NTC Program Progress Performance Report (PPPR) Information Form

For P.I.'s Use

On a semi-annual basis the NTC sponsored P.I. must report Program Progress Performance Report (PPPR) using the format specified in this PPPR Information Form. The form must be submitted electronically to the corresponding NTC Associate Director by 9/15/2015.

Cover Period: 4/1/2015 – 9/30/2015

NTC Funded Project Information (Round/Year 1, 2013-2014)	
University Name	Arizona State University
Project Title	Congestion Mitigation Potential of Autonomous (Driverless) Vehicles: A Scenario-Based Approach
Principal Investigator	Xuesong Zhou
PI Contact Information	Email: xzhou74@asu.edu Phone: 480-965-5827

The form includes the following six parts:

- Part I – Accomplishments: What was done? What was learned?
- Part II – Products: What has the program produced?
- Part III – Participants & Collaborating Organizations: Who has been involved?
- Part IV – Impact: What is the impact of the program? How has it contributed to transportation education, research and technology transfer?
- Part V – Changes/Problems

Supplementary documents/materials can be attached to this form with the submission.

Part I – Accomplishments: What was done? What was learned?	
The information provided in this section allows the OST-R grants official to assess whether satisfactory progress has been made during the reporting period.	
Reporting Period	**4/1/2015 – 9/30/2015**
1. What are the major goals of the program?	The National UTC aims to promote strategic transportation policies, investment, and decisions that bring lasting and equitable economic benefits to the U.S. and its citizens. The Center is concerned with the integrated operations and planning of all modes serving the nation's passenger and freight transportation system, including the institutional issues associated with their management and investments. A balanced multi-modal approach will be used that considers freight and passenger travel mobility, reliability, and sustainability, as well as system operations during periods of both recurring and non-recurring incidents, including response to major emergencies. The modes in this theme include highway, transit, rail, and inter-modal interfaces including ports, terminals and airports. In particular, the center focuses on research, education, and technology transfer activities that can lead to (1) Freight efficiency for domestic shipping and for our international land, air, and sea ports; (2) Highway congestion mitigation with multi-modal strategies; and (3) Smart investments in intercity passenger travel facilities such as high speed rail. Major center activities are as following: • **Advanced & Applied Research Promoting Economic Competitiveness:** Our research activities are multimodal/intermodal and multidisciplinary in scope, with the aims of addressing nationally and regionally significant transportation issues pertinent to economic competitiveness and providing practice-ready solutions. • **Education, Workforce Development, Technology Transfer, & Diversity** The consortium is committed to providing high-quality transportation education and workforce development programs for a broad and diverse audience. Center's efforts will support the development of a critical transportation knowledge base and a transportation workforce that is prepared to design, deploy, operate, and maintain the

	complex transportation systems of the future.
2. What was accomplished under these goals?	In this research, Dr. Xuesong Zhou from Arizona State University has worked closely with Dr. Ram M. Pendyala from ASU and currently at Georgia Institute of Technology. Based on a simplified car following model for individual self-driving cars with linear safety spacing rules, we have extensively studied the macroscopic flow-density relationship under microscopic self-driving behavior models. This connection helps to form a flow prediction mechanism to first predict bottleneck evolution along a corridor, through the an extension of Newell's 3 detector model, and further manage the performance of independently operated self-driving cars under normal and irregular conditions. A medium-scale and a large- scale example using the Phoenix regional network are used to show the potential of a system-wide dynamic programming-based vehicle trajectory optimization method that can coordinate the use of self-driving cars in real time, with various goals of maximizing flow capacity and minimizing energy use.
3. How have the results been disseminated?	• The research results were selected for presentation titled "Minimum number of cars a city needs in a fully coordinated vehicle sharing system", in Institute for Operations Research and the Management Sciences (INFORMS) annual meeting, November 2014, at San Francisco, CA. • Dr. Zhou presented the research results in the Industrial Engineering department at University of Arizona as a guest speaker, March 2015. • The research results were presented as a poster in Fifth Annual Graduate Research Symposium at Arizona State University, March 2015. • The research resulted a paper which has been submitted in Transportation Research Part B and now is available at http://arxiv.org/ftp/arxiv/papers/1507/1507.02731.pdf. • The latest results of our research are selected for presentation titled "Lagrangian Relaxation Solution Approach for the Vehicle Routing Problem with Pickup and Delivery", in Institute for Operations Research and the Management Sciences (INFORMS) annual meeting, November 2015, at Philadelphia, PA. • Our paper has been selected for presentation titled "A city

	with fully coordinated vehicle sharing system: finding optimal solutions for vehicle routing problem with pickup and delivery services with time windows" as one of the three best ITS Arizona Graduate Student Research Paper. The winner will be announced after presentation on October 1st, 2015. • The paper titled "A city with fully coordinated vehicle sharing system: finding optimal solutions for vehicle routing problem with pickup and delivery services with time windows" has been submitted for presentation in next TRB, January 2016.
4. What do you plan to do during the next reporting period to accomplish the goals? (10/1/2014 – 3/10/2015)	• Improve our C++ code so that our model would be applicable for large-scale transportation networks with thousands of travelers. • Solve the VRP with pickup and delivery by some strong and fast heuristics and compare our current results with them. • Apply our current C++ code to attack to other similar optimization problems such as inventory routing problem and solve them efficiently.

Part II – Products: What has the program produced?

Publications are the characteristic product of research projects funded by the UTC Program. OST-R may evaluate what the publications demonstrate about the excellence and significance of the research and the efficacy with which the results are being communicated to colleagues, potential users, and the public, not the number of publications. Many research projects (though not all) develop significant products other than publications. OST-R may assess and report both publications and other products to Congress, communities of interest, and the public.

Reporting Period	**4/1/2015 – 9/30/2015**
1. Journal publications:	The research resulted a paper titled "Finding Optimal Solutions for Vehicle Routing Problem with Pickup and Delivery Services with Time Windows: A Dynamic Programming Approach Based on State-space-time Network Representations" which has been submitted in Transportation Research Part B and now is available at http://arxiv.org/ftp/arxiv/papers/1507/1507.02731.pdf.

2. Books or other non-periodical, one-time publications	
3. Other publications, conference papers and presentations	• The research results were selected for presentation titled "Minimum number of cars a city needs in a fully coordinated vehicle sharing system", in Institute for Operations Research and the Management Sciences (INFORMS) annual meeting, November 2014, at San Francisco, CA. • Dr. Zhou presented the research results in the Industrial Engineering department at University of Arizona as a guest speaker, March 2015. • The research results were presented as a poster in Fifth Annual Graduate Research Symposium at Arizona State University, March 2015. • Dr. Zhou presented the research result with a title of "Solving Simultaneous Vehicle Route Guidance and Traffic Signal Optimization Problem Using Space-Phase-Time Hypernetwork" on July 21, 2015 at 2015 Automated Vehicles Symposium, Michigan. • The latest results of our research are selected for presentation titled "Lagrangian Relaxation Solution Approach for the Vehicle Routing Problem with Pickup and Delivery", in Institute for Operations Research and the Management Sciences (INFORMS) annual meeting, November 2015, at Philadelphia, PA. • Our paper has been selected for presentation titled "A city with fully coordinated vehicle sharing system: finding optimal solutions for vehicle routing problem with pickup and delivery services with time windows" as one of the three best ITS Arizona Graduate Student Research Paper. The winner will be announced after presentation in October 1st, 2015. • The paper titled "A city with fully coordinated vehicle sharing system: finding optimal solutions for vehicle routing problem with pickup and delivery services with time windows" has been submitted for presentation in next TRB, January 2016.

4. Website(s) or other Internet site(s)	• The research resulted a paper titled "Finding Optimal Solutions for Vehicle Routing Problem with Pickup and Delivery Services with Time Windows: A Dynamic Programming Approach Based on State-space-time Network Representations"which has been submitted in Transportation Research Part B and now is available at http://arxiv.org/ftp/arxiv/papers/1507/1507.02731.pdf. • We have incorporated and tested agent-based calculation module in our open-source package Agent+ available at https://code.google.com/p/agent-plus/
5. Technologies or techniques	Lagrangian Relaxation Time dependent forward dynamic programming, routing and scheduling platform for automated vehicle optimization
6. Outreach activities	
7. Courses and workshops	Our undergraduate student, De'Von Jennings, has been working on a learning document for "Finding Optimal Solutions for Vehicle Routing Problem with Pickup and Delivery Services with Time Windows". The goal of this document is to teach undergraduate and graduate students how to solve ridesharing problems who are not familiar with ridesharing problems. This document is created in a question answer format so many questions that a general person would have about ride sharing are explained in great depth. This document also goes through examples of how six-node transportation operate in a state, space, time window. This document also does simple examples of how the ridesharing problems work when there is a single vehicle and a single request, single vehicle, and multiple requests, and multiple vehicles and multiple requests.
8. Inventions, patent applications, and/or licenses	
9. Other products	We have incorporated and tested agent-based calculation module in our open-source package Agent+ available at https://code.google.com/p/agent-plus/

Part III – Participants & Collaborating Organizations: Who has been involved?	
OST-R needs to know who has worked on the project to gauge and report performance in promoting partnerships and collaborations.	
Reporting Period	**4/1/2015 – 9/30/2015**
1. What organizations have been involved as partners?	RubyRide Company, services. Instead of using a "pay as you go" model, RubyRide offer a tiered subscription service starting at $200 a month with no limitations on trips, or an alternative personalized plan. RubyRide's research& development team has been working very closely with ASU's research team to analyze the travel time patterns extracted from RubyRide's GPS trace data and build high-performance vehicle routing algorithms to serve customer's need. RubyRide's research team is extremely interested in how the traffic data from different data sources can be better integrated to improve the efficiency and reliability of vehicle scheduling and routing system.
2. Have other collaborators or contacts been involved?	

Part IV – Impact: What is the impact of the program? How has it contributed to transportation education, research and technology transfer?	
DOT uses this information to assess how the research and education programs: • **increase the body of knowledge and techniques;** • **enlarge the pool of people trained to develop that knowledge and techniques or** • **put it to use; and,** • **improve the physical, institutional, and information resources that enable those people to get their training and perform their functions.**	
Reporting Period	**4/1/2015 – 9/30/2015**
1. What is the impact on the development of the principal discipline(s) of	The advent of new vehicular technologies has raised considerable debate about the potential impacts of such disruptive technologies on traveler behavior, demand for

the program?	transportation services and infrastructure, and transportation network performance. There are a number of disruptive technologies that are being considered with various levels of automation, control, and communication protocols. The US Department of Transportation has ongoing initiatives related to the deployment of connected vehicle systems, and the development of analysis, modeling, and simulation tools that would facilitate the analysis of the impacts and potential congestion benefits that such connected vehicle infrastructure systems may provide. The challenge facing the profession is that there is very little information, analysis, modeling, or behavioral studies that provide a rigorous prediction of the potential impacts of these technologies on human activity-travel behavior, freight systems, public transit and taxi systems, and household and firm location choices (land use).
2. What is the impact on other disciplines?	
3. What is the impact on the development of transportation workforce development?	The open-source learning package which is currently developed and enhanced within this research project, will provide a clean open-source code base to enable transportation researchers and software developers to continue to build upon and expand its range of capabilities to other simulation/optimization packages. The research result of this project will help to develop a rigorous framework that is founded on sound behavioral constructs and analytical methods that would allow the accurate estimation of the impacts of autonomous, driverless, connected, and other advanced vehicular technologies under a variety of scenarios
4. What is the impact on physical, institutional, and information resources at the university or other partner institutions?	
5. What is the impact on	

technology transfer?	
6. What is the impact on society beyond science and technology?	
7. Additional impacts	

Part V – Changes/Problems	
If not previously reported in writing to OST-R through other mechanisms, provide the following additional information or state, "Nothing to Report, if applicable:	
Reporting Period	**4/1/2015 – 9/30/2015**
1. Changes in approach and reasons for change	PI of this project has changed from Dr. Ram M. Pendyala to Dr. Xuesong Zhou, as Dr. Pendyala has moved to Georgia Institute of Technology on August 1st , 2014.
2. Actual or anticipated problems or delays and actions or plans to resolve them	N/A
3. Changes that have a significant impact on expenditures	N/A
4. Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards	N/A
5. Change of primary performance site location from that originally proposed	N/A