THE EVOLUTION, USAGE AND TRIP CHAIN PATTERNS OF TAXI & RIDESOURCING SERVICES--EVIDENCE FROM 2001, 2009 & 2017 US NHTS SURVEY[1]

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1. Introduction

The rise of app-based on-demand ride services, provided by transportation network companies like Uber and Lyft, have significantly transformed people's travel pattern. These services are referred as "ridesourcing", which differ from traditional taxi with its efficient matching algorithm, dynamic pricing model and the ease of payment method(Rayle, Dai, Chan, Cervero, & Shaheen, 2016).

Findings from recent studies are fairly consistent in terms of the user demographics and characteristics of rideshourcing trips (i.e. who, when, where and why), however, the impacts of ridesourcing on other modes carry a strong geographic component and differ on a case-by-case basis. A study indicated that 15% of Americans and 21% of urban Americans had used ridesourcing apps up until 2016 (Smith, 2016). Ridesourcing users were consistently found to be younger and better educated, more likely to be employed and have higher income than general population across the aforementioned surveys. The services were offered mainly in urban area with higher population density (Rayle et al., 2016; Murphy, 2016;Clewlow & Misha, 2017; Yong & Farber, 2019; Taylor & Gattett, 2019). Studies also help to identify the reasons why people choose ridesourcing services as their alternative. The primary reasons cited by urban car users were avoiding drinking under the influence, avoiding difficulties and price of parking, the most common reasons for transit users were high speed, short wait time, whereas the top reasons for taxi users were short wait time, convenience of payment and calling the car (Clewlow & Mishra, 2017; Dills & Mulholland, 2018; Greenwood & Wattal, 2015; Peck, 2017; Rayle et al., 2016).Another dimension in previous studies is the potential impact of ridesourcing on vehicle mile traveled (VMT) and other travel modes. Some studies found that ridesourcing appeared to substitute for private auto trips rather than trips via public, thus curtail overall VMT (Anderson, 2014; Murphy, 2016; Hall, Jonathan D; Palsson, Craig; Price, 2018;). Ridesourcing is found to be most popular between 10 pm and 4 am when transit service is sparse or unavailable, indicating ridesourcing may be a complementary to transit. On the other hand, dissenting evidences also provided by Schaller (2017) indicated that more deadhead miles are generated by for-hired vehicles when they take detours to pick-up passengers or simply circulate around city streets. Alternatively, both Rayle et al. (2016) and Shaheen (2016) provided evidences that ridesourcing both substitutes and complements to public transit, while 8 percent of extra trips are induced by the emerging service which could have been avoided.

Despite their illuminating findings there are several literature gaps need to be fulfilled. First of all, most of the survey were constrained to local or at best regional level, which limits the external validity to generalize findings as nationwide trends. Besides, most of the exiting studies only took a snapshot of people's travel information that were directly related to ridesourcing trips, few studies have investigated the impact of those services on people's travel at trip chain level, which has been recognized as a better way of understanding user travel behavior. Moreover, previous studies compared the similarities, and mostly, differences between users and non-users under non-experimental condition without accounting for self-selection biases. Establishing stronger conditions may be necessary before arguing a causal relationship between those ridesourcing services and certain observed outcomes.

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To fulfill those aforementioned gaps, this study tracks the evolution of on-demand transportation services (taxi & ridesourcing) in the U.S. metropolitan areas in the last decade and assesses their impact on people's daily trip chain pattern based on NHTS data in 2001, 2009 and 2017 survey circle. In particular, the study attempts to answer following questions: (1) What are the trends of on-demand ride services (taxi & ridesourcing) in the U.S. metropolitan areas since 2001? (2) What are differences of mode share and daily trip chain pattern between ridesourcing users and non-users?

2. US National Household Travel Survey

NHTS is conducted periodically to gather travel information about US residents. From first survey in 1969 to the latest survey in 2017 (National Personal Travel Survey through 1995, NHTS since), the series of data has served as a significant resource for understanding travel behavior in a national level. *Household*, *Person*, *Vehicle* and *Trip* tables are available in each survey data package and weights are assigned to corresponding table to generate unbiased population-level estimate. In particular, the Trip table recodes all locations each participate went, travel modes used for each trip segments, as well as the time of arrival and departure, on a given travel day. Therefore, a complete daily travel profile can be constructed based on the sequence of trips. It's worth noting that survey questionnaire and definitions of certain terms had been adjusted overtime, yet most of the travel information are compatible since 2001 survey. Detail are available in each survey circle's user guide (U.S. Department of Transportation, 2017). For on-demand transportation, taxicab and limousine were treated as separate categories of travel mode option in 2001 survey, whereas they were combined into one category as taxicab since 2009 survey, and then ridesourcing services such as Uber and Lyft were combined into the taxicab category in 2017 survey. To keep consistent, taxicab and limousine in 2001 survey data were also combined into taxicab category. Unfortunately, there is no valid way to distinguish traditional taxi and new-emerging ridesourcing trips in 2017 survey due to the nature of data.

2.1 Taxi/RidesourcingUser Trip Chain Pattern

The average count of daily trips was fairly consistent across user groups over years (4 trips per day). Trips by each individual were then connected into ***trip chain***, whichrefers to a sequence of trips to a single or multiple anchor destinations, begin and end at home (Henshe & Reyes, 2000; McGuckin & Nakamoto, 2004). Therefore, if a person returns home in the middle of the day and leave home for other activities, it would be considered as multiple trip chains.Respondents who didn't start and end their daily travel at home were removed the analysis. As nearly one quarter of the users have more than 6 daily trip chains, it is necessary to simplify the typologies consisting of a series of nodes and links to better assess their pattern.

The rules of linking trips were based on the classification and precedence of activities. In this study, the trip chain was categorized into 6 types as Table 2 lists. Mandatory activity (M) has fixed frequency, location and timing. Flexible activity (f) is performed on a regular basis but have some flexible characteristics. Optional activity (o) can vary for all characteristics. Depending on the priority of the activity, mandatory activity is also referred to primary activity, while flexible and optional activity are referred to secondary activities. Only chains with at least one taxi/ridesourcing trip are included in the analysis. The total count and distribution of each chain type was relatively consistent from 2001 to 2009 as Figure shows, whereas both changed significantly from 2009 to 2017. In 2017, the mandatory and non-mandatory trip chains have a share of 39% and 61%, respectively. The simple and complex trip chain chains have a share of 32% and 68%, respectively. By the distribution of trip chain type, the simple optional trip ('H-o-H') chains possess the largest share of 24%, followed by simple flexible ('H-f-H') and simple mandatory trip ('H-M-H'). In terms of trip count, simple mandatory trip increases most dramatically, by nearly 3 times.

Table1 Typologies of trip chains

Trip Chain Type	Configuration	Description
Simple Mandatory	H-M-H	Simple trip chain only with mandatory activities (e.g. work, school)
Complex To / From Mandatory	H-(f/o)-M-(f/o)-H	Flexible/optional activities on the way to or back from mandatory activities
Complex during Mandatory	H-(f/o)-M-f/o-M-(f/o)-H	Flexible/optional activities taking place during mandatory activities
Simple Flexible	H-f-H	Simple trip chain only with flexible household-sustaining activities (e.g. banking, shopping)
Simple Optional	H-o-H	Simple trip chain only with optional activities (e.g. social, recreation)
Complex Non-mandatory	H- f&o -H	Trip chain with both combined flexible and optional activities

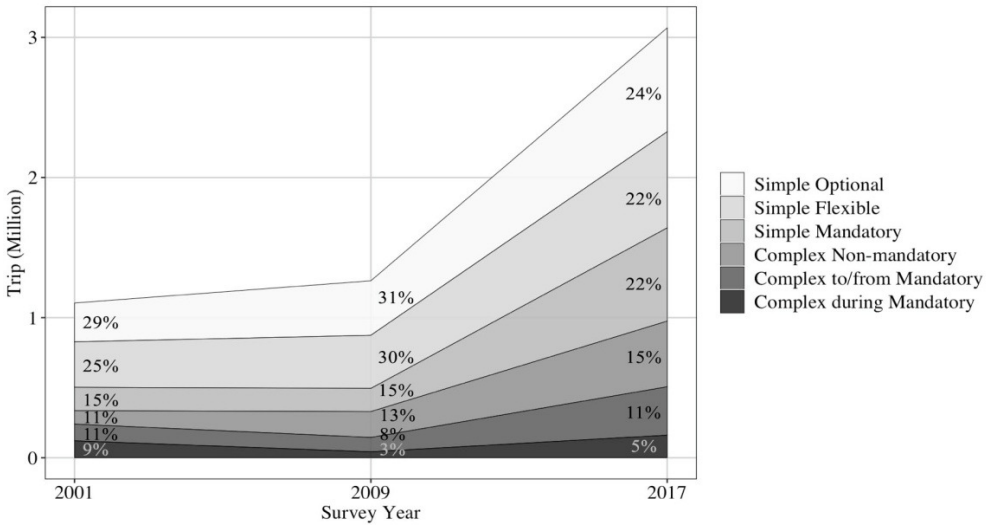


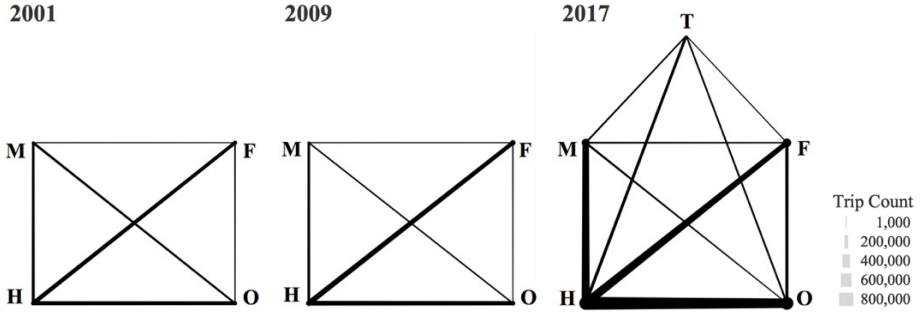
Figure1 Weighted daily count of taxi/ridesourcing trip chain

2.2 Asymmetric OD Links of taxi/ridesourcing Trips

Figure 2 depicts the weighted daily taxi/ridesourcing trip counts based on trip purposes of each OD pair. The distribution stayed relatively consistent from 2001 to 2009, while home-based mandatory, home-based optional, and home-based flexible trips increased explosively from 2009 to 2017 by 237%, 148% and 35%, respectively. Mode transfer trips were only reported in 2017 survey. Although it only accounts for a small portion of total trips, it has the strongest connection with home, which indicates that taxi/ridesourcing may help to solve 'first/last mile' problem.

Note that links in the figure above are directional. The difference between 'H-o' and 'o-H' is represented by the width of the link at two end nodes 'M' and 'H', respectively. The majority of the links in the figure are directionally symmetric, indicating there is comparable demand of taxi/ ridesourcing services from and to those nodes. However, there are observably asymmetric pattern for home-based mandatory, home-based optional, and home-based flexible trips in 2017 ('H-M': 'M-H'=1:1.3; 'H-f': 'f-H'=1:1.9; 'H-o': 'o-H'=1:1.4). For instance, the number of trips from recreation activities back home is more than the trips in reverse. That is to say, those optional trips are very likely to be a part of complex trip chain with mixed activities, and taxi/ridesourcing services may be complementary or substitute to the mode that people use for the trips in the opposite direction. Perhaps, some travelers leave home with public transportation in the

daytime, while take taxi/ridesourcing as alternatives at nighttime back home when public transportation is not available.



Trip Purpose: Trip Purpose: H-home, M-mandatory, F-flexible, O-optional, T-mode transfer

Figure 2 Weighted distribution of OD links of daily taxi/ridesourcing trips

3. Behavior comparison among different users

Table 3 compares the effects of ridesourcing service among non-users, occasional-users and frequent-users. Results indicates that frequent users have lower total daily MT and VMD. In terms of mode share, frequent-users have significant lower rate of auto, but higher rate for public transportation, on-demand services and active transportation. Chi-square test has been implemented. The results and significance indicate the statistically significant relationship between travel decision and respondents' socioeconomic characteristics.

Table 3 Comparison among ridesourcing user and non-users (Weighted)

Variables (%)	**Non Users[1]**	**Occasional Users[2]**	**Frequent Users[3]**	Avg. among groups
Observations[4]	76.5	5.0	3.4	84.9
Avg. Daily Mile Travelled (total)	7.4	7.2	6.1	7.3
Avg. Daily Vehicle Mile Drive (personal vehicle)	5.5	5.3	3.6	5.4
Avg. Daily Vehicle Mile Ride (for-hire vehicle)	0.0	0.1	0.3	0.03
Mode Share (%)				
Motor	86.2	75.4	54.9	82.6
Public Transportation	2.9	5.9	10.8	4.8
Taxi/ridesourcing	0.2	1.0	6.1	0.5
Active Transportation	10.0	17.1	27.2	11.5
Daily Trip Chain (%)[5]				
Mandatory	***32.5***	***39.3***	***42.8***	***33.4***
Simple Mandatory	20.8	21.6	23.4	20.9
Complex to/from Mandatory	8.4	11.6	11.7	8.8
Complex during Mandatory	3.3	6.1	7.7	3.7
Non-mandatory	***55.3***	***50.3***	***47.7***	***57.3***
Simple Flexible	26.3	22.6	20.1	25.8
Simple Optional	18.3	17.4	18.4	20.9
Complex Non-mandatory	10.7	10.3	9.2	10.6

Reference Available On Request

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