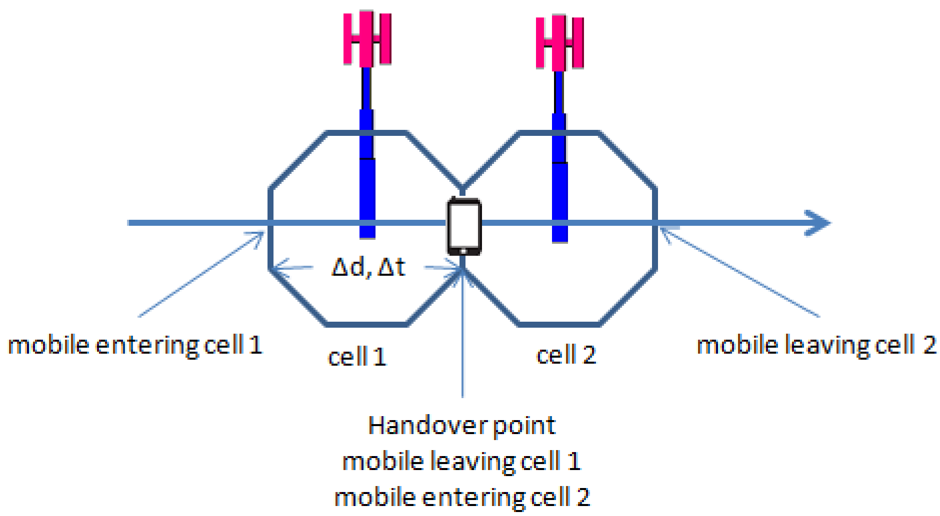

Figure 2 Distance-time analysis from cell data

The model which will be used to describe the behavior of traffic is outlined below. This is a basic one-equation model based on the equation of continuity or conservation of mass. This model also needs a fundamental relationship between density of vehicles and speed of flow. According to the law of conservation of mass, total flow of vehicles exiting from any section cannot be higher than the total flow of the vehicles that are entering, which means that the "total number of vehicles is conserved in the system". The number of vehicles moving in and out accounts for the change in density in that area. To represent the dependence of speed on the density of traffic, Greenshield's model [15] or Underwood's model [16] can be used. The model is described by a nonlinear hyperbolic partial differential equation.

Lighthill-Whitham-Richards Model

Lighthill-Whitham-Richards (LWR) model is a mathematical model used to describe traffic flow problem. The LWR model, named after the authors in [11] and [12], is a macroscopic one-dimensional traffic model. This model is a basic one-equation model which is based on the equation of continuity or conservation of mass. The derivation of the conservation law is given in [13]. According to the law of conservation of mass, total flow of vehicles exiting from any section cannot be higher than the total flow of the vehicles that are entering which means that the "total number of vehicles is conserved in the system". The number of vehicles moving in and out accounts for the change in density in that area. The LWR model is a scalar, time-varying, nonlinear and hyperbolic partial differential equation. This model also needs a fundamental relationship between density of vehicles and speed of flow. The conservation law for traffic in one dimension is given by

$$\frac{\partial \rho}{\partial t} + \frac{\partial (q_{eff})}{\partial x} = 0 \tag{1}$$

The flow $q_{eff}(t)$ takes into account the traffic flows leaving a section and entering the following section, denoted by $q(t)$, as well as the input and output flows at the on- and off-ramps denoted by $r_{in}(t)$ and $r_{out}(t)$ respectively. The flow $q(t)$ is the product of traffic density $\rho(t)$ with the traffic speed $v(t)$, i.e. $q(t) = \rho(t)v(t)$. There are many models researchers have proposed for how the flow should be dependent on traffic conditions. The choice of such function depends on the behavior the model is trying to mimic. There are a number of representations for this function used throughout the literature, some of which have been discussed in [14]. Some of these representations are the Greenshield's model [15] and the Underwood's model [16].

I. Greenshield's Model

Greenshield's model [15] is one of the simplest and most widely used models for velocity-density relationship. This model assumes velocity as a linearly decreasing function of the flow density, and is given by

$$V(\rho) = v_{free}\left(1 - \frac{\rho_i(t)}{\rho_{\max}}\right) \tag{2}$$

where v_{free} is the free flow speed and $\rho_{\max}$ is the maximum density. Free flow speed is the speed of traffic when the density is zero. This is the maximum allowable speed on the freeway section. The maximum density is the density at which there is a traffic jam and the speed is equal to zero. From the above relationship it is clear that for zero density the model allows the traffic to move with free flow velocity and for jam density there is no flow at all.

II. Underwood Model

To represent the dependence of speed on the density of traffic, according to Underwood's model [16], the velocity-density function is represented by

$$V(\rho) = v_{free}\exp\left(-\frac{\rho_i(t)}{a\rho_{\max}}\right) \tag{3}$$

where $a > 0$, v_{free} is the free speed (the maximum speed) and $\rho_{\max}$ is the jam density.

Wireless Data Setup and Collection

The figure below shows the site selected for drive tests. The data was collected using a mobile phone locked to a particular wireless provider's 3G (UMTS) network. The time of handover between each cell was recorded, which appeared as a change in the cell ID in the drive test recording tool. The drive test recording tool used was G-Mon [17] app on the android device. From the time instants between two consecutive handovers and known distances between the handover points (recorded by the latitude and longitude in the tool), we can estimate the speed of the vehicle. Such data was collected and based on those data, a model was developed that can be used to predict the various traffic parameters, such as traffic flow and density.

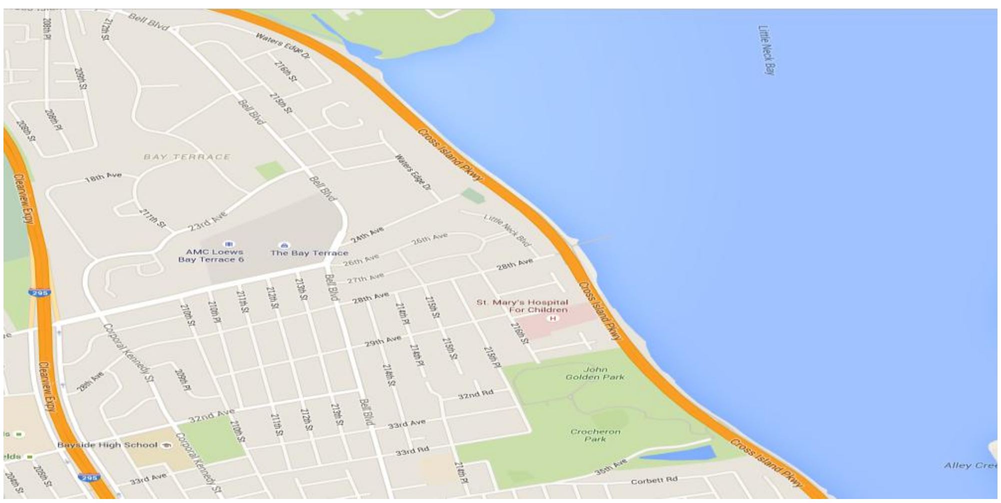

Figure 3 Selected Site for Drive Tests

The velocity of vehicles can be calculated by using the following equation:

$$v = \frac{\Delta d}{\Delta t} \tag{4}$$

where Δd is the distance travelled by vehicle in a cell between handovers and Δt is time travelled between handovers as shown in figure 2. The distance travelled by the vehicles used in the above equation is the total distance between a vehicle entering and leaving a particular cell. Figures 4 and 5 show the vehicle entering and leaving a cell on a section of the Cross-Island Parkway in New York. Figure 5 shows an example of the mobile device handing over from cell ID 51626 to cell ID 28226. Let this be point A. Figure 6 shows the mobile phone handing over from cell ID 28226 to a new cell ID 50378. Let this be point B. The distance and time interval measured between points A and B gives us an estimate of the vehicle velocity.

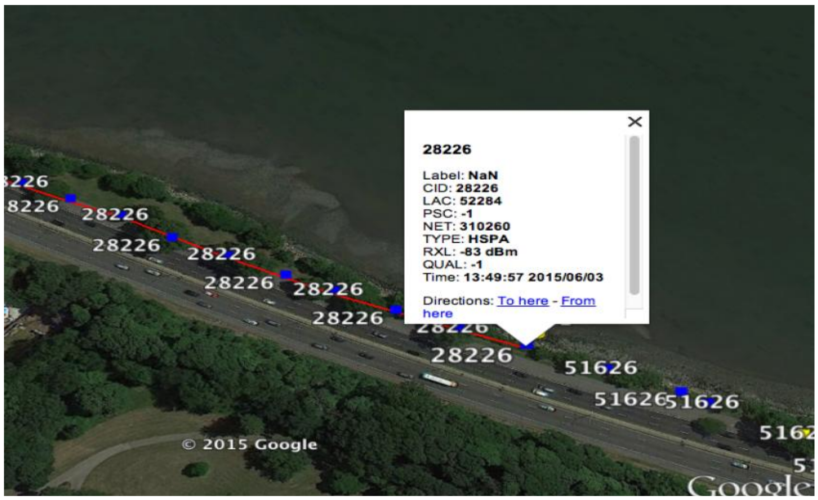

Figure 4 Vehicle entering cell 28226

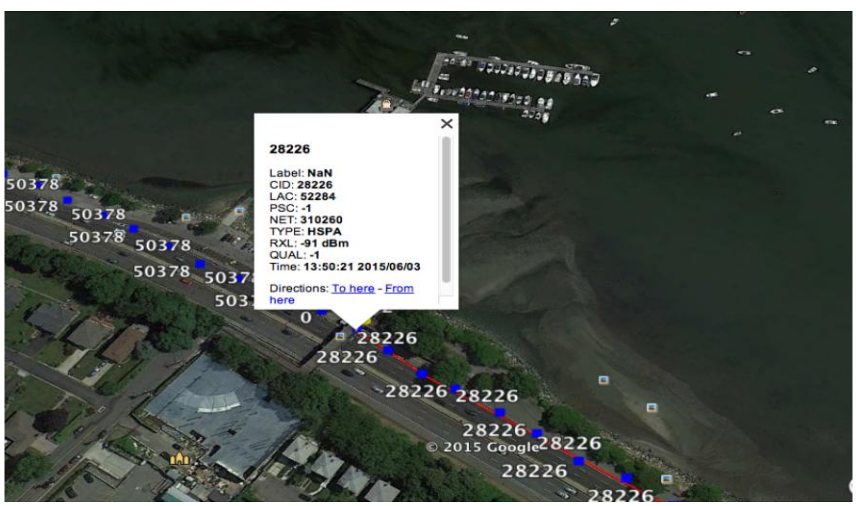

Figure 5 Vehicle leaving cell 28226

The actual density of vehicles passing through a certain cell is obtained from the video recording of the traffic flow. One such snapshot is shown in figure 6 below. A High-Definition camera was mounted and the traffic flow was constantly monitored through video. The video was later processed to obtain the actual count for the density of vehicles.

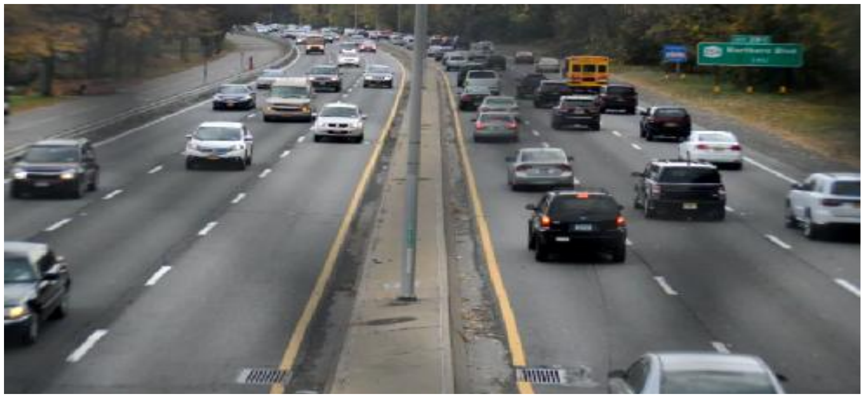

Figure 6 Video Setup for actual density count

The data was collected during repeated drive tests and processed and analyzed. The table below shows an example of one of the processed files collected during the drive tests.

Data point number	Data Point Location	Direction	Condition observed (No Congestion, Slight Congestion/moderate congestion/heavy congestion)	Posted speed limit	Number of Lanes	Cell ID	Neighboring CellID at Start	Neighboring Cell ID End	Delta Time (sec)	Delta Distance (m)	Calculated Velocity m/s	Calculated Velocity miles/Hr	Total Cars	Density per 100m
1	Cross Island Parkway	S	Slight Congestion	50	2	28226	38979	0	47	635.51	13.52148936	30.24676041	62	9.755944045
2	Cross Island Parkway	S	Moderate Congestion	50	2	51626	28226	28226	40	402.66	10.0665	22.51815651	84	20.86127254
3	Cross Island Parkway	N	No Congestion	50	2	51626	28226	28226	20	428.17	21.4085	47.88952999	43	10.04274003
4	Cross Island Parkway	N	No Congestion	50	2	51626	28226	28226	20	449.78	22.489	50.30654366	45	10.00489128
5	Cross Island Parkway	N	No Congestion	50	2	28226	51626	38979	16	338.77	21.173125	47.36301024	34	10.03630782
1	Cross Island Parkway	S	No Congestion	50	2	50378	50377	28226	26	610.38	23.47615385	52.51474758	40	6.553294669
2	Cross Island Parkway	N	No Congestion	50	2	28226			30	630.25	21.00833333	46.99438117	44	6.981356605
3	Cross Island Parkway	S	No Congestion	50	2	50378	50377	38979	24	506.29	21.09541667	47.18918136	41	8.09812558
4	Cross Island Parkway	N	No Congestion	50	2	28226	50378	51626	31	658.28	21.23483871	47.5010601	33	5.01306435
5	Cross Island Parkway	S	No Congestion	50	2	50378	50377	0	90	2092.1	23.24555556	51.99891304	121	5.783662349
6	Cross Island Parkway	N	No Congestion	50	2	28226	51626	50378	24	521.41	21.72541667	48.59845356	31	5.945417234
7	Cross Island Parkway	S	No Congestion	50	2	50378	0	38979	24	549.02	22.87583333	51.17186662	25	4.553568176
8	Cross Island Parkway	N	No Congestion	50	2	28226	51626	50378	31	592.75	19.12096774	42.77245758	32	5.398566006
9	Cross Island Parkway	S	No Congestion	50	2	50378	50377	38979	26	521.03	20.03961538	44.82741724	50	9.596376408
10	Cross Island Parkway	N	No Congestion	50	2	28226	0	51626	27	601.68	22.28444444	49.84896516	38	6.315649515
11	Cross Island Parkway	S	Slight Congestion	50	2	50378	50377	38979	34	525.01	15.44147059	34.54164322	60	11.42835375
12	Cross Island Parkway	N	No Congestion	50	2	28226	51626	38979	30	639.44	21.31466667	47.67963045	48	7.506568247
13	Cross Island Parkway	S	Moderate Congestion	50	2	50378	0	0	50	544.63	10.8926	24.36609264	67	12.30192975
14	Cross Island Parkway	S	Moderate Congestion	50	2	61084	48237	50377	54	659.16	12.20666667	27.30558093	43	6.523454093
15	Cross Island Parkway	S	Heavy Congestion	50	2	50377	61084	50378	23	215.31	9.361304348	20.94067615	40	18.57786447
16	Cross Island Parkway	S	Heavy Congestion	50	2	50378	50377	38979	62	569.01	9.177580645	20.52969725	87	15.28971371
17	Cross Island Parkway	S	Moderate Congestion	50	2	28226	38979	51626	25	280.52	11.2208	25.10025635	78	27.80550406

Table 1: Processed Cellular Data

Here, vehicle speeds are calculated using latitude and longitude and time of handovers provided by the recording tool. The data shown on table 1 illustrates velocities obtained from the cellular data and corresponding actual density from recorded video during different traffic conditions. The different traffic conditions are categorized as:

- White: No Congestion
- Blue: Slight Congestion
- Yellow: Moderate Congestion
- Red: Heavy Congestion

Model Estimation

The data collected during repeated drive tests was analyzed and plotted. Figure 7 shows the relationship between the actual density and velocity of the vehicle flow. The plot illustrates velocities obtained from the cellular data and corresponding actual density from recorded video during different traffic conditions. Here, the density is computed as number of vehicles per 100 meters and the velocity is in miles per hour. The different traffic conditions are categorized with different colors

- Blue-No Congestion
- Yellow-Mild Congetion
- Red-Congestion

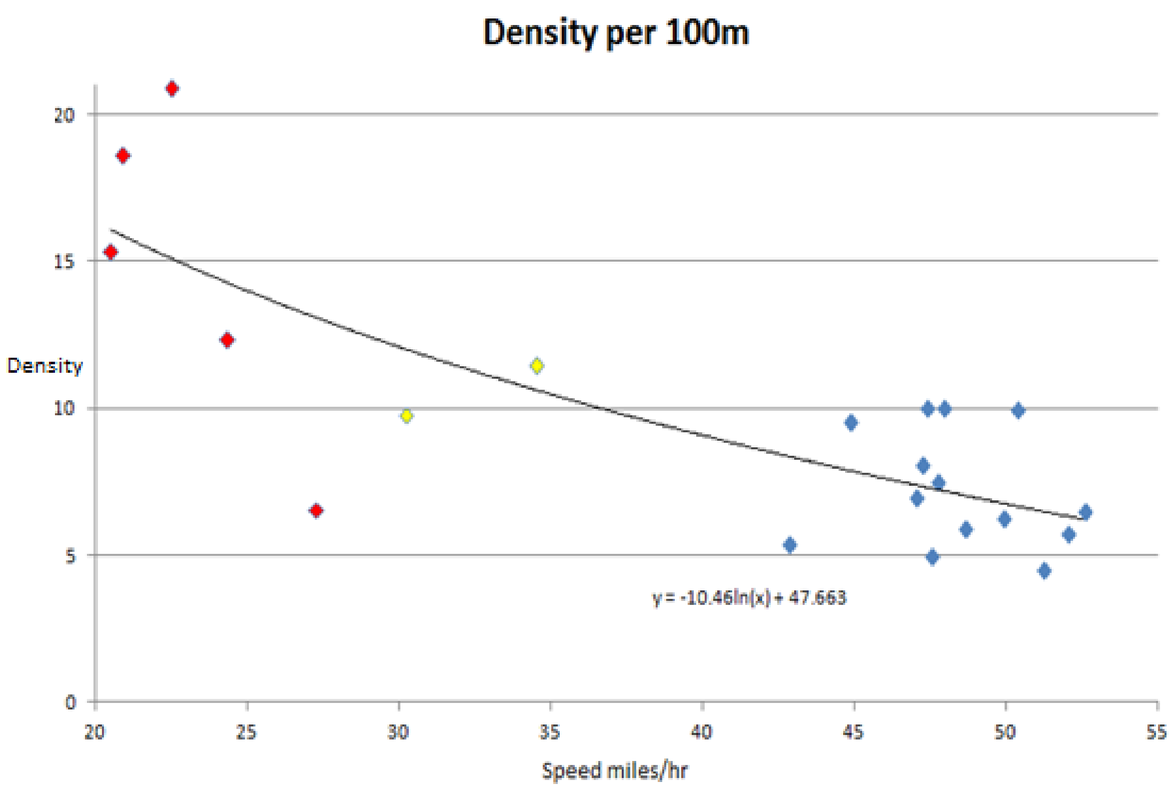

Figure 7 Density versus Velocity from Data

Next a model needs to be formulated to estimate the vehicle density from the cell data. This is done by modifying the Underwood's model and performing regression analysis. Nonlinear regression is used to correct the model so that it can adapt more accurately to the changing dynamics of traffic conditions. Nonlinear regression is a form of regression analysis in which observational data is modeled by a function which is a nonlinear combination of the model parameters and depends on one or more independent variables. The data is fitted by a method of successive approximations.

The model adopted to obtain an estimate density of vehicles is the Underwood's model (3) repeated here

$$V(\rho) = v_{free} \exp\left(-\frac{\rho_i(t)}{a\rho_{\max}} \right)$$

The model can be solved to get an expression for density as

$$\rho = -a\rho_{\max} \ln(\frac{V}{v_{free}}) \tag{5}$$

For our analysis, the jam density $\rho_{\max}$ is assumed to be 20 vehicles per 100 meters, using an average vehicle length of 5 meters. The free flow velocity v_{free} is assumed to be 55 miles per hour, which is the posted speed limit on the freeway mentioned above. By curve fitting the following equation is obtained for the density and velocity relationship

$$\rho = -10.46 \ln(v) + 47.663 \tag{6}$$

Comparing this model with the Underwood model the value of the constant a is found to be 0.563 and accommodating for the constant term, the Underwood's model is modified using the following equation

$$V(\rho) = v_{free} \exp\left(-\frac{(\rho_i(t) - K)}{a\rho_{\max}} \right) \tag{7}$$

The modified model after computation is a best fit with the value of K as 5.743.

Model Validation

In order to check the accuracy of the modified model the density for the previous set of data was calculated using the modified model and plotted against the recorded speeds as shown in Figure 8.

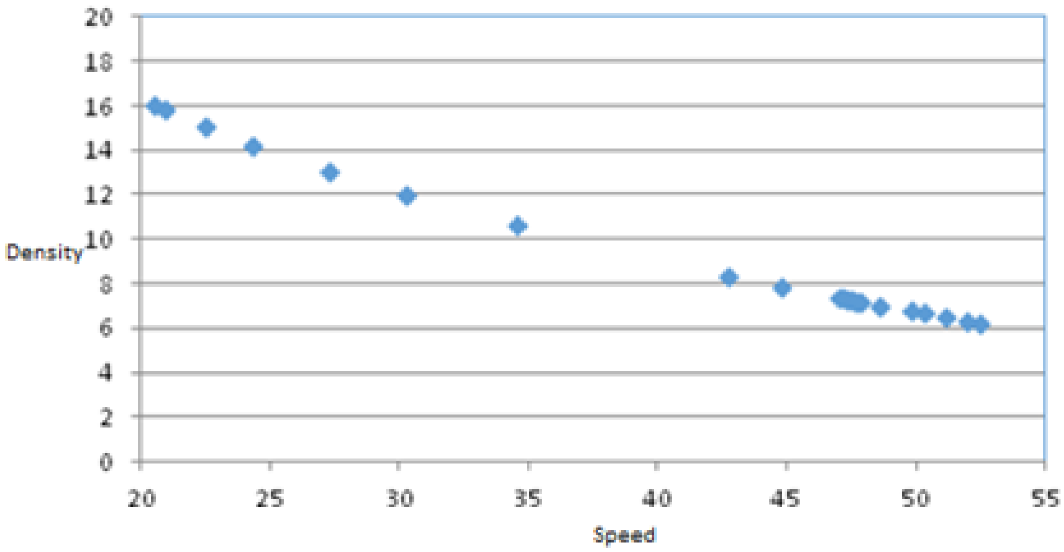

Figure 8 Estimated Density versus Speed (Data Set#1)

The model validated by estimating the densities on the same freeway using different set of cellular data obtained on different days and times of the day. The estimated densities from the model were then analyzed and compared with the actual densities as obtained from the new set of data using video counting. Figure 9 shows the plot of estimated density versus speed for one such data set.

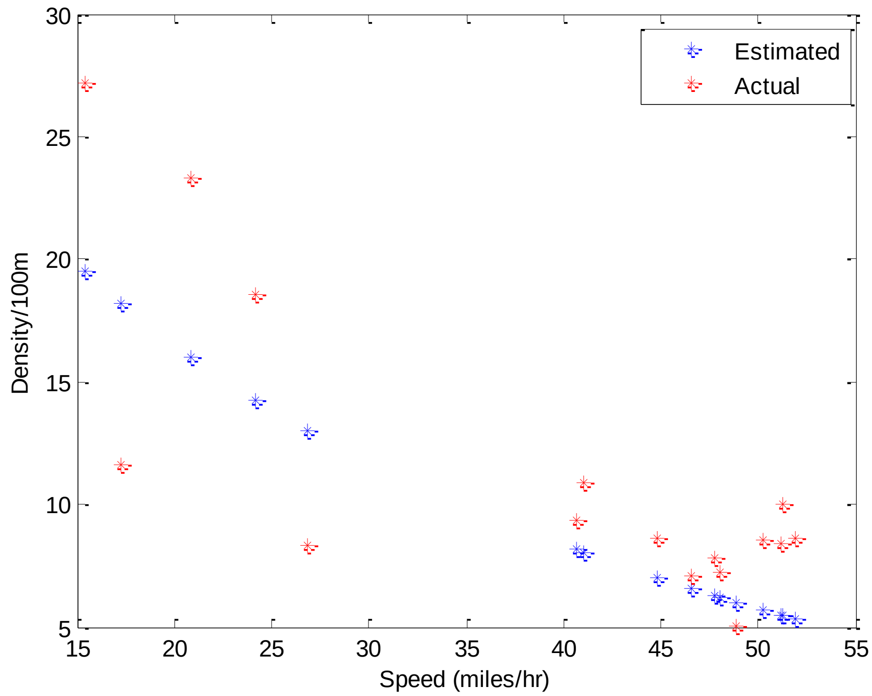

Figure 9 Estimated Density versus Speed (Data Set#2)

Figure 10 compares the estimated density with the actual density using a new set of collected data. Here delta density is the difference between actual density and estimated density. We can see from the figure 10 that the model is fairly accurate in the range of speeds greater than 35 miles per hour. At higher congestion (lower speeds) the accuracy of density varies between ±7 cars /100 m.

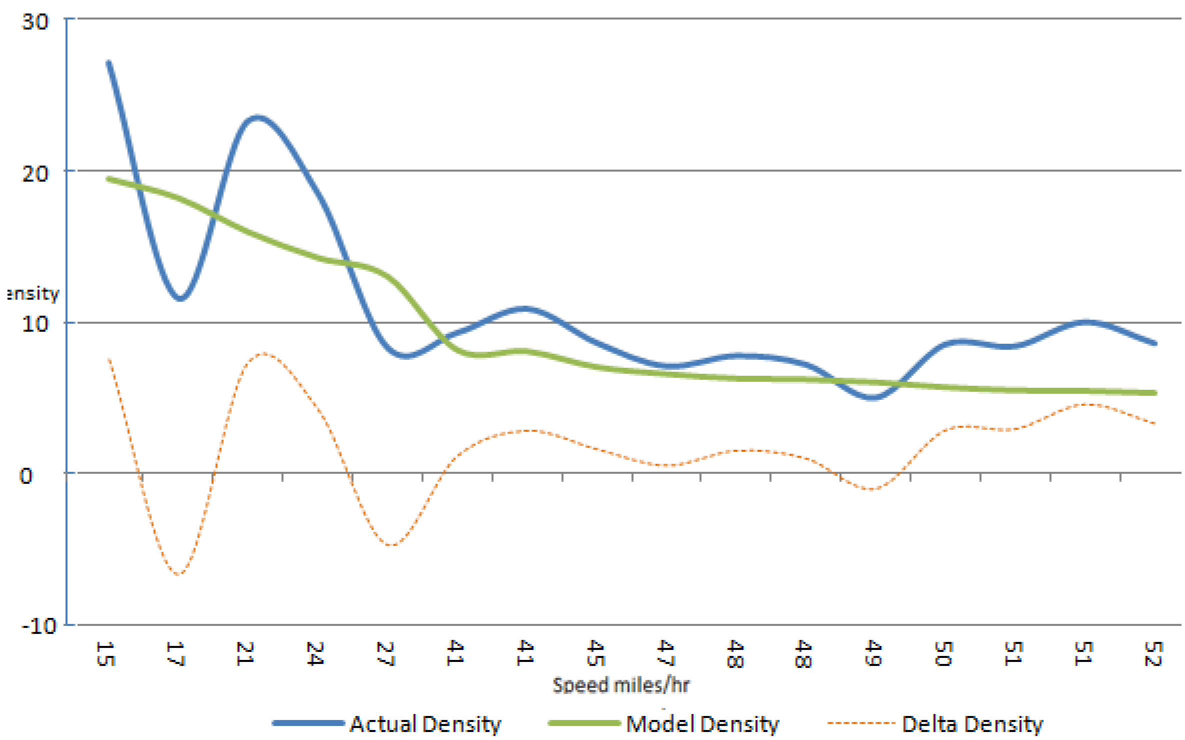

Figure 10 comparison of estimated model density with predicted density at different speeds

After analyzing many data sets on different days the value of constant value of K in the modified model was finally fixed as 7.583 for the above mentioned freeway for more accuracy.

Traffic Dynamics and Next State

After modifying the Underwood's model, the next step is to obtain accurate predictions for the *future* traffic quantities such as vehicle density, if the current cellular velocity estimate is known. In order to get the predictions for the next state of the traffic density the LWR dynamic model is used. The LWR model presented earlier is discretized for the freeway according to the setup shown in figure (1). The discretization will be performed according to the time intervals ΔT

and therefore the density of the vehicles for the *i*-th section of the freeway varies in time according to the following equation

$$\rho_i(t+1) = \rho_i(t) + \frac{\Delta T}{d_i}[(q_{i-1}(t) - q_i(t)], \qquad i = 1,2,3,.....N \tag{8}$$

The discretization time ΔT corresponds to the handover time between two consecutive cell sites and d_i is the distance between that handover. Here $\rho_i(t)$ is the density of the vehicles in the *i*-th section and $q_i(t)$ is the flow of vehicles leaving the *i*-th section and is the product of the density and speed i.e; $q_i(t) = \rho_i(t)v_i(t)$, with $v_i(t)$ as the average speed of vehicles in the same section corresponding to the cellular speed. Using this relationship and modified Underwood's model the algorithm will generate the next state value for the density assuming the initial traffic conditions are known and the cellular speeds are available. The discretized LWR traffic dynamics is then simulated with the modified model

$$V(\rho) = v_{free} \exp\left(-\frac{(\rho_i(t) - K)}{a\rho_{\max}} \right) \tag{9}$$

for the upcoming state after the data for the initial state was known. Figure 11 shows one such simulation where values of density are predicted from the algorithm for one section of the freeway and are then compared and validated against the actual data collected from the drive tests.

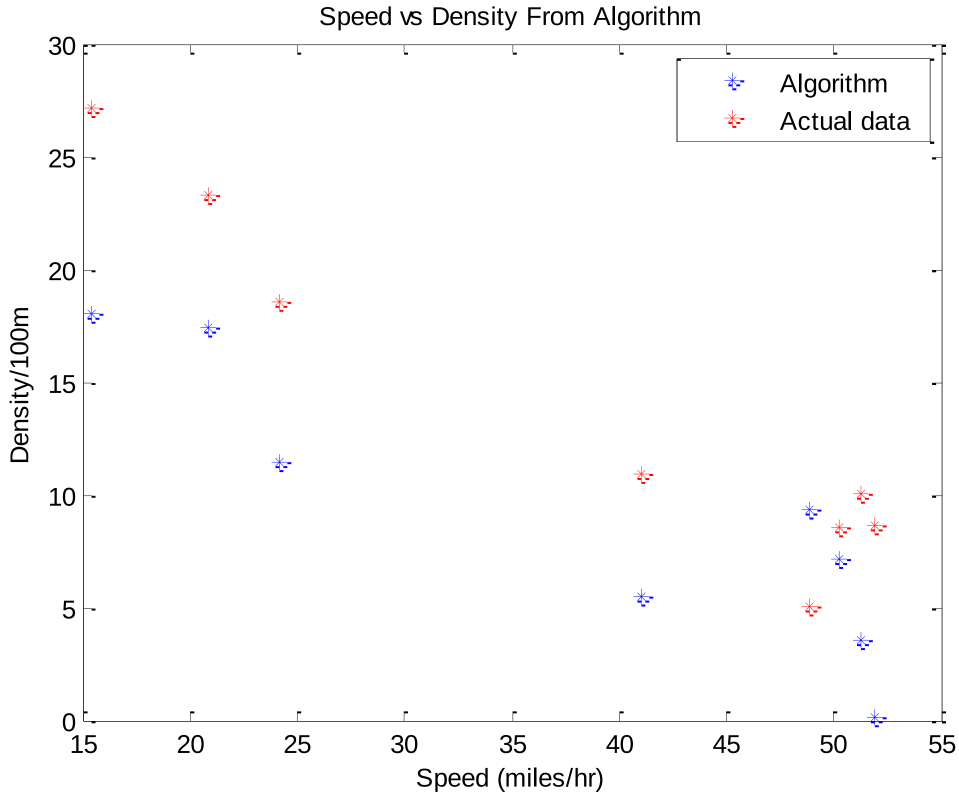

Figure 11 Predicted Density versus Speed

Finally in figure 12 the predicted values of density from the LWR algorithm are compared with the estimation of density for the same section using only modified Underwood's model. The results clearly indicate that the combination of traffic dynamics and the modified model deliver a more accurate prediction of the traffic conditions based on the available cellular data.

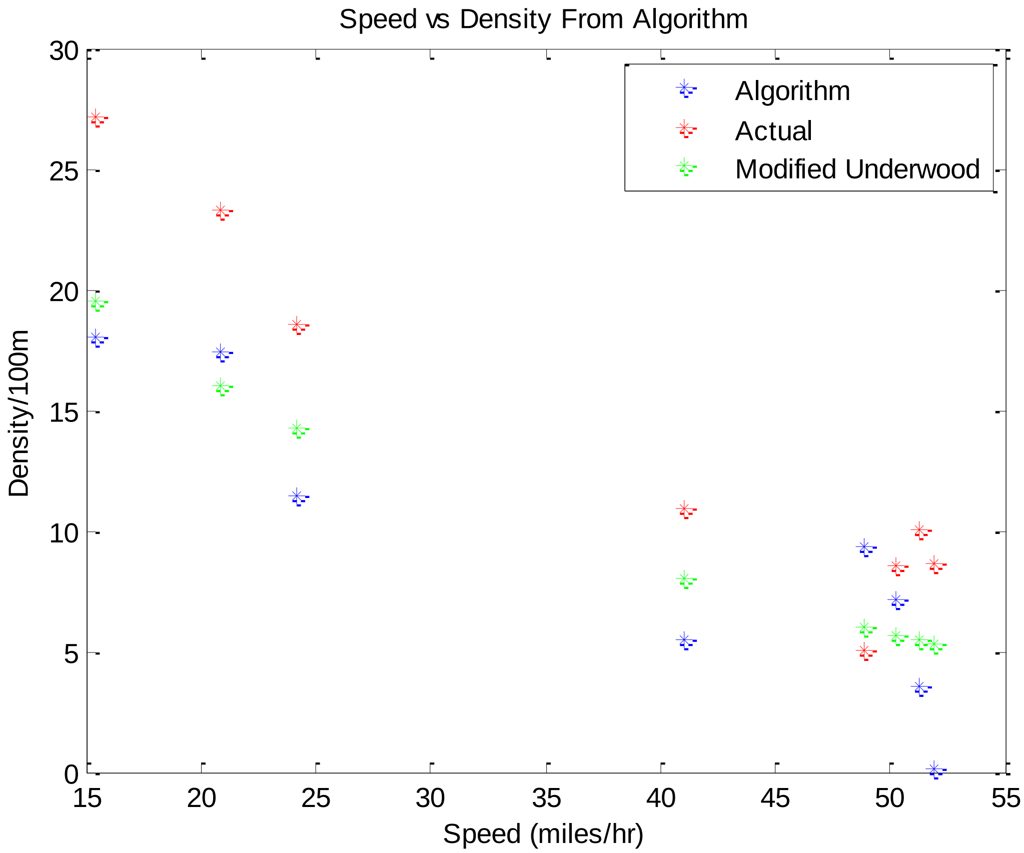

Figure 12 Predicted and Estimated Densities versus Speed

Conclusion

In this project we were able to estimate traffic density using speed data from wireless cellular networks. The collection of wireless data was done using drive testing. Using the test data a model was developed that can predict the density of traffic. The significance of such a prediction lies in the observation that wireless cell infrastructure is already built through the most part of the country. These sites can be used to collect and report such data that can help transportation engineers estimate important traffic parameters like vehicle density. Whichever location or cell site is chosen to collect and report such data would need an initial analysis to obtain the coverage area of such a cell and if necessary, to tweak the model as shown in this report. Furthermore, in this project we also completed an analysis on the prediction of the future traffic data if the current cellular velocity estimate is known, using the LWR model. The results indicated that the combination of traffic dynamics and the modified model deliver a resonably accurate prediction of the traffic conditions based on the available cellular data.

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