Data-Driven Vehicle Preference Modeling and Prediction: A Multidimensional Network Analysis Approach

Mingxian Wang [a], Zhenghui Sha [b], Yun Huang [c], J. Sophia Fu [c], Yan Fu [a], Noshir Contractor [c], Wei Chen [c]

[a] Ford Motor Company; [b] University of Arkansas; [c] Northwestern University

Introduction

The auto market in China has seen unprecedented expansion during the past decade and has become highly complex with the evolving marketing structures and diverse consumer needs and tastes. To decide which vehicle segments and customer groups automakers should focus on and exploit the trends of "bigger market" and "repeat buyers," a more granular understanding of the effect of customers' social interactions and preference heterogeneities is needed. Our study aims to develop a data-driven multidimensional network modeling approach for analyzing and predicting heterogeneous, complex customer preferences using buyer survey data collected in China. The developed methodology can support product attribute prioritization and revenue/volume forecast for future product planning and development.

Methodology

The core of the proposed research is to model customer-product interactions as a complex socio-technical network. Specifically, we propose a Multidimensional Customer-Product Network (MCPN) framework to simultaneously model "customer" and "product" entities as well as multiple types of relations such as consideration decision, purchase decision, product association, and social connection.

We start with the simplest unimodal network configuration where customers' cross-shopping behaviors and product similarities are analyzed to reveal the implied product competition, market segmentation, and product positions. We then include multidimensional structures to integrate customer preference decisions with product feature similarities and model the dependence of preference heterogeneity, product feature association, and consideration and purchase decisions. Finally, social influences on new product adoptions are analyzed by introducing customer-customer relations together with other product-product and customer-product relations, as shown in Fig.1.

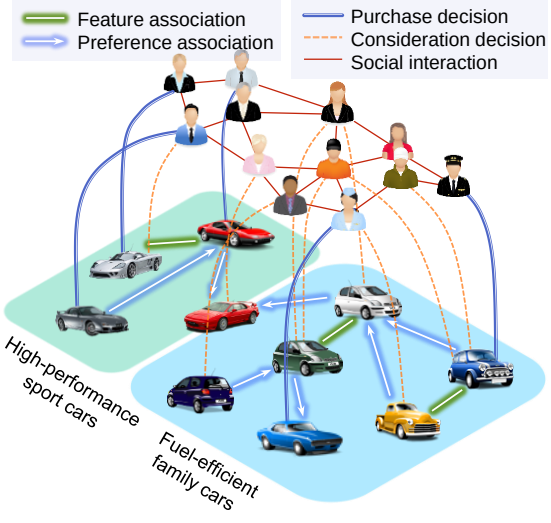

Fig. 1. Modeling Customer-Product Relations as a Complex Socio-Technical Networked System

In this study, both descriptive network analyses and analytical network models are performed. In descriptive analyses, for example, our research examines the impact of product features using joint correspondence analysis (JCA) [1]. Taking customer-product relations and similarity relations between products as a network, we incorporate multiple relations, attributes of customers, and features of

products, to identify the principal factors in vehicle purchase. The graphical output from the JCA (Fig. 2) remarkably simplifies the complex relationship structures between different sets of variables and generates a simple yet exhaustive description of the underlying relationships. The results can be used as a guideline to better understand the product feature space and explore new predictors of customer preferences.

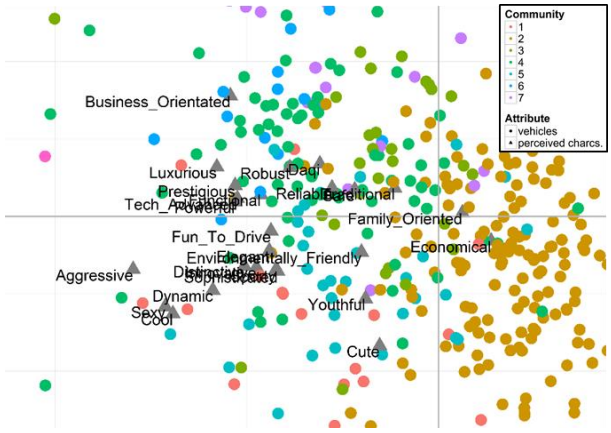

Fig. 2. Joint Correspondence Analysis result of Vehicles and Perceived vehicle characteristics

In analytical network modeling, we employ the Exponential Random Graph Models (ERGM) [2] as a unified statistical framework for analyzing multiple relations in an MCPN in support of engineering and business decisions. We find that the inferential network analysis with ERGMs enables the detailed modeling of both network structures and customer/product attributes in a rigorous statistical sense. In addition to ERGM, we also explored the capability of other network models. For example, the multiple regression quadratic assignment procedure (MRQAP) [3] is employed to predict product co-consideration relations as a function of various effect networks created by associations of product attributes and customer demographics. With the developed MRQAP model, simulation can be performed to forecast technological impacts on customers' co-considerations and product competitions. In this study, we forecast the impacts of the adoption of two vehicle technologies – the fuel economy-boosting technology and the turbo engine technology. The case study provides vehicle designers with insights into the change of market competitions brought by these new technological developments.

Summary and Discussion

The proposed Multidimensional Customer-Product Network (MCPN) framework has been successfully applied to investigate products' co-consideration relations [4-7], customers' consideration decisions [4] and choice decisions [8]. Through various network models, we have demonstrated the use cases of MCPN, which enable the graphical exploration of the product feature space and the forecast of technological impacts (e.g., turbo) on competitions among individual products and brand lines in a market. Our proposed MCPN framework for complex customer-product systems also provides a platform, which enables rich opportunities of cross-disciplinary network research.

The proposed multidimensional network preference models have the following advantages: 1) product associations can be modeled explicitly, 2) evaluation of social influence is achievable, 3) nested decisions can be analyzed through network structural modeling, 4) interdependencies among product/customer attributes can be handled, and 5) ERGM results can be easily integrated into a vehicle design optimization problem.

Acknowledgement

The authors gratefully acknowledge financial support from Ford-Northwestern Alliance Project and NSF (CMMI-1436658).

References

[1] Greenacre, M. & Blasius, J. “Multiple correspondence analysis and related methods”, CRC Press, 2006.
[2] Wang, P., Robins, G., Pattison, P. & Lazega, E. “Exponential random graph models for multilevel networks”. *Social Networks*.
[3] Krackhardt, D. “Predicting with networks: Nonparametric multiple regression analysis of dyadic data”. *Social networks*, 10(4), 1988, 359-381.
[4] Wang, M., et al. “Modeling customer preferences using multidimensional network analysis in engineering design”. *Design Science*, 2016. 2.
[5] Wang, M., et al. “A Network Approach for Understanding and Analyzing Product Co-consideration Relations in Engineering Design”. *in DS 84: Proceedings of the DESIGN 2016 14th International Design Conference*. 2016.
[6] Wang, M., et al. “Forecasting Technological Impacts on Customers’ Co-Consideration Behaviors: A Data-Driven Network Analysis Approach”. *ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference,* Volume 2A: 42nd Design Automation Conference: V02AT03A040. doi:10.1115/DETC2016-60015.
[7] Sha, Z., et al. “Modeling Product Co-Consideration Relations: A Comparative Study of Two Network Models.” *in Submitted to the 21st International Conference on Engineering Design, ICED17*. Vancouver, Canada, Aug. 21-25, 2017.
[8] Fu, J., et al. “Modeling Customer Choice Preferences in Engineering Design Using Bipartite Network Analysis.” *in Submitted to the ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.* Cleveland, OH, Aug. 6-9, 2017.