**Predictors of Adoption of the General Transit Feed Specification by US transit agencies**

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**ABSTRACT**

The Abstract should be a stand-alone summary of the contents of the paper, equaling 250 words or less. It should present the primary objectives and scope of the study, techniques, methods or approaches briefly described and a concise summary of findings and/or conclusions reached.

**Keywords:** Format Example, Guide, Keyword, Keyword

**INTRODUCTION**

The development and widespread adoption of the general transit feed specification (GTFS) data format for transit route and schedule data has transformed the way travelers plan transit trips *(1)*. This data standard was introduced in December 2005 by TriMET, the public agency operating mass transit in Portland, Oregon in partnership with Google. Sixteen years later, most –but not all—transit agencies have begun publishing their route and schedule information in this format. What might explain a transit agency’s decision about whether and when to adopt this data format?

Little prior research has been done on the determinants of GTFS adoption. In one study focusing on California, Frick et al. *(2)* found that small transit agencies (reduced reporters) and rural transit agencies were less likely to have published GTFS feeds and independent public transit authorities are more likely to publish GTFS-r feeds than other types of agencies like departments within local governments.

Studies on the adoption of other technologies may be informative in identifying agency characteristics that are generally associated with openness to innovation. Rogers’ *(3)* work on diffusion of innovation highlights several characteristics of organizations that correlate with being early adopters of new technologies, including larger size, greater complexity – defined as high level of knowledge and expertise among its members, social interconnectedness, presence of an innovation champion, and organizational slack recognizing the availability of additional resources, especially for high-cost innovations.

Existing literature on technology transfer and information sharing amongst transit agencies and more broadly, public institutions, is scarce. Iseki et al. *(4)* have found that early adopters of smart cards for fare payment tended to be those with greater funding availability and those with established relationships with other transit agencies.

There is a need for empirical analysis to determine the factors that influence technology transfer and adoption. The purpose of this study is to evaluate the adoption of GTFS by 498 transit agencies in the United States that were providing scheduled transit service in 2006 at the time of its inception. The results of this analysis can inform efforts by state- and national-level agencies seeking to encourage innovation by identifying agencies most likely to be open to adopting new technology. It can also help local agencies identify peers who are likely to have experience with innovation and experimentation.

**DATA AND METHODS**

**Data**

Based on the literature above, we hypothesize that a transit agency’s attitude towards the adoption of a new technology standard is related to its location, the population it serves, its neighboring agencies, the popularity of the new technology, its size, the household characteristics of the district, its expenditure distribution, and its financial status. Agencies of different regions may hold different opinions about technology upgrades. Meanwhile, suppose the institution serves a larger population, a denser district, or an area with a higher percentage of renter-occupied households; In that case, it may face more pressure from customers to make its information available. Similarly, if a large number of fellow agencies nearby have adopted the new technique, or the national-level acceptance rate is high, the transit agency may be more eager to upgrade to catch up with local standards. Besides, institutions of bigger size, better financial status, or more spare money left after paying for general administration might be more favorable towards transitioning to new standards. Size: Represents both agency size characteristics such as service area, passenger revenue miles, revenue, expenses and fare recovery rate, as well as city size and demographic characteristics such as urbanized area, population and density.

For this research, we have used data from primarily three sources

(i) Data about transit agencies taken directly from the Federal Transit Administration’s National Transit Database (NTD) which holds records of the financial, operating, and asset conditions of transit systems *(5)*. We identified 493 transit agencies in the United States that were providing scheduled transit services in 2005, when the GTFS data standard was initially published. Our sample includes transit agencies’ information each year from their establishment to their dissolution or adoption of GTFS standards between 2005 to 2020. The resulting sample consists of 5,528 observations of 493 transit agencies across the country.

(ii) Data about the adoption of GTFS drawn from the first publicly available feed available on three sources of archived GTFS feeds (OpenMobilityData, GTFS Data Exchange, and Transitland). We identified the earliest published GTFS feed available for each agency, if any and used the publication date to estimate the length of time it took for each agency to adopt the GTFS data standard.

(iii) Data about demographic characteristics of urbanized areas taken directly from the 2000 Decennial United States Census and 2010 Decennial United States Census (United States Census Bureau 2000, 2010).

The figure below shows the percentage of transit agencies that adopted GTFS between its introduction in 2006 to 2020 (**Figure 1**).

Chart

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**Figure 1 Adoption of GTFS by transit agencies by year**

Diagram, map

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**Methods**

We identified several variables to understand their potential relationship with GTFS adoption (**Table 1**). We categorize these 18 variables into 8 data categories:

(i) Locational characteristics of the agency: census region and division. This represents the geographic and regional location of the transit agency which also serves as a proxy for its distance from Portland where GTFS was first introduced.

(ii) Agency size: vehicles operated in annual maximum service, vehicle revenue miles, fare revenue, ridership, operating expenses, general administration salary

(iii) City demographic characteristics:

a) City size: population and population density

b) Household characteristics: percentage of renter-occupied households

(iv) Technology penetration: year, percentage, and the number of agencies that have adopted the GTFS standard. We look at the existing adoption rate for GTFS to understand its potential influence on other agencies to adopt it.

(v) Peer agencies in the same urbanized area: number of agencies in the same urbanized area, the percentage that the agency’s vehicle revenue miles account for in the whole urbanized area

(vi) Institutional characteristics of the agency: agency, organization, or institution type

(vii) Financial situation of the agency: fare recovery (fare revenue divided by operating expenses)

(viii) Organizational slack: overhead (the percentage that general administration salary takes in the whole operating expenses). We use expenditure distribution of the agencies, specifically wages and salaries as a way of understanding organizational slack and the availability of resources at hand for the agency to adopt new technologies.

**TABLE 1 Variables and sources of data**

|  |  |  |
| --- | --- | --- |
| **Variable Category** | **Name of Variable** | **Data Source** |
| Institutional characteristics | Agency Type | National Transit Database; Data Category: Agency Information (2005 – 2020)  2005 – 2007: agency\_info.xlsx  2008 – 2011: Agency\_Information.xlsx  2012 – 2013: Agency\_Information\_0.xlsx  2014: Agency-Information.xlsx  2015: Agency\_information\_1.xlsx  2016: Agency Information.xlsx  2017 – 2018: Agency Info\_1.xlsx  2019: Agency Info.xlsx  2020: Agency Information.xlsx |
| Organization Type |
| Institution Type |
| Agency Size | Service Area | National Transit Database; Data Category: Agency Information (2005 – 2020)  2005 – 2007: agency\_info.xlsx  2008 – 2011: Agency\_Information.xlsx  2012 – 2013: Agency\_Information\_0.xlsx  2014: Agency-Information.xlsx  2015: Agency\_information\_1.xlsx  2016: Agency Information.xlsx  2017 – 2018: Agency Info\_1.xlsx  2019: Agency Info.xlsx  2020: Agency Information.xlsx |
| Passenger Car Scheduled Revenue Miles | National Transit Database; Data Category: Annual Database Service  2005 – 2011, 2014, 2016 – 2020: Service.xlsx  2012 – 2013, 2015: Service\_0.xlsx |
| Vehicle Scheduled Miles |
| Unlinked Passenger Trips |
| Vehicle Revenue Miles |
| Vehicles Operated in Annual Maximum Service | National Transit Database; Data Categories:  Table 26: Fare per Passenger and Recovery Ratio (2005 – 2014)  Annual Database Service (2015 – 2020)  2005, 2007: Table\_26.xlsx  2006: Table 26 - Fare per Passenger and Recovery Ratio.xlsx  2008 – 2011: T26\_Pass\_Fare\_Recovery\_Ratio.xlsx  2012 – 2013: Table 26 Pass Fare Recovery Ratio.xlsx  2014: Table 26 Pass Fare Recovery Ratio\_2.xls  2015: Service\_0.xlsx  2016 – 2020: Service.xlsx |
| Fare Revenue | National Transit Database  Table 26: Fare per Passenger and Recovery Ratio (2005 – 2014)  Annual Database Fare Revenues (2015 – 2020)  2005, 2007: Table\_26.xlsx  2006: Table 26 - Fare per Passenger and Recovery Ratio.xlsx  2008 – 2011: T26\_Pass\_Fare\_Recovery\_Ratio.xlsx  2012 – 2013: Table 26 Pass Fare Recovery Ratio.xlsx  2014: Table 26 Pass Fare Recovery Ratio\_2.xls  2015: Fare\_Revenue.xlsx  2016 – 2020: Fare Revenue.xlsx |
| Operating Expenses | National Transit Database  Table 26: Fare per Passenger and Recovery Ratio (2005 – 2014)  Annual Database Operating Expense (2015 – 2020)  2005, 2007: Table\_26.xlsx  2006: Table 26 - Fare per Passenger and Recovery Ratio.xlsx  2008 – 2011: T26\_Pass\_Fare\_Recovery\_Ratio.xlsx  2012 – 2013: Table 26 Pass Fare Recovery Ratio.xlsx  2014: Table 26 Pass Fare Recovery Ratio\_2.xls  2015: Operating\_Expenses\_0.xlsx  2016 – 2019: Operating Expenses.xlsx  2020 Operating Expenses\_0.xlsx |
| Fare Recovery Rate | Fare revenue / Operating Expenses |
| City Size | Urbanized Area | National Transit Database; Data Categories:  Appendix D: 2000 U.S. Urbanized Areas (UZAs), Populations, Square Miles and Densities Reported by Transit Agencies (2005 – 2013)  Annual Database Agency Information UZAs (2014 – 2018)  Annual Database Agency Information (2019 – 2020)  2005: Appendix\_D.xlsx  2006: Appendix D – 2000 US Urbanized Areas, Populations, Square Miles and Densities Reported by Transit Agencies.xlsx  2007: AppendixD.xlsx  2008 – 2011: xD\_UZA\_Pop\_SqMiles\_Dens.xlsx  2012 – 2013: Appendix D.xlsx  2014: Agency UZAs.xlsx  2015: Agency\_uza.xlsx  2016 – 2018: Agency UZA.xlsx  2019: Agency Info.xlsx  2020: Agency Information.xlsx |
| Population |
| Area (Square miles) |
| Population Density |
| Total Number of Households | 2000 Decennial Census (Variable code: H004001)  2010 Decennial Census (Variable code: H004001) |
| Total Number of Renter-occupied Households | 2000 Decennial Census (Variable code: H004003)  2010 Decennial Census (Variable code: H004004) |
| Percentage of Renter-occupied Households | Total number of renter-occupied households / Total number of households |
| Locational characteristics | US Census Region | 4 US Regions (Northeast, Midwest, West, South)  9 US Divisions (New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific) |
| Technology Penetration | Date of adopting GTFS data standard | Retrieved earliest published GTFS feed date from GTFS Data Exchange, OpenMobilityData, and Transitland |
| Number of Agencies that adopted GTFS Data Standard | Summary of agencies by year and GTFS status |
| Total Number of Agencies | Summary of agencies by year and GTFS status |
| Percentage of Agencies Adopting GTFS Data Standard | Number of agencies that has adopted GTFS data standard / Total number of agencies |
| Organizational slack | Expense Category | National Transit Database; Data Category: Annual Database Operating Expense  2005 – 2011: Operating\_Expenses.xlsx  2012, 2015, 2020: Operating\_Expenses\_0.xlsx  2013: operating expenses.xls  2014, 2016 – 2019: Operating Expenses.xlsx |
| Operator’s Salaries and Wages |
| Other Salaries and Wages |
| Fringe Benefits |
| Total Salary of General Administration | Summary of the total salary of general administration (sum of operator’s salaries and wages, other salaries and wages, and fringe benefits) by agencies’ ID |

**Model**

We use multiple logistic regression models to shed light on the relationships between the transit agency’s GTFS adoption status and different categories of variables. We started by selecting one variable from each category. For instance, Model 1 contains nine variables in total, each describing one influencing element: Division, Organization Type, population density, the share of the agency’s vehicle revenue miles in the whole urbanized area, the number of agencies that have adopted the GTFS standard, Vehicle Revenue Miles, the percentage of renter-occupied households, Overhead (the portion that general administration salary takes in the whole operating expenses), and the fare recovery rate.

Based on the best fit model from the first round of experiments, we followed up by testing combinations of variables inside each category. Apart from Division, Organization Type, Population Density, the share of the agency’s vehicle revenue miles in the whole urbanized area, the percentage of renter-occupied households, Overhead, and the fare recovery rate, Model II includes three variables describing the adoption rate (Year, the percentage of agencies that have adopted the GTFS standards, and the number of agencies that have adopted the GTFS standard) and three variables describing the size of the agency (Vehicles Operated in Annual Maximum Service, ridership, and Operating Expenses).

Model III serves as a control group, including very different variables from the list: Region, Organization Type, Population, the number of agencies that have adopted the GTFS standard, Vehicles Operated in Annual Maximum Service, and the fare recovery rate.

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**RESULTS**

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**DISCUSSION**

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 (1)

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 (2)

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**CONCLUSIONS**

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**ACKNOWLEDGMENTS**

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**AUTHOR CONTRIBUTIONS**

The authors confirm contribution to the paper as follows: study conception and design: X. Author, Y. Author; data collection: Y. Author; analysis and interpretation of results: X. Author, Y. Author. Z. Author; draft manuscript preparation: Y. Author. Z. Author. All authors reviewed the results and approved the final version of the manuscript.

**REFERENCES**

1.McHugh, Bibiana. 2013. “Pioneering Open Data Standards: The GTFS Story.” In *Beyond Transparency: Open Data and the Future of Civic Innovation*, edited by Brett Goldstein and Lauren Dyson, 1st edition, 125–36. San Francisco: Code for America Press.

2. Frick, Karen Trapenberg, Tanu Kumar, and Alison Post. 2020. “Background Paper: The General Transit Feed Specification (GTFS) Makes Trip-Planning Easier — Especially During a Pandemic — Yet Its Use by California Agencies Is Uneven.” University of California Institute of Transportation Studies. 10.7922/G2ZG6QJZ.

3. Rogers, Everett M. 2003. *Diffusion of Innovations*. 5th edition. New York: Free Press.

4. Iseki, Hiroyuki, Allison Yoh, and Brian Taylor. 2007. “Are Smart Cards the Smart Way to Go?: Examining Their Adoption by U.S. Transit Agencies.” *Transportation Research Record: Journal of the Transportation Research Board* 1992 (January): 45–53. https://doi.org/10.3141/1992-06.

5. National Transit Database, Federal Transit Administration. Retrieved from: https://www.transit.dot.gov/ntd/transit-agency-profiles

6. Morcous, G., K. Wang, P. C. Taylor, and S. P. Shah. *NCHRP Report 819: Self-Consolidating*

*Concrete for Cast-in-Place Bridge Components.* Transportation Research Board, Washington, D.C., 2016. http://dx.doi.org/10.17226/23626.

7. *Guide to Developing Performance-Related Specifications.* FHWA-RD-98-155, FHWA- RD-98-156, FHWA-RD-98-171, Vol. III, Appendix C. www.tfhrc.gov/pavement/pccp/pavespec. Accessed March 5, 2003.

8. Von Quintus, H. L., and A. L. Simpson. *Documentation of the Backcalculation of Layer Parameters for LTPP Test Sections.* Publication FHWA-RD-01-113. FHWA, U.S. Department of Transportation, 2002.

9. Shunk, G. A. Urban Transportation Systems. In *Transportation Planning Handbook* (J. D. Edwards, Jr., ed.), Prentice Hall, Englewood Cliffs, N.J., 1992, pp. 88–122.

10. Corbett, J. J. Toward Environmental Stewardship: Charting the Course for Marine Transportation. Presented at 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2018.