

Center for Teaching Old Models New Tricks (TOMNET)

A USDOT Tier 1 University Transportation Center

PROJECT PROPOSAL

Title: Latent variable models of Attitudes and Preferences, and their Prediction of Autonomous Vehicle Adoption Intent

Principal Investigator: Kevin J. Grimm, Ph.D., Professor, Department of Psychology, Arizona State University

Co-Principal Investigator: Ram Pendyala, Ph.D., Professor, School of Sustainable Engineering and the Built Environment, Arizona State University

1. Introduction/Problem Statement

In summer 2019, Dr. Sara Khoeini and Dr. Ram Pendyala launched a survey to understand how the market may perceive, adopt, and adapt to transformative transportation technologies mainly autonomous vehicles and mobility-on-demand services in the Phoenix Metropolitan area. The final survey was part of their study, *Attitudes towards Emerging Mobility Options and Technologies – Phase 2: Pilot and Full Deployments*. Briefly, the goal of their study was to examine attitudes and perceptions of emerging mobility options and technologies including autonomous vehicles and mobility-on-demand services that are bringing transformative changes in the transportation landscape. A major goal for the data collected from this survey was to measure and understand people's attitudes towards and perceptions of these technologies and services in order to enhance transportation forecasting models.

The funded project proposal from Drs. Khoeini and Pendyala resulted in a dataset with $N > 1,000$ with a series of targeted questions for following topics: (A) Attitudes and Preferences, (B) Household Vehicles and Residential Preferences, (C) Current Travel Patterns, (D) Mobility on Demand and Shared Mobility Services (Use and Attitudes), (E) Thoughts on Autonomous Vehicles (Familiarity, Perceptions, & Attitudes), and (F) Background Information (Demographics). This project proposal focuses on the analyses of this extensive dataset to examine (1) Dimensionality and Factor Structure of participant Attitudes and Preferences toward transportation and life in general (Section A) using both common factor models and latent class models, and (2) Prediction

of aspects of participant thoughts on Autonomous Vehicles (Section E) with a particular focus on predicting attitudes regarding autonomous vehicle adoption (buying, leasing, expense).

Autonomous vehicles (AV) (also referred to as driverless cars or self-driving cars) are capable of navigating without human input using an array of technologies such as radar, lidar, GPS, odometry, and computer vision. Most industry experts suggest that autonomous vehicles will be on the road within a few years (Stoll, 2016). For example, the US Secretary of Transportation expects driverless cars to be in use all over the world by 2025 (Hauser, 2015), and The Institute of Electrical and Electronics Engineers (IEEE) predicts that up to 75% of all vehicles will be autonomous by 2040 (IEEE, 2012). In addition to the availability of AVs, ride-hailing companies, such as Uber and Lyft, have changed the transportation landscape as they provide door-to-door mobility-on-demand through the use of mobile apps.

Given these new transportation technologies and services, it is necessary for transportation forecasting models to account for market dynamics that will result from increased penetration of these technological innovations. Enhancing transportation forecasting models based on people's attitudes toward and perceptions of these technologies and services is necessary. The data collected by Drs. Khoeni and Pendyala, provide the foundation for enhancing the forecasting models by capturing ample data on attitudes and perceptions, AV adoption expectations, ride-hailing use and attitudes, and background characteristics. Additionally, data from collaborating sites (Tampa, Atlanta, Austin) is available to examine the replicability of our models.

2. Project Objectives

The overall goal of this project is use latent variable models to examine the factor structure of participant attitudes toward transportation, and determine whether these attitudes and perceptions are associated with the expected adoption of AVs and the adoption of ride-hailing services.

3. Proposed Methodology and Data (1 page)

The data analysis of the participant attitudes and perceptions items will include four phases: (1) Exploratory factor analysis, (2) Confirmatory factor analysis, (3) Examination of latent class models, and (4) predictive models of transportation adoption. The exploratory factor model is written as

$$\mathbf{y}_i = \Lambda\boldsymbol{\eta}_i + \mathbf{u}_i \quad (1)$$

where \mathbf{y}_i is a $P \times 1$ vector of item responses for participant i , $\mathbf{\Lambda}$ is a $P \times Q$ matrix of factor loadings, $\boldsymbol{\eta}_i$ is a $Q \times 1$ vector of common factor (latent variable) scores participant i , and \mathbf{u}_i is a $P \times 1$ vector of unique factor scores for participant i . In the exploratory factor model, the number of factors (Q) is equal to the number of items (P) and the number of factors to retain is determined through parallel analysis (Horn, 1965). Once the number of factors retained is determined, the common factor solution will be rotated using oblique rotation approaches (e.g., promax) with the goal of achieving simple structure. These exploratory factor analyses will be conducted using 50% of the sample.

The second step of our data analysis involves specifying and estimating a confirmatory factor analysis model using the remaining 50% of the sample. The specified confirmatory factor model will be based upon the final exploratory factor model in terms of the number of common factors and the factor loading pattern. The confirmatory factor analysis model will be estimating using weighted least squares mean and variance adjusted estimator (WLSMV) using a probit link function to account for the ordinal nature of the item responses. The fit of the confirmatory factor model will be evaluated using the Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), the Tucker-Lewis Fit Index (TLI), and the Standardized Root Mean Square Residual (SRMR).

In addition to these common factor analyses, we will examine whether unobserved (latent) classes of participants exist in the data. These models will be based on the confirmatory factor analysis (e.g., factor mixture models [Lubke & Muthen, 2005]) and based directly upon the item responses (e.g., latent class model). The number of classes will be determined using a combination of approximate likelihood ratio tests (e.g., Bootstrap Likelihood Ratio Test) and information criteria (e.g., Bayesian Information Criterion).

The fourth part of our data analytic strategy is to predict use of ride-hailing technology and expected adoption of AV. Given the results of our confirmatory factor analyses and finite mixture models, we will extend these models to include ride-hailing use and expected adoption of AV as outcomes for our latent variables. Given the ordinal nature of the outcomes, ordinal regression models are specified within the structural equation modeling with the latent variables as predictors.

4. Work Plan

The following tasks will be undertaken in this project.

Task 1 – Exploratory Factor Analyses: Exploratory factor analyses will begin after initial data screening (basic univariate and bivariate descriptive statistics – frequencies, polychoric correlations). Exploratory factor analyses will be conducted using the Mplus program and Dr. Grimm along with his graduate student will conduct these analyses. Upon completion of these analyses, a summary of analyses and results will be written by Dr. Grimm and his graduate student. A meeting with Dr. Pendyala to discuss findings and next steps for the confirmatory factor analyses will then take place. Any concerns raised by Dr. Pendyala may lead to additional analyses or changes in the planned confirmatory factor analyses.

Task 2 – Confirmatory Factor Analyses: Confirmatory factor analyses will be conducted using the Mplus program and be led by Dr. Grimm in conjunction with his graduate student. Upon completion of these analyses, a summary of analyses and results will be written by Dr. Grimm and his graduate student. A meeting with Dr. Pendyala to discuss findings and next steps will then take place. Any concerns raised by Dr. Pendyala may lead to additional latent variable models.

Task 3 – Finite Mixture Modeling: The finite mixture models (factor mixture models and latent class analyses) will be conducted by Dr. Grimm in conjunction with his graduate student. These analyses will be conducted in the Mplus program. Upon completion of these analyses, a summary of analyses and results will be written by Dr. Grimm and his graduate student. A meeting with Dr. Pendyala to discuss findings and next steps will then take place. At this meeting we will review all analyses conducted up to this point, and discuss the plan for predicting AV Adoption and Ride-hailing use. Our current plan of ordinal regression models may be modified or extended to use more exploratory analyses, such as classification trees (Breiman et al., 1984).

Task 4 – AV Adoption and Ride-hailing Use Prediction: The results of Tasks 1 through 3 will guide the nature of the final model on the predictor side (continuous latent variables vs. categorical latent variables); however, in both cases the latent variables will be used to predict ordinal variables regarding use and adoption of novel transportation technology. This work will be led by Dr. Grimm with assistance from his graduate student. Upon completion of this work, a meeting with Dr. Pendyala will occur to discuss findings and next steps for dissemination. At this meeting, we will also discuss whether additional exploratory analyses should be conducted.

Task 5 – Deliverables and Dissemination: The final deliverables of the project will include a comprehensive report documenting the data analysis plan, results, and discussion of relevant findings. This report will serve as the basis of a manuscript that will be submitted to a transportation journal.

5. Project Schedule

The project schedule is shown in Figure 1 below.

Figure 1 Project Schedule

Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
2020					2021						
Task 1					Task 2						
2021					2022						
Task 3			Task 4			Task 5					

As per the schedule, the exploratory factor analyses will be undertaken between August and December 2020, confirmatory factor analyses will be undertaken between January 2021 and May 2021, finite mixture modeling will take place between June 2021 and October 2021, prediction modeling will take place between November 2021 and January 2022, and the final report will be written between February 2022 and July 2022.

6. Relevance to the Center Theme/Mission

One of the center’s mission is to advanced methods to reflect the role of attitudes, perceptions, values, and preferences in activity-travel behavior and mobility choice models. The data collected by Drs. Khoeini and Pendyala align with these missions, and the goals of the proposed data analysis methods strive to understand the structure of the attitudes and perceptions questions, and how these attitudes and perceptions are associated with current use of ride-hailing technologies and expected adoption of AVs – two novel mobility choices that have transformed and continue to transform the transportation industry.

7. Anticipated Outcomes and Deliverables

The proposed project will result in detailed analyses of transportation data that will serve as the basis of, at least, one manuscript that will be submitted for publication. A manuscript outlining the most important results from the proposed analyses will be submitted for publication before the conclusion of the project period. The programming scripts outlining these data analyses will be made available to the center, and this documentation can serve as the basis of future data analytic projects for the center.

8. Research Team and Management Plan

The research team is led by Dr. Kevin Grimm, who will serve as the Principal Investigator for the project at Arizona State University. Dr. Ram Pendyala will serve as the co-principal investigator for the project and will review and guide data analysis. The project will support one highly qualified Ph.D. student, who will assist with all aspects of data analysis and manuscript preparation.

Kevin Grimm, Ph.D. is Professor of Psychology in the College of Liberal Arts and Science at Arizona State University, where he directs the Health and Developmental Research Methods Laboratory at Arizona State University. Dr. Grimm received his B.A. in Mathematics and Psychology with a concentration in Education from Gettysburg College in 2000, and his M.A. and Ph.D. in Psychology from the University of Virginia (2001-2006). At the University of Virginia, Dr. Grimm studied structural equation modeling and longitudinal data analysis (e.g., growth curve analysis, longitudinal mixture modeling, longitudinal measurement, and dynamic models) with John McArdle and John Nesselrode. After completing his Ph.D., Dr. Grimm worked with Robert Pianta as a research associate in the Center for the Advanced Study of Teaching and Learning at the University of Virginia. In 2007, Dr. Grimm became an Assistant Professor in the Department of Psychology at the University of California, Davis and in 2011, he was promoted to Associate Professor at the University of California, Davis. In 2014, Dr. Grimm moved to Arizona State University and was promoted to Full Professor in 2016.

Grimm is a leading expert in structural equation modeling, multilevel modeling, longitudinal data analysis, and machine learning. He has published more than 150 peer-reviewed research articles and book chapters, is the primary author of *Growth Modeling: Structural Equation and Multilevel Modeling Approaches*, and the recipient of the Society of Multivariate Experimental Psychology's Early Career Award in 2018. Dr. Grimm's research focuses on longitudinal methods for the study of change at the individual and group-level. His research in longitudinal methods has highlighted the use of the structural equation modeling framework to specify linear and nonlinear change models to study individual patterns of development (change), growth mixture models to evaluate whether there are unmeasured groups of individuals that follow distinct change patterns, and latent change models to evaluate lead-lag relationships in multivariate repeated measures. Grimm's current research focuses on data integration, the specification of growth models for binary and ordinal outcomes, longitudinal measurement invariance, and the development and application of data mining techniques for psychological science.

Ram M. Pendyala, Ph.D. is a Professor of Transportation Systems in the School of Sustainable Engineering and the Built Environment at Arizona State University. He serves as the Director of TOMNET. Pendyala is an expert in activity-travel behavior modeling and has led the development of a number of large-scale behaviorally robust microsimulation model systems. He has published

extensively in the literature and serves as the Chair of the Transportation Research Board's Planning and Environment Group (2015-2018). He previously served as Chair of the Travel Analysis Methods Section (2009-2015) as well as the Traveler Behavior and Values Committee (2003-2009). He has also served as the Chair of the International Association for Travel Behavior Research (IATBR). He is currently an Associate Editor for Transportation Research Part D. He has his Ph.D. and MS degrees in Civil and Environmental Engineering with a specialization in transportation from the University of California at Davis, and his Bachelor's degree in Civil Engineering from the Indian Institute of Technology-Madras in India.

9. Technology Transfer Plan

The project team believes in executing an effective technology transfer plan by disseminating project information and results widely to the professional community. During the duration of this particular project, each milestone will be disseminated using one of the TOMNET communication mechanisms (e.g., website, webinar, seminar, and teleconference). Project team members will collaborate in the preparation of technical reports and manuscripts. Project team members will participate in conferences and deliver presentations about this work and the outcomes of the effort.

10. Workforce Development and Outreach Plan

The project will employ a full-time Ph.D. graduate student as a graduate research associate. The doctoral student will be involved in all aspects of the project including data preparation, exploratory factor analyses, confirmatory factor analyses, finite mixture modeling, and predictive modeling. Findings from the project will be integrated into graduate-level courses taught at various institutions in the consortium so that the research and workforce development activities of the center are seamlessly blended together.

11. References

Hauser, J. (2015). Wirtschaft. Retrieved on 2020, July 15 from:

<http://www.faz.net/aktuell/wirtschaft/unternehmen/verkehrsminister-foxx-selbstfahrende-autos-in-10-jahren-standard-13811022.html>

Horn, J. L. (1965). A rationale and test for the number of factors in factor analysis.

Psychometrika, 30, 179-185.

IEEE (2012). News Release. Retrieved on 2020, July 15 from:

http://www.ieee.org/about/news/2012/5september_2_2012.html

Lubke, G. H., & Muthén, B. (2005). Investigating population heterogeneity with factor mixture models. *Psychological methods*, 10, 21.

Stoll, J. D. (2016). The Wall Street Journal. Retrieved on 2020, July 15 from:

<https://www.wsj.com/articles/gm-executive-credits-silicon-valley-for-accelerating-development-of-self-driving-cars-1462910491>

12. Qualifications of Investigators

See curriculum vitae after the budget

13. Budget Including Non-Federal Matching Funds

Institution: Arizona State University

Project Title: Latent variable models of Attitudes and Preferences, and their Prediction of Autonomous Vehicle Adoption Intent

Principal Investigator: Kevin J. Grimm, Ph.D.

Budget Period: 8/1/2020 - 07/31/2022

CATEGORY	Budgeted Amount from Federal Share	Budgeted Amount from Matching Funds	Explanatory Notes; Identify Source of Matching Funds
Faculty Salaries		\$15,153	
Other Staff Salaries			
Student Salaries	\$23,300		
Fringe Benefits	\$2,330	\$3,985	
Total Salaries & Benefits	\$25,630	\$19,138	
Student Tuition Remission	\$19,463		
Operating Services and Supplies			
Domestic Travel			
Other Direct Costs (specify)			
Other Direct Costs (specify)			
Total Direct Costs	\$45,094	\$19,138	
F&A (Indirect) Costs	\$14,609	\$10,908	
TOTAL COSTS	\$59,703	\$30,046	

Grant Deliverables and Reporting Requirements for UTC Grants (November 2016)

Exhibit F

UTC Project Information	
Project Title	Latent variable models of Attitudes and Preferences, and their Prediction of Autonomous Vehicle Adoption Intent
University	Arizona State University
Principal Investigator	Kevin J. Grimm, Ph.D.
PI Contact Information	Department of Psychology Arizona State University Tempe, AZ 85287-1104 kjgrimm@asu.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	US Department of Transportation (Federal UTC): \$60,000 Department of Psychology, Arizona State University (Cost Share): \$30,000
Total Project Cost	\$89,749
Agency ID or Contract Number	
Start and End Dates	8/1/2020 – 7/30/2022
Brief Description of Research Project	In summer 2019, Dr. Sara Khoeini and Dr. Ram Pendyala launched a survey to understand how the market may perceive, adopt, and adapt to transformative transportation technologies mainly autonomous vehicles and mobility-on-demand services in the Phoenix Metropolitan area. A major goal for the data collected from this survey was to measure and understand people’s attitudes towards and perceptions of these technologies and services in order to enhance transportation forecasting models. This project proposal focuses on the analyses of this extensive dataset to examine (1) Dimensionality and Factor Structure of participant Attitudes and Preferences toward transportation and life in general (Section A) using both common factor models and latent class models, and (2) Prediction of aspects of participant thoughts on Autonomous Vehicles (Section E) with a particular focus on predicting attitudes regarding autonomous vehicle adoption (buying, leasing, expense).

<p>Describe Implementation of Research Outcomes (or why not implemented)</p> <p>Place Any Photos Here</p>	<p>The proposed research will lead to technical reports describing the factor structure of participant attitudes and perceptions related to transportation, and examining how attitudes and perceptions are associated with novel transportation technology. Research papers will follow the technical reports.</p>
<p>Impacts/Benefits of Implementation (actual, not anticipated)</p>	<p>In addition to the technical reports, and submitted manuscripts, the programming scripts will be an example for examining factor structures for survey items in transportation engineering.</p>
<p>Web Links</p> <ul style="list-style-type: none"> • Reports • Project Website 	

KEVIN J. GRIMM

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Education

Ph.D., Psychology (Quantitative), University of Virginia, 2006

M.A., Psychology (Quantitative), University of Virginia, 2003

B.A., Mathematics/Psychology, Gettysburg College, 2000

Employment and Professional Experience (last 25 years)

Professor, Psychology, Arizona State University (2016-present)

Associate Professor, Psychology, Arizona State University (2014-2016)

Associate Professor, Psychology, University of California, Davis (2011-2014)

Assistant Professor, Psychology, University of California, Davis (2007-2011)

Research Associate, Center for Advanced Study of Teaching and Learning (2006-2007)

Fields of Interest and Expertise

(1) Structural Equation Modeling; (2) Longitudinal Data Analysis; (3) Multilevel Modeling; (4) Machine Learning; (5) Multivariate Analysis

5 Recent Relevant Publications

1. **Grimm, K. J.**, Ram, N., & Estabrook, R. (2017). Growth modeling: Structural equation and multilevel modeling approaches. New York, NY: Guilford.
2. **Grimm, K. J.**, Mazza, G., & Davoudzadeh, P. (2017). Model selection in finite mixture models: A k -fold cross-validation approach. *Structural Equation Modeling: A Multidisciplinary Journal*, 24, 246-256.
3. **Grimm, K. J.**, & Liu, Y. (2016). Residual structures in growth models with ordinal outcomes. *Structural Equation Modeling: A Multidisciplinary Journal*, 23, 466-475.
4. **Grimm, K. J.**, Zhang, Z., Hamagami, F., & Mazzocco, M. M. (2013). Modeling nonlinear change via latent change and latent acceleration frameworks: Examining velocity and acceleration of growth trajectories. *Multivariate Behavioral Research*, 48, 117-143.
5. **Grimm, K. J.**, Ram, N., & Estabrook, R. (2010). Nonlinear structured growth mixture models in *Mplus* and *OpenMx*. *Multivariate Behavioral Research*, 45, 887-909.

Graduate Student Supervision/Advising

Graduated: 9 PhDs (7 women)

Current Supervision: 2 PhDs

Honors and Awards

- | | |
|-----------|---|
| 1999 | Earl Ziegler Junior Mathematics Award, Gettysburg College |
| 2000 | Earl Ziegler Senior Mathematics Award, Gettysburg College |
| 2001-2004 | Presidential Fellowship, University of Virginia |
| 2002-2005 | NIA Aging Research Methodology Traineeship, University of Virginia |
| 2005 | American Psychological Association Dissertation Research Award |
| 2005 | Society of Multivariate Experimental Psychology Dissertation Research Award |
| 2005-2006 | Institute of Education Sciences Fellowship, Curry School of Education, University of Virginia |
| 2015 | Elected member of the Society of Multivariate Experimental Psychology |
| 2017 | SMEP Early Career Award for Contributions to Multivariate Experimental Psychology |

RAM M. PENDYALA

Professor, Sustainable Engineering and the Built Environment
Senior Sustainability Scientist - Global Institute of Sustainability

Arizona State University (ASU), Tempe, AZ 85287-3005 Email: pendyala@asu.edu

Education

Ph.D., Civil Engineering (Transportation), University of California-Davis, December 1992.

M.S., Civil Engineering (Transportation), University of California-Davis, June 1990.

B.Tech., Civil Engineering, Indian Institute of Technology-Madras, June 1988

Employment and Professional Experience (last 25 years)

Professor, Sustainable Engineering and the Built Environment, ASU, 2006-2014 & 2016-present.
Frederick R. Dickerson Chair Professor, School of Civil and Environmental Engineering, Georgia Institute of Technology, 2014-2016

Senior Sustainability Scientist - Global Institute of Sustainability, ASU, 2011-Present.

Asst/Assoc/Professor, Civil & Environmental Engineering, Univ of South Florida, 1994-2006.

Assistant Professor, Civil Engineering, University of Louisiana at Lafayette, 1992-1994.

Fields of Interest and Expertise

(1) Multimodal transportation systems planning; (2) Activity-travel behavior analysis; (3) Transportation demand modeling and forecasting; (4) Mobility analytics and visualization; (5) Statistical and econometric analysis of transportation data; (6) Dynamic mobility management; (7) Travel survey methods and data collection; (8) Built environment – transportation – energy

5 Recent Relevant Publications (from over 200)

1. Garikapati, V. M., Pendyala, R. M., Morris, E. A., Mokhtarian, P. L., and McDonald, N. (2016). Activity Patterns, Time Use, And Travel of Millennials: A Generation in Transition? *Transport Reviews*, 36(5), pp. 558-584.
2. Pinjari, A. R., Augustin, B., Sivaraman, V., Imani, A. F., Eluru, N., and Pendyala, R. M. (2016). Stochastic Frontier Estimation of Budgets for Kuhn–Tucker Demand Systems: Application to Activity Time-Use Analysis. *Transportation Research Part A*, 88, pp. 117-133.
3. Shin, J., Bhat, C. R., You, D., Garikapati, V. M., and Pendyala, R. M. (2015). Consumer Preferences and Willingness to Pay for Advanced Vehicle Technology Options and Fuel Types. *Transportation Research Part C*, 60, pp. 511-524.
4. Garikapati, V. M., You, D., Pendyala, R. M., Jeon, K., Livshits, V., and Vovsha, P. S. (2015). Tour Characterization Framework Incorporating Activity Stop–Sequencing Model System. *Transportation Research Record: Journal of the Transportation Research Board*, 2494, pp. 77-86.
5. Archer, M., Paleti, R., Konduri, K., Pendyala, R., & Bhat, C. (2013). Modeling the connection between activity-travel patterns and subjective well-being. *Transportation Research Record: Journal of the Transportation Research Board*, 2382, pp. 102-111.

Graduate Student Supervision/Advising

Graduated: 10 PhDs (includes 2 women), 50 Masters; **Current Supervision:** 4 PhDs

Recent Honors and Awards

Pyke Johnson Award for Best Paper in Planning and Environment, Transportation Research Board of the National Academies, 2011 and 2013

Invited Speaker, Distinguished Lecture Series, Department of Civil and Environmental Engineering, Florida International University, 2015

Invited Keynote Speaker at 5 International/National Conferences, 2014-2016