University Transportation Research Center - Region 2

Final Report

Empirical Analysis of Consumer Aspects of Autonomous Cars

Performing Organization: State University of New York (SUNY)

June 2016

Sponsor:
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

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.

Project No(s):
UTRC/RF Grant No: 49997-53-25

Project Date: June 2016

Project Title: Empirical Analysis of Consumer Aspects of Autonomous Cars

Project's Website:
http://www.utrc2.org/research/projects/empirical-analysis-consumer-aspects

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2.Government Accession No.	3. Recipient's Catalog No.
–	- -------	--------
4. Title and Subtitle Empirical Analysis of Consumer Aspects of Autonomous Cars		5. Report Date June 11, 2016
		6. Performing Organization Code -------------
7. Author(s) Scott LeVine		8. Performing Organization Report No. ----
9. Performing Organization Name and Address SUNY New Paltz		10. Work Unit No. -----------
		11. Contract or Grant No. 49997-53-25
12. Sponsoring Agency Name and Address University Transportation Research Center The City College of New York 137th Street and Convent Avenue New York, NY 10031		13. Type of Report and Period Covered Final report, June 1, 2015 to May 31, 2016
		14. Sponsoring Agency Code ----------

15. Supplementary Notes

16. Abstract

17. Key Words	18. Distribution Statement

19. Security Classif (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	10	

Form DOT F 1700.7 (8-69)

I. Introduction

This research was funded via a 'start-up grant' provided by the University Transportation Research Center, Region 2.

The objective is to advance the state-of-knowledge regarding Vehicle Automation technologies (cf. Anderson et al. 2014), by:

1) identifying theoretical issues raised by Vehicle Automation, and
2) supporting the collection of empirical evidence (through a *Stated Preference* survey instrument) to characterize consumer preferences for emerging Vehicle Automation concepts.

The field data collection (n=370) was undertaken by the firm *Qualtrics*[1]. Using UTRC2 funds, Qualtrics provided n=200 completed surveys, with sampling according to a pre-specified quota plan (see Section V). This was matched with Professional Development funding provided by SUNY to support the collection of an additional n=170 completed responses, for a total achieved sample of n=370 complete responses.

II. Overview of Work Plan

The research consisted of the following tasks:

- Theoretical analysis of mode choice descriptors and traffic flow regimes of Automated Vehicles
- Development of survey instrument
- Pilot-testing of survey instrument
- Fieldwork (data collection)

Initial QA/QC analysis of the empirical data is contained in Sections V and VI of this report; further analysis of the data collected in this study with advanced statistical methods is planned for later in Summer 2016.

III. Theory

The theoretical contribution of this study was twofold:

1) This research incorporated the *Assured Clear Distance Ahead* legal standard into the context of Autonomous Cars, which extends from earlier simulation of traffic streams of Autonomous Cars in that the vehicles are specified to follow *Defensive Driving* principles. This was done for both intersections (this analysis was published as Le Vine et al. 2016) and freeway segments (this analysis has been written up and is now under internal review, with submission-for-publication planned later in summer 2016).

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[1] www.qualtrics.com

2) This research identified and tested novel attributes of Automated Cars in the context of Mode Choice modeling. For instance, this is the first study of which the authors are aware to investigate travelers' willingness-to-pay for the possibility of traveling at very high speeds (up to 100 miles/hour) in an Autonomous Car.

IV. Data collection

The empirical fieldwork was undertaken by the market-research firm *Qualtrics*, under the direction of the author.

Data were collected in four batches:

1) April 25th, 2016
2) May 9th, 2016
3) May 17th, 2016
4) May 19th, 2016

The survey questionnaire was identical across the four batches, with the exception of the numerical values in the *Stated Preference* module. The logic for varying the numerical values in the *Stated Preference* module is to increase the variability in the dataset, which increases the robustness of the regression parameters and minimizes the opportunity for collecting *Stated Preference* that do not provide useful information in model estimation (see Section VI).

The fieldwork program was designed for the sample to be nationally-representative of U.S. adults in terms of age and gender (see next section). Qualtrics provided survey respondents from their online panel; respondents received incentives in the form of *"…points [that] can be pooled and later redeemed in the form of gift cards, skymiles, credit for online games, etc."*[2] The value of the incentives are variable, approximately equivalent to $1/respondent for completing this survey.

In the *Stated Preference* module, respondents were presented with the task of deciding how to travel to "see relatives that live in another part of the country", and were presented the following options:

- Drive a 'normal' car or take a bus (see next paragraph)
- A "Semi-Driverless" Car[3]

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[2] Personal communication from Qualtrics' S.J. Campbell, 4/14/2016

[3] The text describing the driverless cars is as follows:

Carmakers are now experimenting with driverless cars, which use sensors and computers to 'drive' themselves. It works a bit like an advanced form of Cruise Control, but you tell a driverless car the destination address of your journey and it is able to brake by itself, change lanes, and make turns to get you there. In the different scenarios, you will see two types of "driverless cars":

1) *A "semi-driverless" car can drive itself for nearly all of the journey (you just need to enter the destination address). However, you must keep your hands on the steering wheel and be ready to take control at any time in case something goes wrong to avoid accidents.*

- A "Completely Driverless" car
- Take a commercial air flight

The *Stated Preference* module consisted of 10 replications for each respondent. During each replication, the cost and duration of each of the options in the listing above were varied according to a pre-defined D-efficient design (cf. Rose and Bliemer 2009).

The questionnaire branched on the basis of whether or not the respondent holds a driver's license. In the *Stated Preference* module, licensed respondents were presented with the option to drive a 'normal' (i.e. not Autonomous) car if they wish, whereas unlicensed respondents were instead provided the option to take an inter-city bus. The questionnaires were otherwise identical, with the exception of a question about how fast drivers drive on Interstate Highways (which was not asked of unlicensed respondents).

Per the terms of the agreement, only complete responses (i.e. no partially-completed surveys) were provided in the final dataset. No surveys completed in less than 4 minutes were included in the final dataset. The average time to complete the survey was 14 minutes and 43 seconds.

V. Descriptive statistics

The breakdown of the sample's socio-demographic characteristics was as follows:

- Female/Male: 50%/50%
- Age:
  - 15-17: 1%
  - 18-20: 2%
  - 21-29: 16%
  - 30-39: 19%
  - 40-49: 16%
  - 50-59: 19%
  - 60-69: 16%
  - 70+: 11%
- Relationship status:
  - Married: 42%
  - Widowed: 5%
  - Divorced: 16%
  - Separated: 1%
  - Domestic Partnership: 3%
  - Single, but living with significant other: 8%
  - Single, never married: 25%
- Area of residence:

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2) *A "completely-driverless" car will drive itself for the entire journey, after you tell it your destination. You are free to do whatever you wish as you travel with no need to ever keep your hands on the wheel, as the car avoids accidents on its own.*

- Rural: 16%
    - Small town: 15%
    - Suburban: 46%
    - Urban: 22%
    - Unsure: 1%
- Approximate household income (last year):
    - Up to $25K: 24%
    - $25K to $50K: 26%
    - $50K to $75K: 20%
    - $75K to $100K: 16%
    - $100 to $200K: 10%
    - $200K+: 1%
    - Unsure: 1%
    - Prefer not to answer: 4%
- Presence of children (under age 18) in household
    - Yes: 31%
    - No: 68%
    - Prefer not to answer: 1%
- Driver's license status:
    - Yes: 90%
    - No: 10%

After the Stated Preference module (see Section VI below), the survey concluded with an additional set of questions. The first three of these questions asked about speed selection when driving, preferences for programming instructions of autonomous cars, and prioritization of their benefits In order to minimize primary effects for the questions consisting of agreement-with-statements or prioritization, the order in which these statements were presented was randomized (i.e. different for different respondents). In the tables that follow, color-coding is used for ease of interpretation (darkest green for the largest percentages and darkest red for the smallest percentages, excluding 'Unsure' responses):

- When you drive on Interstate Highways, which of these is closest to your typical cruising speed:
    - Slower than 60 miles/hour: 4%
    - 60 – 69 mph: 43%
    - 70 – 79 mph: 44%
    - 80 – 89 mph: 5%
    - 90+ mph: 0%
    - I don't usually drive on Interstate Highways: 2%
    - Unsure: 1%
    - Question not asked (unlicensed respondents): 10%

- Driverless cars will need to be programmed with instructions of how to follow behind other cars. Following closely can reduce the severity of traffic congestion, but this could increase the risk of rear-end crashes. Which of these statements best describes your view of how driverless cars should be programmed:
    - Driverless cars should be programmed to follow closely behind the car ahead of it in traffic, in order to reduce traffic congestion, even if this increases the possibility of rear-ending the car ahead: 9%
    - The person riding in a driverless car should have the choice of whether to leave a large distance behind the car ahead of it, if they wish to reduce the possibility of rear-ending the car ahead, even if this makes traffic congestion worse: 48%
    - Driverless cars should be programmed to leave a large distance behind the car ahead of it, in order to reduce the possibility of rear-ending the car ahead, even if this makes traffic congestion worse: 42%

Driverless cars may open up new possibilities. Please rank how important each of the following items would be to you, with 1 meaning "Most Important" and 5 meaning "Least Important":	**Most important**				**Least Important**
Being able to read, sleep, send text messages or do other activities inside the car besides driving, while the car does the driving	9%	19%	23%	25%	23%
Being able to send a driverless car to pick up or drop off packages, groceries, or children, without a human driver inside the vehicle	13%	17%	16%	22%	32%
Having the highest possible level of safety in a driverless car	51%	12%	12%	10%	15%
Having traffic congestion reduced, so that traffic moves more smoothly even when there are many cars on the road	15%	29%	25%	21%	11%
When there are few other cars on the road, being able to travel much faster (higher speed) than drivers are allowed to drive today	12%	23%	24%	22%	19%

The remaining questions all were presentations of statements with candidate responses on a 5-point scale ranging from ‘Strongly Disagree’ to ‘Strongly Agree’.

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Unsure
I enjoy driving.	27%	38%	20%	8%	7%	1%
If I had the choice, I would rather be driven around in a car than be a driver.	23%	31%	16%	16%	13%	1%
I am confident when using new technologies.	19%	35%	24%	15%	6%	1%
I prefer cars to public transportation.	48%	32%	12%	4%	3%	1%
I trust new technologies to be safe and reliable.	16%	28%	29%	13%	10%	4%
If I needed to travel with children, I would rather drive than fly regardless of how long it would take.	19%	32%	20%	13%	9%	7%
When traveling with others I would rather drive than fly regardless of distance.	24%	23%	24%	18%	9%	2%
When traveling with children it is easier to use private transportation. than public.	34%	31%	16%	8%	6%	5%
During this 'game', while choosing how to get to my relative's home, I assumed I was traveling alone.	24%	25%	21%	18%	7%	4%
I care about environmental issues.	26%	40%	21%	7%	6%	0%
Environmental factors play a role in my travel choices.	14%	25%	28%	17%	16%	0%
I tend to carpool when it is possible.	7%	17%	24%	17%	31%	4%
If possible, I would rather walk or ride a bike to a local destination than drive or take public transportation.	13%	20%	20%	21%	24%	3%
How quickly I will arrive at my destination is the most important factor in my transportation decisions.	12%	27%	28%	17%	14%	1%
I would take public transportation if it would get me to my destination more quickly than a car.	14%	29%	20%	20%	13%	3%
I would be willing to pay extra if it would get me to my destination more quickly.	13%	28%	31%	17%	9%	2%
Comfort is the most important factor in my transportation decisions.	15%	33%	29%	16%	5%	0%
I would pay more for additional comfort while traveling.	13%	38%	30%	9%	8%	2%
I would be willing to accept a slower speed in exchange for additional comfort while traveling.	13%	41%	28%	12%	5%	2%
I feel uncomfortable using public transportation.	19%	27%	21%	17%	15%	1%
Traveling by car is more enjoyable than public transportation.	43%	36%	16%	3%	1%	1%
I feel frustrated when I can't drive at the speed limit or faster	17%	32%	21%	16%	13%	1%

VI. Logistic regression

In order to verify that the empirical data from the *Stated Preference* survey were suitable to address this study's research questions, two logistic regression models (Ben-Akiva and Lerman 1985, Train 2009) were estimated using *Biogeme* software (Bierlaire 2003). The first is the traditional "multinomial logit", whereas the second is the "mixed logit with panel effects (using 1,000 random draws)"; the latter model accounts for the characteristic that a respondent's choices in each of their 10 scenarios is expected to share unobserved correlation due to that person's idiosyncratic (but stable) preferences); any such correlation is ignored in the multinomial model estimation.

	Multinomial logit		**Mixed logit with panel effects**	
Parameter name	**Parameter estimate**	**p-value**	**Parameter estimate**	**p-value**
Alternative specific constant (Bus)	0.813	0.11	2.48	<0.005
Alternative specific constant (Completely driverless car)	0.455	0.11	1.85	<0.005
Alternative specific constant (Normal car)	0.852	<0.005	2.24	<0.005
Alternative specific constant (Plane)	Fixed at zero		Fixed at zero	
Alternative specific constant (Semi-driverless car)	-0.0640	0.86	1.31	0.01
Cost (dollars)	-0.00278	<0.005	-0.00600	<0.005
Maximum travel speed (mph)	0.0138	<0.005	0.0130	<0.005
Travel time (minutes), Bus	-0.00127	0.11	-0.00205	0.01
Travel time (minutes), Completely driverless car	-0.00177	<0.005	-0.00225	<0.005
Travel time (minutes), Normal car	-0.00216	<0.005	-0.00268	<0.005
Travel time (minutes), Plane	-0.00375	<0.005	-0.00697	<0.005
Travel time (minutes), Semi-driverless car	-0.00141	0.07	-0.00189	0.01
Panel effect			-3.42	<0.005
Rho-squared	0.163		0.267	
Adjusted rho-squared	0.160		0.264	

As expected, overall model goodness-of-fit (measured by the adjusted rho-squared statistic, which is analogous to adjusted-r-squared for linear regression) improved when the panel structure of the data was taken into account (in the mixed logit specification).

All parameters for travel time and cost have the expected (negative) sign, indicating that, *ceteris paribus,* respondents were less likely to select alternatives that were more expensive or took additional time. These diagnostic results provide a measure of confidence that the data appear reasonable and suitable for further policy-relevant analysis. To the author's knowledge, the result that travelers appear to (positively) value the maximum speed at which they travel, independently from the duration of their journey, is a novel finding with consequences for how automated cars are programmed to operate on freeways.

A counter-intuitive result is that the parameter for Travel Time for the “Semi-driverless car” option is smaller than for the “Completely driverless car”. This is contrary to *a priori* expectations, as it has been theorized by researchers (Malokin et al. 2015, Zmud et al. 2016) that travelers in Completely driverless cars may have lower values of Travel Time, as being disengaged from the driving task allows the vehicle occupant to focus on other productive or leisurely activities. Further analysis into this issue is needed to identify whether the result reported here is anomalous, or indicative of a misunderstanding on the part of researchers regarding people’s preferences for the various technologies of autonomous cars.

VII. Future research

This research enabled both theoretical advancement and the collection of novel *Stated Preference* empirical data, and has led to one peer-reviewed journal publication, with two further articles planned for Summer 2016 (see next section).

The immediate future research will consist of statistical analysis of the empirical data, to address policy-relevant questions that could not be answered in the absence of this type of empirical evidence.

More broadly, important research needs relating to autonomous cars include:

- Analysis of the limits of V2X communication to increase capacity, if constrained by current legal precedent
- The traffic flow properties of autonomous cars in the presence of pedestrians, and when maneuvering across/into other traffic streams (e.g. left turns, weaving, merging)
- Analysis of automated cars’ manufacturers’ liability in instances of ‘cut-in’ lateral maneuvers by other vehicles
- Quantitative analysis of the trade-offs between efficiency and safety in the context of autonomous cars

VIII. Research products

The theoretical results from this research have formed the basis of one published journal paper (Le Vine et al 2016). This paper was preceded by a conference-paper version, which was presented at the January 2016 Annual TRB meeting

A second journal paper is currently in preparation, with submission planned for June 2016:

- Le Vine, S., Liu, X., Kong, Y., Polak, J. (In preparation) *Vehicle Automation, Legal Standards of Care, and Freeway Capacity*.

A conference-poster version of this in-preparation paper has been submitted to the July 2016 Automated Vehicles Symposium; at the time of writing we are awaiting news of whether or not it will be accepted. A full-paper version will be submitted for presentation at the January 2017 TRB Meeting.

A third paper is currently in preparation, with submission planned for June 2016:

- Le Vine, S., Lustgarten, P. (In preparation) *Mode choice analysis of long-distance travel in the presence of autonomous and semi-autonomous cars.*

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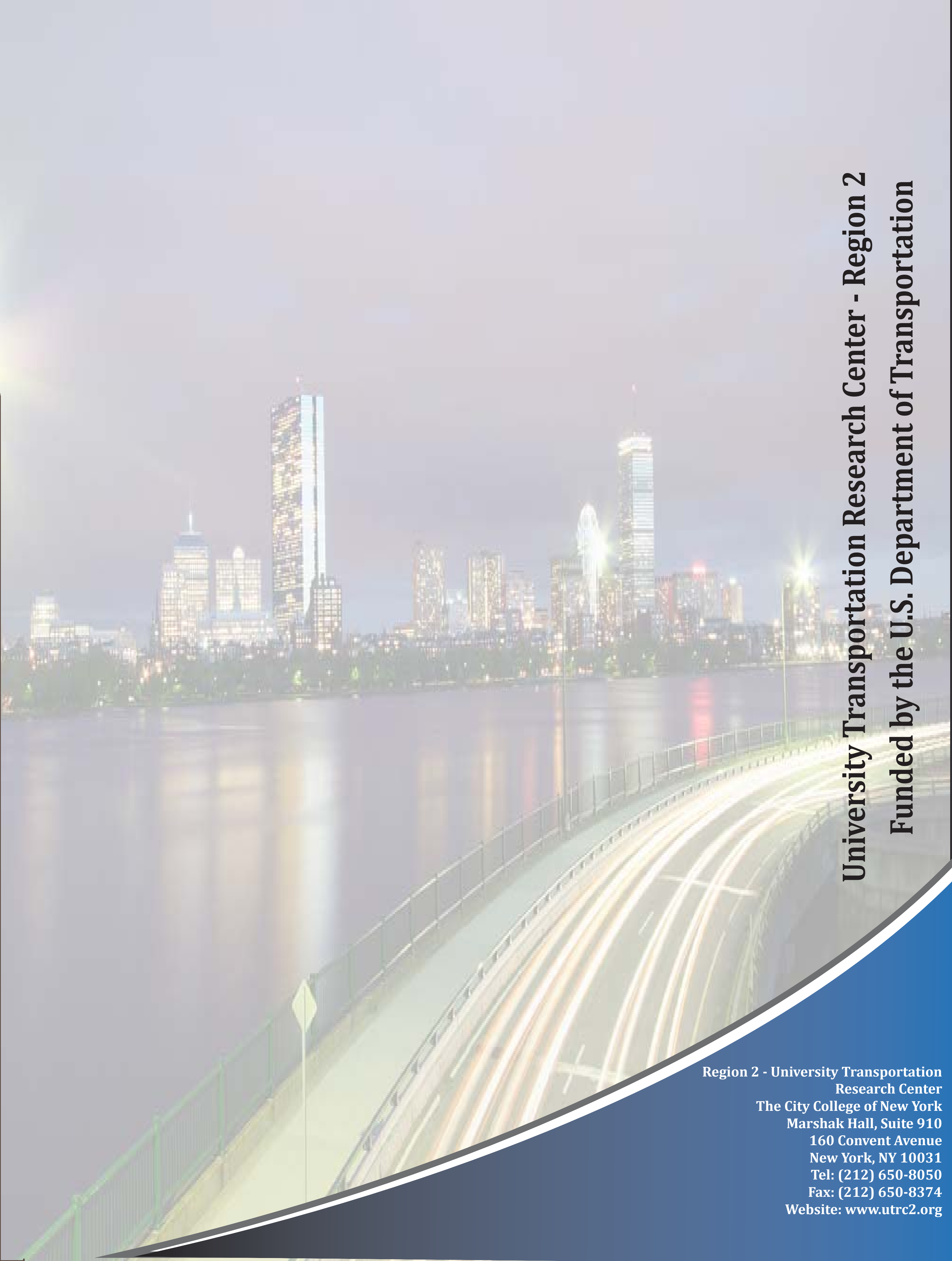

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