Abstract—This paper presents a feedback control design for a coordinated ramp metering problem. We design an optimal traffic allocation scheme for ramps based on Godunov’s numerical method and using distributed-diffusive model. Most of the previous work for designing feedback control for ramp metering is based on either the discretized linear methods such as ALINEA or nonlinear methods based on the traffic ODEs. Limitation with these models is that neither do they produce vanishing viscosity weak solutions in the limit nor do they satisfy the entropy conditions. We utilize distributive-diffusive model to construct a condition for maximizing the traffic flow on the freeway stretch. And then design a Godunov method based optimal allocation scheme which gives us the actual control for each ramp individually. We show the stability properties of the closed-loop system and validate the effectiveness of the feedback control law by running a simulation using real traffic flow measurements with parameter estimation.

Index Terms—Coordinated Ramp Metering, Traffic Control, Godunov, Feedback

I. INTRODUCTION

Ramp meters are used to control the inflow into the freeway so that better flow conditions can be achieved on the freeway. One of the methods to optimize and control the flow on the freeways is coordinated ramp metering [1]. Ramp metering can be designed as fixed periodic cycles using the historical data or time of day schedules, or it can also be designed based on sensor measurements and feedback control in real time. Coordinated ramp metering problem refers to a freeway system that has entry and exit ramps on it at various points. The question for the design then becomes, how should the ramp metering be designed taking into account mutual interactions of various ramps and their overall effect on performance of the freeway. Figure 1 illustrates a ramp system that can be controlled by metering to effect the traffic conditions on the freeway.

Various types of dynamics have been used to design control laws for isolated ramps. These dynamics include, simple inflow outflow based steady state model in [2], linearized discrete time model in [3], fuzzy logic based controller in [4], and a neural network based controller in [5]. Many lumped parameter based models and distributed models have been studied in [6]. Lumped parameter models used previously had a flaw in them as they did not produce vanishing viscosity weak solutions in the limit. In order to address this issue, enhanced Godunov based hybrid models have been presented in [7], [8] and [9] for isolated ramp metering problem. The Godunov based model treats the problem as a hybrid system with discrete states, where in each state there are different inflow and outflow conditions. When there are no uncertainties, then the controller knows exactly which discrete state the system is in, and hence the nonlinear dynamics can be canceled such as in feedback linearization [7] and sliding mode control [10].

This work uses the idea of Godunov based hybrid model for isolated ramps (see [9] and [8]) to design a coordinated ramp metering system using the distributed modeling described in [6]. Our contribution to the topic of feedback ramp controls is that we use an entropy consistent distributed model to come up with a constraint condition for maximizing the traffic flow on the freeway stretch. And then we combine this constraint along with the Godunov based numerical technique to design an optimal allocation scheme, which provides the coordinated control law for the individual ramps. Combining the distributed model with the Godunov’s scheme for designing the coordinated feedback control law is completely new, and hence the control design in a novel contribution to this area.

Structure of rest of the paper is as follows: section II presents a literature survey of the topic, section III provides a mathematical background of the traffic flow models used in this paper, section IV formulates the coordinated ramp problem, and designs a feedback control law and finally section V and section VI present the simulation results and concluding remarks respectively.

II. LITERATURE SURVEY

Ramp metering is one of the main methods to control flow conditions on a freeway segment. It can be used to influence the amount of traffic on a freeway by controlling the inflow from connected streets. Literature containing ramp metering techniques can be found dated more than 45 years, see [2], [11], [12], and [13]. Early researchers have mainly used optimization based methods for ramp metering such as [14], [15], and [16]. A decentralized ramp control design is presented in [17]. One of the first feedback control theory based control law for ramp metering problem is ALINEA (see [3]) which uses...
concepts of linearization and time discretization. Intelligent control methods such as neural network based controller is presented in [5],[18] and [19] and fuzzy logic based in [4], [20] and a combined approach using Fuzzy-Neuro algorithm in [21]. Many researchers assessed the effectiveness of proposed ramp metering methods (see [22], and [23]) and their cost benefits [24]. Many countries, such as Italy [25], U.S.A [26], Germany [27], France [28], New Zealand [29], Netherlands [30] and U.K. [31] have been utilizing ramp metering for controlling traffic flows on the freeway, for a good amount of time. A general overview of ramp metering problem is covered in the Traffic Control Systems Handbook [32]. Nonlinear lumped parameter model based feedback control is detailed in [6]. Various model formulations such as the distributed model, lumped model, and their continuous and discrete time versions are shown in [33], [34], [35] and [36]. Recently, there has been an interest in developing control law for ramp metering using the distributed LWR model (such as in [6] and [37]. The work in [6] is based on feedback linearization in the distributed setting, while the methodology in [37] uses adjoint based optimization. Godunov’s numerical method based discretization and feedback linearization has been used in [7] and [8] to model the ramp metering problem, assuming no uncertainties in the system parameters. The paper [9] considers a Godunov approximation based dynamics with uncertainties in the system parameters, and presents a way to design robust controllers. The paper [10] uses sliding mode control for the same problem assuming perfect knowledge of the model by the controller, and the paper [38] deals with the problem of uncertain free flow speed using sliding mode control.

Many ideas pertaining to the isolated ramp metering problem have been extended to design the coordinated ramp metering system. These include use of nonlinear state feedback control in [39] and use of microscopic mathematical model in [40]. A nonlinear model-predictive hierarchical control approach is presented for coordinated ramp metering of freeway networks in [41] and nonlinear optimal control concepts are applied to the same problem in [42], [43], [44] and [45]. An evolutionary fuzzy system is presented for coordinated and traffic responsive ramp metering in [46],[47], an adaptive fuzzy systems is used for the same in [48], and a neuro-fuzzy algorithm in [49]. A multilayer control structure and PSO (Particle Swarm Optimization) algorithm are used for coordinated ramp control on freeways in [50]. Heuristic ramp-metering coordination strategy is implemented at Monash freeway, Australia [51].

III. MATHEMATICAL BACKGROUND
A. LWR, Greenshield’s and Diffusive Models for Traffic
The macroscopic traffic flow model formulates the relationship among the key traffic flow parameters such as density, flow etc. The classic LWR (Lighthill-Whitham-Richard) model was proposed in 1956. It is a one-dimensional macroscopic traffic model named after the authors in [52] and [53]. The dynamics of traffic flow using this model is given by equation (1).

$$\frac{\partial}{\partial t} \rho(t, x) + \frac{\partial}{\partial x} f(t, x) = 0$$

(1)

where, $\rho$ is the traffic density and $f$ is the flux. Traffic flux is defined as the product of traffic density and the traffic speed $v$ , i.e. $f = \rho \times v$. There are many models which link traffic density to traffic speed. One of them is Greenshield’s model which proposes a linear relationship between traffic density and traffic speed (see [54]). This model is given by equation (2).

$$v(\rho) = v_f \left( 1 - \frac{\rho}{\rho_m} \right)$$

(2)

where $v_f$ is the free flow speed and $\rho_m$ is the maximum possible density or jam density. Free flow speed is the traffic speed when there is no traffic, i.e. when the traffic density is zero. Traffic jam density is the density at which there is a traffic jam, i.e. when the traffic speed is zero.

Traffic flow using Greenshields model is given by:

$$f(t) = v_f \rho(t) \left( 1 - \frac{\rho(t)}{\rho_m} \right)$$

(3)
Diffusion is a very useful concept mentioned in the literature of traffic flow models by many researchers ([55], [56], [57]). Introduction of diffusion concept in the traffic flow models makes them more realistic. Diffusion term accommodates the "the diffusion effect" due to the fact that each driver is observing the road straight ahead of him and constantly adjusting his speed according to road density and flow conditions. This adjustment makes the flow dependent on the gradient of density, leading into an effective diffusion. The diffusive term helps model the speed reductions due to shock waves as gradual ones rather than the sudden ones. Incorporating the diffusion term in Greenshield’s model Equation (2) gives

\[ v(\rho) = v_f \left(1 - \frac{\rho}{\rho_m}\right) - D \frac{\partial \rho}{\partial x} \rho \]  

(4)

and we can rewrite the traffic flow using equation (2) and (4) as

\[ f(t) = v_f \rho(t) \left(1 - \frac{\rho(t)}{\rho_m}\right) - D \frac{\partial \rho(t, x)}{\partial x} \]  

(5)

where \( D \) is the diffusion coefficient.

Combining equation (2) and (5) we get the distributed-diffusive model for traffic flow as follows

\[ \frac{\partial}{\partial t} \rho(t, x) + v_f \frac{\partial}{\partial x} \rho(t, x) - 2 \frac{\rho}{\rho_m} v_f \frac{\partial}{\partial x} \rho(t, x) - D \frac{\partial^2}{\partial x^2} \rho(t, x) = 0 \]  

(6)

B. Godunov based Model

To study the traffic characteristics and to gain an insight into the system evolution we consider a Riemann problem with a piecewise constant initial condition. Consider an initial value problem for a Riemann’s problem where the initial condition is a piecewise constant initial condition. Figure 2 shows the characteristics of traffic where the initial traffic data is shown on the \( x \)-axis, traffic density is piecewise constant. The middle section has the jam density \( \rho_m \), the upstream has a lower density \( \rho_0 \) and the downstream has zero density. As time increases, the shock wave travels upstream and at the same time the jam dissipates as a rarefaction onto the downstream. This can be observed on the \( y \)-axis.

![Fig. 2: Traffic Characteristics](image-url)

The Godunov method is based on solving the Riemann problem where the initial condition is a piecewise constant function with two values \( \rho_l \) and \( \rho_r \) for the upstream (left) and downstream (right) densities (see [61]). Either a shockwave or a rarefaction wave originates from the junction of the two densities. A shockwave develops if \( f'(<\rho_l) > f'(<\rho_r) \) (see [62]).

The speed of the shockwave is given by Equation (7). In this equation, \( x_s(t) \) is the position of the shockwave as a function of time. If the shock speed is positive then the inflow at junction between the two traffic densities will be a function of upstream traffic density, whereas if the shock speed is negative then the inflow at junction between the two traffic densities will be a function of downstream traffic density.

\[ s = \frac{dx_s(t)}{dt} = \frac{[f(\rho_l) - f(\rho_r)]}{\rho_l - \rho_r} \]  

(7)

A rarefaction develops if \( f'(\rho_l) < f'(\rho_r) \). The rarefaction can be entirely to the left, or to the right or in the middle.

The analysis of the shockwave and rarefaction conditions gives us the Godunov based ODE model for traffic. ODE for this method is derived from the conservation law (see figure 3), and is given by Equation (8), where we have assumed unit length for the section.

\[ \frac{d\rho(t)}{dt} = f_{in}(t) - f_{out}(t) + u(t) \]  

(8)

![Fig. 3: Godunov Dynamics](image-url)

Now, the inflow \( f_{in}(t) \) will be a function of upstream density \( \rho_l \) and downstream density \( \rho_r \). Here upstream and downstream are with respect to the left junction. Hence we have the relationship given by Equation (9) where we have used the function \( F(\cdot, \cdot) \) that will be obtained from the Godunov method.

\[ f_{in}(t) = F(\rho_l, \rho) \]  

(9)

Similarly, for the right junction, the outflow \( f_{out}(t) \) is given by Equation (10).

\[ f_{out}(t) = F(\rho, \rho_r) \]  

(10)

The function \( F(\rho_l, \rho_r) \) in terms of its arguments is given by the Godunov method as follows (see section 13.5, pages 143-145 [61]).

\[ F(\rho_l, \rho_r) = f(\rho^*(\rho_l, \rho_r)) \]  

(11)

Here, the flow-dictating density \( \rho^* \) is obtained from the following (see [61]):
1) \( f'(\rho_l), f'(\rho_r) \geq 0 \Rightarrow \rho^* = \rho_l \)
2) \( f'(\rho_l), f'(\rho_r) \leq 0 \Rightarrow \rho^* = \rho_r \)
3) \( f'(\rho_l) \geq 0 \geq f'(\rho_r) \Rightarrow \rho^* = \rho_l \) if \( s > 0 \), otherwise \( \rho^* = \rho_r \)
4) \( f'(\rho_l) < 0 < f'(\rho_r) \Rightarrow \rho^* = \rho_c \)

where, \( \rho_c \) is obtained as the solution to \( f'(\rho_c) = 0 \). \( \rho_c \) is called the critical traffic density and is equal to \( \rho_m/2 \).

Hence depending on the traffic densities on the left and right side of the junction, flow at the junction can have three possible values, i.e., \( F_q(\rho_l, \rho_r) \) can have three distinct values, \( f(\rho_l), f(\rho_r), \) or \( f(\rho_c) \), where \( q \in \{1, 2, 3\} \). Possible transitions between these three discreet states are shown in figure 4.

IV. COORDINATED RAMP METERING

A. Problem Formulation

Figure 5 illustrates the coordinated ramp model, where main freeway section has an inflow given by \( f \), the inflows controlled by the first and second ramps are given by \( u_1 \) and \( u_2 \). The traffic density on the main freeway section just before the first and second ramp is given by \( \rho_{l1} \) and \( \rho_{l2} \), traffic density just after the first and second ramp is given by \( \rho_{r1} \) and \( \rho_{r2} \). Length of the freeway section from the start up to the second ramp is \( L_1 \) and upto the end of freeway section (containing both ramps) is \( L_2 \).

Fig. 5: Coordinated Ramp Metering

The aim is to keep the aggregate traffic density on the freeway section containing the two ramps equal to the critical density, hence we define an error function as in [6]:

\[
e(t) = \int_{0}^{L_2} (\rho(t, x) - \rho_c)dx
\]

The limits of integral for the problem are from the start to the end of the mainline that includes both ramps. The function \( e(\cdot) \) is a mapping at each time \( t \) from the space of functions on \([0, L]\) to the space of real numbers. The objective for the control law is to make the error term go to zero asymptotically.

We will try to achieve the closed-loop dynamics represented by

\[
\dot{e}(t) + k_1 e(t) + k_2 \int_{0}^{t} e(s)ds = 0
\]

which will enable us to obtain

\[
\lim_{t \to \infty} e(t) = 0
\]

B. Feedback Control Design

In order to design a desired control law that makes the error term go to zero asymptotically, we start differentiating the error term with respect to time to get

\[
\dot{e}(t) = \frac{d}{dt} \int_{0}^{L_2} (\rho(t, x) - \rho_c)dx
\]

Breaking up the integral as the sum of integrals of two sections of the freeway we get

\[
\dot{e}(t) = \frac{d}{dt} \int_{0}^{L_1^-} (\rho(t, x) - \rho_c)dx + \frac{d}{dt} \int_{L_1^+}^{L_2} (\rho(t, x) - \rho_c)dx
\]

Simplifying further, we get

\[
\dot{e}(t) = \int_{0}^{L_1^-} \frac{d}{dx} \rho(t, x)dx + \int_{L_1^+}^{L_2} \frac{d}{dt} \rho(t, x)dx
\]

Using the conservation equation (1) here, after equating total to partial derivative, gives

\[
\dot{e}(t) = -\int_{0}^{L_1^-} \frac{\partial}{\partial x} q(t, x)dx - \int_{L_1^+}^{L_2} \frac{\partial}{\partial x} q(t, x)dx
\]

Equating the partial derivative to total derivative, we get

\[
\dot{e}(t) = -\int_{0}^{L_1^-} dq(t, x) - \int_{L_1^+}^{L_2} dq(t, x)
\]

solving the integrals yield:

\[
\dot{e}(t) = q(t, 0) - q(t, (L_1^-)) + q(t, (L_1^+)) - q(t, L_2)
\]

The flow at the left most boundary is produced by the freeway and ramp inflows. Therefore, we have,

\[
q(t, 0) = u_1 + f(t)
\]

From the boundary condition at the second ramp, we also have

\[
q(t, L_1^+) = q(t, L_1^-) + u_2
\]

Substituting (21) and (22) in (20) gives

\[
\dot{e}(t) = u_1 + u_2 + f(t) + q(t, L_2)
\]

Hence, we can write

\[
u_1 + u_2 = q(t, L_2) - f(t) - k_1 e(t) - k_2 \int_{0}^{t} e(s)ds
\]

Equation (24) provides a constraint that would ensure the maximum possible flow on the stretch of freeway including
the two ramps. Adding the diffusion term in this constraint gives

\[ u_1 + u_2 = v_f \rho(t, L_2) \left( 1 - \frac{\rho(t, L_2)}{\rho_m} \right) - D \frac{\partial q}{\partial x} \bigg|_{x=L_2} \]

\[ -f(t) - k_1 e(t) - k_2 \int_0^t e(s) ds \] (25)

For further analysis, we will be using the condition obtained in equation (25), which is derived using distributive-diffusive model.

C. Optimal Allocation using Godunov Scheme

Analysis in the previous section provides with a constraint on \( u_1 + u_2 \), but not a way to calculate individual \( u_1 \) and \( u_2 \). For this, we use a Godunov based scheme to determine the individual \( u_1 \) and \( u_2 \), while honoring the condition in (25), as far as possible. Design of decision rule based on Godunov based scheme is discussed below and illustrated in figure 6 as well.

- Case (i): \( f'(\rho_l) \geq 0 \) and \( f'(\rho_r) \geq 0 \)
  \[ \Rightarrow \rho_l \leq \rho_m/2 \quad \text{and} \quad \rho_r \leq \rho_m/2 \]
  \[ \Rightarrow \rho^* = \rho_l \]
  Decision: We try to make \( \rho_l \to \rho_m/2 \) by judiciously choosing \( u \).

- Case (ii): \( f'(\rho_l) \leq 0 \) and \( f'(\rho_r) \leq 0 \)
  \[ \Rightarrow \rho_l \geq \rho_m/2 \quad \text{and} \quad \rho_r \geq \rho_m/2 \]
  \[ \Rightarrow \rho^* = \rho_r \]
  Decision: We choose \( u = 0 \).

- Case (iii): \( f'(\rho_l) \geq 0 \) and \( f'(\rho_r) \leq 0 \)
  \[ \Rightarrow \rho_l \leq \rho_m/2 \quad \text{and} \quad \rho_r \geq \rho_m/2 \]
  - if \( s > 0 \) \( \Rightarrow \rho^* = \rho_l \)
    Decision: We try to make \( \rho_l \to \rho_m/2 \) by judiciously choosing \( u \).
  - if \( s \leq 0 \) \( \Rightarrow \rho^* = \rho_r \)
    Decision: is we choose \( u = 0 \).

- Case (iv): \( f'(\rho_l) \leq 0 \) and \( f'(\rho_r) \geq 0 \)
  \[ \Rightarrow \rho_l \geq \rho_m/2 \quad \text{and} \quad \rho_r \leq \rho_m/2 \]
  \[ \Rightarrow \rho^* = \rho_c \quad \text{(critical density)} \]
  Decision: We choose \( u = 0 \).

Summary of the decision rule is that there are total five cases. Three of them require \( u \) to be zero (call this case as A) and two of them require \( u > 0 \) (call this case as B). Now we define a variable \( K \) such that, \( K = u_1 + u_2 \) (see equation 25), and define \( \alpha \) such that

\[ \alpha = \left( \frac{\rho_m}{2} - \rho_{\ell_1} \right) + \left( \frac{\rho_m}{2} - \rho_{\ell_2} \right) \] (26)

and a variable \( p \) such that, \( K = p \times \alpha \)

Decision rule for coordinated ramp control using the Godunov based optimal allocation scheme is given in table I.
TABLE I: Decision Rule for Coordinated Ramp Control

<table>
<thead>
<tr>
<th>Ramp 1</th>
<th>Ramp 2</th>
<th>Decision Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>( u_1 = 0 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( u_2 = 0 )</td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>( u_1 = 0 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( u_2 = \min(K, \frac{\rho_m}{2} - \rho_2) )</td>
</tr>
<tr>
<td>B</td>
<td>A</td>
<td>( u_1 = \min(K, \frac{\rho_m}{2} - \rho_1) )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( u_2 = 0 )</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>( u_1 = \frac{\rho_m}{2} - \rho_1 ) if ( K \geq \alpha )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( u_2 = \frac{\rho_m}{2} - \rho_2 ) if ( K &lt; \alpha )</td>
</tr>
</tbody>
</table>

V. SIMULATION RESULTS

The simulations were performed using the data obtained from the ramps at the intersection of I-15 NB and Tropicana and at the the intersection of I-15 NB and Flamingo in Las Vegas as shown in Figure 7. This location is chosen based on inputs from Freeway and Arterial System of Transportation (FAST). Criterion for selection of freeway involved several factors including, that both the on ramps (at Tropicana and Flamingo) have a ramp meter that is controlled based on freeway sensors. Further the location ensures a wide range of data in terms of density, speed and traffic flow which is important for testing robustness in the model.

![Fig. 7: Ramp Metering Problem Location](image)

The data was collected from freeway detectors between roadway id : 59, segment id : 2 and roadway id : 72, segment id : 1. It was collected from 6 A.M. to 12 P.M. on a Thursday. The detectors at the location are loop detectors and the counts are polled every 5 min. This data is aggregated and then reported at every 15 min. Counts on the ramp are obtained through video based detection. Application of the least square estimator to the flow density relationship gave us the values of \( v_f \) and \( \rho_m \) approximately 70 miles/hour, and 86 vehicles/mile respectively. We use these values of traffic parameters in our simulation.

We analyze the results of the coordinated ramp control law by observing the traffic densities in the freeway section between the first and second ramp and in the section after the second ramp. Profile of traffic density between the two ramps is shown in figure 8 and traffic density profile after the second ramp is shown in figure 9.

![Fig. 8: Traffic Density in between the two Ramps](image)

Ramp controls are shown in the figure 10. Error profile defined in equation (12) is shown in figure 11.

We observe that density profile in both sections of freeway converge very close to the desired value of critical density (43 in this case). While \( \rho_1 \) converges to 42.7, \( \rho_2 \) stays between 42.2 to 43, values which are very close to the critical density. Also, the error function approaches to zero asymptotically.

Hence the densities and error profile goes asymptotically to the desired values, as in the case of isolated ramp problem using Godunov scheme ([9]).
This paper presented a novel feedback control law using distributive-diffusive modeling and the Godunov-based dynamics for coordinated ramp metering problem. The paper used a coupled control law condition derived from distributive modeling and then developed Godunov-based optimal allocation strategy for optimizing the performance of the system. The study presented a theoretical derivation of the control law and the hybrid model. Finally, the paper presented simulation results for the designed control laws, which showed the density on the freeway section stabilizing gradually around the critical or desired density.

VII. ACKNOWLEDGMENT

Authors are thankful to the Freeway and Arterial System of Transportation (FAST) for providing necessary details and the data.


Sharyya Agarwal is a doctoral student in the Electrical and Computer Engineering department at the University of Nevada LasVegas. His M.S. degree is in Electrical and Computer Engineering from University of Nevada LasVegas (2012). His B.Tech degree is in Electronics and Communication Engineering from Indian Institute of Technology, Guwahati (2009). His research areas include, feedback control, intelligent transportation systems, ramp metering, database management and design, etc.
Pushkin Kachroo is currently a visiting Professor at the University of California at Berkeley working with Professor Shankar Sastry. He is also the Lincy Professor of Transportation in the department of Electrical and Computer Engineering at the University of Nevada Las Vegas (UNLV). He is the director of the Transportation Research Center at UNLV and also the Associate director of the Mendenhall Innovation Program at the Thomas a Hughes College of Engineering at UNLV. He was an Associate Professor at Virginia Tech before he joined UNLV in 2007. He obtained his Ph.D. in Mechanical Engineering from University of California at Berkeley performing research in Vehicle Control in 1993 under Professor Masayoshi Tomizuka, and obtained another Ph.D. in Mathematics from Virginia Tech in Mathematics in the area of hyperbolic system of partial differential equations with applications to Traffic Control and Evacuation under Professor Joseph A. Ball. He has authored 10 books on traffic and vehicle control. He has authored more than 120 publications that include books, research papers, and edited volumes. He has taught about 30 different courses in Virginia Tech in the areas of electrical and computer engineering, and mathematics. Similarly, he also taught 30 different courses at UNLV since 2007. He has graduated more than 35 graduate students, and has been P.I. or Co P.I. on projects worth more than 4 Million Dollars. He was awarded the most outstanding new professor at Virginia Tech, and also has received many teaching awards and certificates, both at Virginia Tech and UNLV. He also received the faculty excellence award from CSUN UNLV in 2011.

Sergio Contreras is a doctoral student in Electrical and Computer Engineering at the University of Nevada, Las Vegas. He received his B.S. degree in Electrical Engineering and his dual M.S. degree in Electrical Engineering and Mathematical Sciences from University of Nevada, Las Vegas. He is currently a research assistant at the UNLV Transportation Research Center. His research interests include using smartphones for transportation applications as well as using them as lagrangian sensors for traffic modeling.

Shankar Sastry is the Dean of the College of Engineering at the University of California, Berkeley. He currently holds the Nippon Electronics Corporation (NEC) Distinguished Professorship in the College of Engineering and the Walter A. Haas School of Business. He was elected to the National Academy of Engineering in 2001 and is a recipient of the Donald P. Eckman Award in 1990. Sastry obtained his bachelor degree from Indian Institute of Technology, Bombay (1977), his master and PhD degrees from University of California, Berkeley (1979, 1980, 1981). His PhD advisor was Professor Charles Desoer. He became an Assistant Professor at Massachusetts Institute of Technology (1980-2), Assistant Professor, Associate Professor, and Professor at University of California, Berkeley (1983-present).