Southeastern Transportation Center: Proposal Cover Page
O/E Grant 2014-2015

UNIVERSITY:	University of Tennessee, Knoxville	
TITLE OF PROJECT:	**Connected and Automated vehicles: What are the implications of partial adoption?**	
FEDERAL FUNDS: $50,000		
Requested Amount: $50,000	**Proposed Duration: 18 months**	**Desired Start Date: April 1, 2016**
MATCHING FUNDS: $50,000 (inclusive of forfeited F&A costs from STC $ and start-up $)		
Source 1: Start-up account of Dr. Khattak	**Source 2:**	
DEPARTMENT SUBMITTING PROPOSAL:		
PI Name/Title: Asad Khattak, Beaman Professor of Civil & Env. Eng. – CO-PI Jackeline Rios-Torres, Research Coordinator I Civil & Env. Eng. Department		
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Signature:	**Date: February 12, 2016**	
SUBCONTRACTING INSTITUTION: University of Tennessee		
ADMINISTRATIVE REPRESENTATIVE AUTHORIZED TO CONDUCT NEGOTIATIONS: N/A		
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ADMINISTRATIVE ORGANIZATION'S REPRESENTATIVE: UT, Knoxville		
Name/Title: N/A		
Address:		
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Fax:		
Email:		
Signature:	**Date:**	
OTHER REQUIRED SIGNATURES: None		
Name/Title:		
Address:		
Phone:		
Fax:		
Email:		
Signature:	**Date:**	

STC Research Project Description

Project Title: Connected and Automated vehicles: What are the implications of partial adoption?

Principal Investigators: Asad J. Khattak & Jackeline Rios-Torres
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Project Start Date: April 1, 2016 **End Date:** Sep. 1, 2017
Other Milestones, Dates: Quarterly & final reports; abstracts and articles submitted for presentation and peer-reviewed publication.
Project #: To be Assigned

Project Objectives: The objectives of this study are to:

1) Using realistic behavioral rules, develop a tool to simulate scenarios in which fully automated vehicles interact with partially automated vehicles in a coordinated system.
2) Analyze the implications that such interaction among vehicles with different levels of automation have on the safety and congestion in a traffic coordination system.
3) Propose countermeasures to improve the safety and congestion in a coordinated traffic system.

Abstract: With increasing attention focused on connected and automated vehicles (CAVs), this study will explore the opportunities and challenges associated with the adoption and use of such systems. CAVs represent the opportunity to greatly enhance safety, and reduce both congestion and emissions. Adoption of new technologies is often messy, even if they follow the familiar S-shaped adoption curve. Among the challenges is how will partial adoption of automated technologies, characterized by levels 0 to 5, work in a transportation network? We will develop simulations to help us understand the impacts of CAVs in transportation networks. Specifically, our research will focus on developing network simulations and algorithms to understand how variations in driving control will impact safety and congestion. Specifically, this exploratory study will use novel tools to understand the implications of partial automation on the traffic network performance. This problem is made complex by the unpredictable nature of partial automation, where humans have different levels of involvement. The study will account for traveler behavior under various automation scenarios and model the traffic flows at nodes in a network (merging facilities and intersections). In particular, the study will develop simulations and algorithms to better understand how variations in driving control will impact safety and congestion.

Task Descriptions: The project will consist of the following key tasks: 1) Simulator implementation; 2) Safety and congestion implications analysis; 3) Safety and congestion implications evaluation; 4) Solutions to improve safety; and 5) Preparation and submission of quarterly and final reports, as well as abstracts for conferences and manuscripts for peer-reviewed publication.

Total Budget: The budget includes $50,000 from the STC with a commitment of $50,000 in matching funds. An itemized budget is included as Appendix A.

Student Involvement (Thesis, Assistantships, Paid Employment): The project team will include Mr. Mohsen Kamrani, who is a 1st year PhD student in transportation at University of Tennessee, Knoxville.
Relationship to Other Projects: 1. This project will be highly synergistic to with major research initiatives of STC, but uniquely understand the implications of connected and automated vehicles on the traffic network. 2. The project will further strengthen a key strategic area of research focus at STC, by addressing the areas of **safety and congestion through connected and automated vehicles**.
Technology Transfer Activities: The following activities are expected: 1. Conference presentation: Submit at least one paper for presentation at a topical conference, e.g., "19th International Conference on Connected Vehicles" in Boston USA, 2017 or TRB 2017. 2. Technical paper: A technical paper based on the findings will be submitted to a conference and a refereed journal for review and publication. The journals to be considered will include ASCE Journal of Transportation Engineering, IEEE Transactions on Intelligent Transportation Systems, Journal of Safety and Security, Transportation Research Record, and Accident Analysis and Prevention. 3. Press releases: Principal Investigators will work with STC staff to produce press releases for technology transfer purposes. 4. Contact with industry: The project will engage key stakeholders from automotive companies in the state such as VW and Nissan.
Potential Benefits of Project: 1. Generating new knowledge regarding safety in traffic networks comprising of connected and partially automated vehicles: the study will include analysis of the safety issues that could arise when partially automated vehicles interact with fully automated vehicles and how those issues could affect the efficiency, in terms of fuel consumption, of the vehicles under control. 2. Developing tools for safety analysis: The project will generate a simulation tool to study scenarios in which fully connected and automated vehicles interact with connected, partially automated vehicles under the commands of a traffic coordination system. 3. The project will contribute to work force development through the education, training, and professional development opportunities provided to students engaged in the project.
TRB Keywords: Connected vehicles, automated vehicles, crashes, safety, modeling, analysis support tool

Problem Statement:

The economic impacts of traffic crashes in the US amounted to $836 billion of losses in 2010 [1]. Traffic congestion is also responsible for substantial social, environmental and financial costs [2]. Due to economic and population growth as well as changes in social interactions and travel behavior, an INRIX report estimates congestion costs $124 billion per year in 2013, and this number is expected to grow to $186 billion in 2030. Some of the congestion is due to control systems. Efforts to address the congestion issue includes the use of adaptive traffic lights [3],[4],[5], and attempts to optimize the operation of ramp metering [6], [7], [8], [9].

Considering the increased consciousness regarding the need for a safer and more sustainable transportation system [2], future traffic control strategies should increase the safety of the traffic network and encourage more efficient use of the roads and significant reduction, if not elimination, of stop-and-go driving. Connected an Automated Vehicles (CAV) can play a key role to address those issues. In automated vehicles at least some control functions are performed without direct driver input [10], [11] and connected vehicles allow for vehicle-to-vehicle V2V and vehicle-to-infrastructure V2I communication [12], [13]. As semi-automated vehicles can already be found in the market, a widespread use of CAV is anticipated in the near future.

A system of connected and automated vehicles (CAV) offers significant potential to reduce crashes and related losses as well as reduce traffic congestion. In particular, autonomous traffic coordination control strategies are receiving increased attention as they show potential to address these issues and even reduce fuel/energy consumption [14], [15], [16], [17]. The development and deployment of CAVs opens up a world of possibilities and questions. Our research will focus on vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications to tackle the difficult task of integrating automated controls with the complex and unpredictable part of partial automation, where humans have different levels of involvement. Some of them will still be doing distracted driving, which has become a significant factor in motor vehicle crashes, particularly with the relative omnipresence of mobile phones and increasing market share of "infotainment systems" in vehicles [18]. For example, during test drives of Google's driverless cars over the past couple of years, of the 14 recorded collisions involving these cars, 11 were caused by distracted drivers of other vehicles rear-ending the self-driving vehicle (CBS News, 2015). Among the challenges is how will partial adoption of automated technologies, characterized by levels 0 to 5, work in a transportation network? In this context, *our research will focus on developing behaviorally-based simulations and algorithms to understand how variations in driving control will impact safety and congestion.*

The interaction between automated and non-automated vehicles raises many concerns as the driving styles and driving responses to the information they receive vary from driver to driver and that can become a disturbance in the traffic network. The main of those challenges is related to the safety in the traffic network system. This research project looks forward to answering fundamental research questions:

(1) What are the safety and congestion implications of having vehicles with different levels of automation interacting in the implementation of a traffic coordination control strategy for a particular scenario, e.g., an intersection, a merging on-ramp, a roundabout?
(2) What are appropriate measures to counteract the disturbances produced in partially automated mixed traffic and improve safety and congestion in such scenarios?

In this research, methods will be developed to analyze the interaction of vehicles with different levels of automation. And how they can impact the safety and congestion of a particular traffic coordination control strategy. Strategies that help in minimizing the safety impacts in the system will be evaluated. The project's expected outcomes include a better understanding of the safety considerations that are relevant for the interaction of vehicles with different levels of automation in traffic coordination control strategies as well as countermeasures to improve the safety of the traffic network in the particular scenario to be considered, i.e., merging facilities. Additional outcomes are articles submitted for peer-reviewed publication, presentations at topical venues and a technical report with the efforts of the project and their outcomes will transfer the knowledge generated in this project. The project will also contribute to work force development through education and training opportunities provided to students engaged in the project.

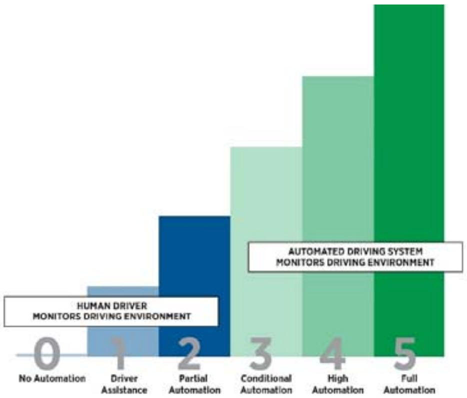

Figure 1. Levels of vehicle automation (Source: SAE).

Research Objectives

Works related to the design of traffic coordination control strategies are available since 1969 [19]. Subsequently, different methods have been proposed using either centralized or decentralized control concepts; a survey of the methods can be found in Rios-Torres et al. [20]. Most of these concepts have been designed under the assumption that all the vehicles under control are fully automated. Traffic coordination control at merging roads to coordinate mixed automated and non-automated vehicles have also been developed [21]. However, no studies were found that explore the safety implications of such coordination systems involving different levels of vehicle automation. The main research objective of this study is to understand the impacts that different vehicle automation levels can have in the safety and efficiency of a traffic coordination system at intersections. The significance of this problem is that it allows us to (1) analyze the safety issues that can arise in the implementation of traffic coordination strategies, and (2) propose strategies or counter-measures that can increase the safety of these coordination systems.

Research Approach

The main tasks are to:

(1) Implement a behaviorally-based simulator that allows representing the uncertainties that can be produced by drivers and vehicles with low levels of automation in the traffic coordination process.
(2) Analyze how the uncertainties produced by human driving can affect the safety (crashes) and congestion of the traffic coordination system.
(3) Evaluate the risk of crashes and congestion in the traffic network under coordination.
(4) Propose strategies to minimize the effects of uncertain driver decisions in the system.
(5) Disseminate the findings through various outlets.

Task 1: Developing a behaviorally-based vehicle simulator. The main outcome of this task is a simulator that integrates realistic and often uncertain driver behavior. The SAE standard J3016 [11] define the levels of automation for a vehicle on a scale from 0 to 5, with 0 corresponding to no automation and 5 to full automation (Figure 1). By following this scale, we want to focus our analysis in the interactions between vehicles with levels of automation 0, 3 and 5.

For the no automation case, we assume that the driver is receiving some sort of driving feedback assistance, i.e., a set of instructions regarding the speed profile that he/she must follow to guarantee safety on the road. For level 3 which is partial automation, it is assumed that the vehicle is autonomous. However, the driver would eventually be required to take over the control of the car and follow the required speed profile provided by a driver feedback system. In both cases a human driver is required for all or a portion of the trip, and thus, a driver model is required as a part of the vehicle simulator.

Microscopic simulators use car following models to describe driver behavior, this impose a limitation when trying to explore the safety implications of CAVs on traffic coordination systems. To overcome this issue, we will implement a vehicle-driver simulator in MATLAB/SIMULINK that will be later used in the framework of the traffic coordination system. The simulator will model the vehicle dynamics and driver behavior as a feedback control system (Figure 2) in which the driver is the controller [22], [23]. Because our focus is to analyze driver behavior in the framework of a traffic coordination system for vehicles crossing an intersection, we are concerned with the longitudinal control of the vehicle, i.e., the braking/acceleration maneuvers executed by a driver to keep the vehicle speed as close as possible to the desired reference speed.

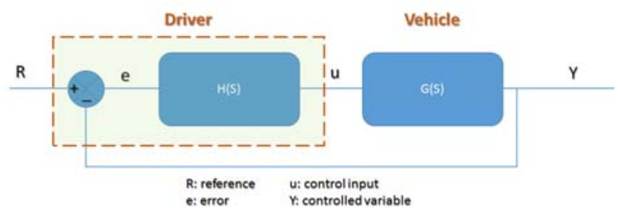

Figure 2. Basic control structure of the simulator. "R" is the desired speed reference and "Y" the actual vehicle speed

To achieve the goal of simulating the driver response to instructions received by a driver assistance system, we plan to model the driver as a PID controller [24] that will try to minimize the error between a desired optimal speed profile and the actual vehicle speed by adjusting the control input, i.e., acceleration/braking. The control input $u(t)$ of a PID controller combines a proportional term (proportional to the error), an integral term (proportional to the integral of the error) and a derivative term (proportional to the derivative of the error) and can be described by the equation below (1).

$$u(t) = K\left(e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d \frac{d}{dt}e(t) \right) \quad (1)$$

Where $e(t) = (R - Y)$ is the error between the desired reference (R) and the actual output (Y) of the control system and K, T_i, and T_d are the parameters of the controller. The control action of the integral term is based on past system states, the proportional control action is based on the present and the derivative control action is a "predictive" control action, it tries to predict the future output to minimize the error. The three parameters need to be tuned to achieve reduced error between the desired and actual system output.

To have an approximation to different driving styles, we can have three different PID controllers ("driver" models), tuned to achieve three levels of accuracy when following the reference driving profile. They could represent a calm, a normal, and an aggressive driver.

The vehicle velocity is calculated from the vehicle longitudinal dynamic equation (2):

$$m\dot{v} = F_{trac} - \frac{1}{2}\rho_{air} C_d A_f v^2 - mg\sin(\alpha) - mgC_r\cos(\alpha) \tag{2}$$

Where ρ_{air} is the air density, C_d is the drag coefficient, A_f is the vehicle frontal area, v is the vehicle longitudinal speed, m is the vehicle mass, g is the acceleration due to gravity, α is the road grade and C_r is the rolling resistance coefficient. The tractive force F_{trac} is calculated as a function of the acceleration, and it has to account for the limitations of the vehicle powertrain components.

Task 2: Safety implications analysis. In this task, we will use "realistic" driving profiles of the simulated "human" drivers as a feedback into the traffic coordination controller to determine the implications on safety (specifically we will evaluate the number of crashes) that the uncertain driving behavior can have on the coordinated fleet of vehicles. In this phase of the project, we will use the traffic coordination control framework for merging on-ramps proposed in [17]. In this framework, the vehicles are optimally coordinated while they are merging into a main road, in such a way that collisions are avoided and the total fuel consumption is minimized.

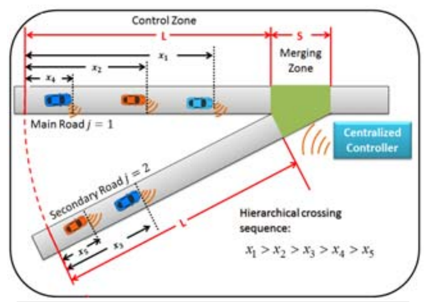

Figure 3. Hierarchical vehicle sequence

The traffic coordination control system operates in a centralized way, i.e., there is a central controller that coordinate all the vehicles that are inside a control zone. When a vehicle reaches the *control zone* it starts communicating with the centralized controller. Then, the controller defines a hierarchical vehicle sequence starting with the vehicle that is closer to the *merging zone* (Figure 3). In the analysis a single subscript is used to identify each vehicle on the *control zone*, starting from the one that is closest to the *merging zone*, i.e., $i = 1$, to the one which is farthest from the *merging zone*. The control problem to optimally coordinate *n* vehicles is formulated as to minimize the L^2-norm of the control (acceleration/deceleration):

$$\min_{u_i} J = \min_{u_i} \frac{1}{2} \sum_{i=1}^{n} \int_0^{t_i^f} u_i^2 dt \tag{3}$$

Subject to:

Vehicle dynamics:	Initial conditions:	Final conditions:	Safety constraints:
$\dot{x}_i = v_i$	$x_i(t_i^0) = 0$	$x_i(t_i^f) = L + S - x_i(t)$	Rear end collision avoidance: $t_{i+1}^{\delta} \ge t_i^{out}$
$\dot{v}_i = u_i$	$v_i(t_i^0) = v_{des}$	$v_i(t_i^f) = v_{des}$	Lateral collision avoidance: $t_{i+1}^{in} \ge t_i^{out}$

Where t_i^0 is the time that the vehicle *i* enters the *control zone*, $x_i(t)$ is the distance at time *t* that the vehicle *i* has proceeded inside the *control zone*, and t_i^f is the time the vehicle *i* exits the *merging zone*. Thus, the safety constraints are stated as time constraints that will be defined in such a way that a safe headway is kept between consecutive vehicles.

The main assumption in this framework is that all the vehicles in the system are in level 5 of automation as defined by SAE, i.e., full automation (see figure 1). Thus, we plan to use the realistic driving profiles as a feedback to the central controller, to analyze how well the algorithm can handle the fact that the partial automated vehicles cannot follow the commanded velocity profile with 100% accuracy and what kind of safety issues arise under these conditions.

To analyze the safety implications, we assume that the merging vehicles are vehicles with level 1, level 3 and level 5 of automation.

- Level 1 vehicles: we assume that the centralized controller send the optimized velocity profile to the vehicle and this information is displayed to the driver who will try to follow it.
- Level 3 vehicles: we assume that a portion of the driving profile have to be followed by the driver, while the rest of it will be followed by the vehicle. In this case, it is particularly important to analyze the implications of the response time of the driver, when he/she is requested to take over the control of the vehicle.
- Level 5 vehicles: As they are fully automated, we assume they can accurately follow the demanded optimal velocity profile.

With these assumptions, we will use the “human produced” driving profiles to analyze how many crashes occur in the system when different rates of level 1 (L1), level 3 (L3) and level 5 (L5) vehicles appear in the fleet of vehicles to be controlled. To be able to evaluate safety, we propose to simulate a baseline scenario in which all the vehicles have level -1 of automation, i.e. current situation, there is not automation, not coordination nor any kind of feedback assistance for the drivers. Then, we propose to analyze 11 different scenarios with different penetration rates of L-1, L0, L3 and L5 vehicles (Table 1).

Table 1. Study design: Simulation scenarios

	$S_{Baseline}$	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
L-1	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
L0	0%	100%	93%	85%	60%	40%	20%	0%	0%	0%	0%
L3	0%	0%	5%	10%	25%	40%	50%	50%	30%	10%	0%
L5	0%	0%	2%	5%	15%	20%	30%	50%	70%	90%	100%

Task 3: Crash risk evaluation. The study will explore how variations in speed and longitudinal accelerations are related to safety and congestion. For example, the MOVES model can be used to estimate fuel consumption and emission or we can use the polynomial metamodel proposed in [25] that yields vehicle fuel consumption as a function of the speed and acceleration:

$$\dot{f}_v = \dot{f}_{cruise} + \dot{f}_{accel}, \qquad (4)$$

where $\dot{f}_{cruise} = w_0 + w_1 \cdot v + w_2 \cdot v^2 + w_3 \cdot v^3$ estimates the fuel consumed by a vehicle traveling at a constant speed v, and $\dot{f}_{accel} = a \cdot (r_0 + r_1 \cdot v + r_2 \cdot v^2)$ is the additional fuel consumption when the vehicle accelerates with α. The polynomial coefficients w_j, *j*= 0,…,3, and r_k, *k*=0,1,2, are usually calculated from experimental data. Following a similar methodology (illustrated in Figure 4), we want to explore the likelihood of defining the crash risk as a function of speed (v) and vehicular jerk ($\dot{a}$):

$$C_{risk} = f(v, \dot{a}) \qquad (5)$$

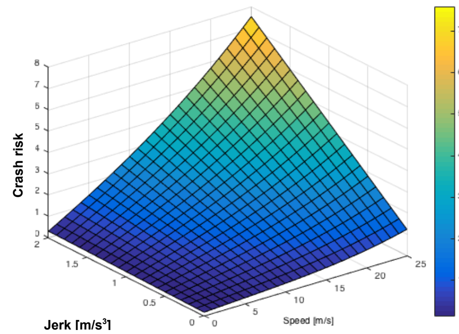

Figure 4. Illustrative model for crash risk function

Task 4: Propose solutions to improve safety and congestion. There is evidence that variations in speed can increase crash risk. Thus, the focus of this task is to improve safety and congestion. For example, the efforts will be concentrated on the derivation of solutions to minimize the effects of the disturbances when merging vehicles are being optimally coordinated. If the C_{risk} function can be derived, we would propose the implementation of a driver feedback system that would help the drivers to achieve a safer driving style. This feedback system, can be used in real time to warn the driver if an unsafe driving style is detected. It can also provide an offline score that will help the driver realize that changes are needed to achieve a lower risk of crash while driving.

Task 5: Final report and paper preparation. Quarterly reports and a final report will document the findings of this research project. Additionally, abstracts will be submitted to topical conferences like the Transportation Research Board Annual meeting for technical presentations, and at least one manuscript will be submitted for peer reviewed publication.

Research Duration and Cost

The proposed schedule is:

Task	Month																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Task 1	■	■	■	■	■	■	■											
Task 2							■	■	■	■	■	■						
Task 3									■	■	■	■	■	■				
Task 4													■	■	■	■	■	
Task 5			■	■			■	■			■	■			■	■	■	■

Qualifications of the Research Team

The research team consists of Dr. Khattak, Dr. Rios-Torres, who each have significant experience and expertise in transportation safety in general and various aspects related to congestion and connected/automated vehicles. Dr. Khattak has successfully led more than more than 50 research projects and mentored scores of graduate and undergraduate students. The following is a brief summary of their qualifications pertinent to this project. Appendices B and C provide additional details for Drs. Rios-Torres and Khattak and their roles on the project.

Dr. Khattak's relevant work covers a broad spectrum of topics that relate to connected and automated vehicles as well as intelligent transportation systems, e.g., incident management and the role of incidents and accidents during evacuations. He has contributed to the creation of knowledge by authoring/co-authoring 108 scholarly journal articles on transportation, 52 technical reports to research sponsors, and making over 130 presentations at professional conferences. As a principal- or co-investigator, obtained 64 sponsored projects totaling more than $9.0 million. He has disseminated the scientific knowledge as Editor-in-chief of Science Citation Indexed *Journal of Intelligent Transportation Systems*, (2-year impact factor of 1.377 in 2014 and Associate Editor of the *Intl. J. of Sustainable Transportation*, (2-year impact factor of 2.447 in 2014). He is special adviser to Journal of Transportation Safety and Security, Editorial Advisory Board Member Analytic Methods in Accident Research. He has created unique opportunities in engineering research and education and was invited by the Governments of Portugal, South Korea, and France to work on intelligent transportation research and education issues. Active in the Transportation Research Board as a member of the Committee on User Information Systems; co-chair of TRB Advanced Traveler Information Systems sub-committee, 2003-to date. He has developed and delivered new courses in intelligent transportation systems and has relevant expertise in the development and implementation analysis of intelligent transportation systems. His highly cited works include behavioral response to advanced traveler information, traffic incident management, and transportation safety studies. His recent work includes vehicle connectivity and analysis of large-scale datasets, as well as collaborations with faculty from other fields. A National Science Foundation research grant and a peer-reviewed publication below illustrate some of his relevant work:

1. Khattak—Principal Investigator, with Chakraborty & Nambisan as Co-PIs, Study of Driving Volatility in Connected and Cooperative Vehicle Systems, US National Science Foundation, University of Tennessee at Knoxville, $399,793, Sept. 1, 2015-Aug 31, 2018.
2. Wang X., A. Khattak, J. Liu, G. Amoli, & S. Son, What is the level of volatility in instantaneous driving decisions? *Transportation Research* Part C, Volume 58, Part B, September 2015, pp. 413-427.

Dr. Jackeline Rios-Torres received her PhD Degree in Automotive Engineering from Clemson University in 2015. She worked as an intern at ORNL where she finished her Ph.D. dissertation developing an energy-efficient, online, optimal coordination system for merging vehicles. She has worked on a number of projects related to connected and automated vehicles, intelligent transportation systems, eco-driving and energy management. A key aspect of Dr. Rios-Torres' research efforts have been the broad variety of scenarios she has used to analyze and develop strategies to increase the energy efficiency in the transportation sector. Such scenarios include individual vehicles, driver-vehicle interaction and fleet of vehicles. Dr. Rios-Torres has authored/coauthored more than 10 research papers and she has extensive hands-on experience developing MATLAB and Simulink applications.

Appendix A: Itemized Budget and Overview

Southeastern Transportation Center
Proposed Budget
O/E Grant 2014-2015

Title: Connected and Automated vehicles: What are the implications of partial adoption?

University: **University of Tennessee, Knoxville**

		Federal Funds	Matching Funds
Salaries:			
	Faculty	17,969	
	Post-Doc	13,300	
	Administrative Staff		
	Other Staff		
	Graduate Student Salaries/Stipends	0	24,000
	Undergraduate Student Salaries/Stipends		
	Total Salaries/Stipends		
	Benefits (including student health insurance)	7,623	1680
	Total Salaries and Benefits	**38,892**	**25,680**
Other Direct Costs:			
	Permanent Equipment		
	Expendable Equipment and Supplies	200	
	Computer Costs		
	Non-salary Education Costs – tuition/fees		8000
	Other Costs: (specify)		
	Printing / duplication		
	Postal expense		
	Communication		
	Conference Registration / Fees		
	Travel	590	
	Computer Costs		
	Other miscellaneous costs:		
	Total Other Direct Costs	790	
	Indirect Costs at 26%	**10,317**	**17,177**
TOTAL COSTS		**49,999**	**50,857**

Budget Overview

0.9 month of support for Dr. Khattak and 3.8 month of support for Dr. Rios-Torres is included in the budget to support their efforts over the duration of the project. One graduate student assistant is to work on the project during the 2016-2017 academic year and 2017 summer. They will be on 25 percent Research Assistantship appointments.

Annual salary increases and fringe benefits are estimated for individuals based on the policies at UT.

The travel budget is to support participation in a conference to present papers related to the project.

The graduate student who will be working on this project starting in April 2016 will have GTA/GRA appointments. Therefore, the associated tuition fees will be covered from the departmental fee waiver pool, and they are shown as a match.

The start-up account for Dr. Khattak will cover the assistantships, wages, and benefits for the student. Since these will be from his start-up accounts at UT, he will not be subject to F&A costs. However, the unrecovered F&A costs are used as match.

Facilities and Administrative (F&A) costs are calculated based on the policies at UT and the STC program. The forfeited F&A costs are used as part of the matching funds.

Appendix B: Biographical Summary of Research Team

Asad Khattak (Principal Investigator)

As professor and researcher, Dr. Khattak has worked on several projects related to transportation safety and congestion. Dr. Khattak's safety work covers a broad spectrum of topics that relate to automobile, bicycle, and pedestrian modes as well as transportation network performance (incident management and the role of incidents and accidents during evacuations), as well as volatility of drivers in connected and automated vehicle environments.

Knowing that visualization, modeling and simulation tools can potentially improve safety, Khattak has recently used big data to visualize and model the relationship between volatile driving and its effects on safety. He applies rigorous analytical methods (ordered probability, negative binomial, and hierarchical models as well as spatial analysis techniques) and Bayesian statistics to analyze various safety issues: driving volatility, collisions between cars and trucks, vehicle rollover, weather-related crashes, speed limit changes, rear-end crashes, work zones, pedestrian and bicycle crashes, and secondary traffic incidents.

Dr. Khattak's safety innovations have improved data collection and application of analytical methods. Large safety databases often lack accessible crash data on certain high-risk locations such as work zones (or railroad crossings) or intersections. Given that little is known about how specific roadway characteristics influence injury, Dr. Khattak has investigated crashes in various high-risk locations using new methods to obtain crash data. For example, his team used police report narratives to extract new variables that are not available in standard police crash reports. The variables provide new insights into the role of new variables on safety outcomes.

Dr. Khattak has extensive academic publishing experience. He has authored or coauthored 95 scholarly journal articles and is editor of Journal of Intelligent Transportation Systems, which is Science Citation Indexed with a 2-year impact factor of 1.377. Dr. Khattak is Associate Editor of SCI-indexed International Journal of Sustainable Transportation, and he serves on the editorial advisory boards of Transportation Research, Part C, and Analytic Methods in Accident Research. He is involved in the Journal of Transportation Safety and Security as a special adviser.

Dr. Jackeline Rios-Torres (Co-Principal Investigator)

Dr. Jackeline Rios-Torres received her PhD Degree in Automotive Engineering from Clemson University in 2015. She worked as an intern at ORNL where she finished her Ph.D. dissertation developing an energy-efficient, online, optimal coordination system for merging vehicles.
She has worked on a number of projects related to connected and automated vehicles, intelligent transportation systems, eco-driving and energy management.

A key aspect of Dr. Rios-Torres' research efforts have been the broad variety of scenarios she has used to analyze and develop strategies to increase the energy efficiency in the transportation sector. Such scenarios include individual vehicles, driver-vehicle interaction and fleet of vehicles. Dr. Rios-Torres has authored/coauthored more than 10 research papers and she has extensive hands-on experience developing MATLAB and Simulink applications.

Appendix C: Roles, Responsibilities & Project Management

Dr. Khattak will serve as the Principal Investigator and will be responsible for the overall management of the project and statistical analysis of the FRA collision and inventory data. He has successfully managed several research projects and is an expert in the area of statistical modeling. He will mentor Mr. Mohsen Kamrani, first year graduate student, who will work on the project. Dr. Rios-Torres will serve as Co-Principal Investigator and she will be responsible for developing the simulation tool, a topic on which she has significant experience over the past 6 years. Dr. Khattak will be primarily responsible for mentoring and working with the graduate student and Dr. Rios-Torres will assist in this task. They will work closely with biweekly team meetings on literature review, development of analytical, modeling and decision support framework efforts. They will lead the students in developing presentations, manuscripts and technical reports.

Appendix D: References

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