UMTRI-2015-3 FEBRUARY 2015

POTENTIAL IMPACT OF SELF-DRIVING VEHICLES ON HOUSEHOLD VEHICLE DEMAND AND USAGE

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Report No. UMTRI-2015-3
February 2015

Technical Report Documentation Page

1. Report No. UMTRI-2015-3	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Potential Impact of Self-Driving Vehicles on Household Vehicle Demand and Usage		5. Report Date February 2015
		6. Performing Organization Code 383818
7. Author(s) Brandon Schoettle and Michael Sivak		8. Performing Organization Report No. UMTRI-2015-3
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.		10. Work Unit no. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address The University of Michigan Sustainable Worldwide Transportation http://www.umich.edu/~umtriswt		13. Type of Report and Period Covered
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

In this report we present an analysis of the potential for reduced vehicle ownership within households based on sharing of completely self-driving vehicles that employ a "return-to-home" mode, acting as a form of shared family or household vehicle. An examination of the latest U.S. National Household Travel Survey (NHTS) data shows a general lack of trip overlap between drivers within a majority of households, opening up the possibility for a significant reduction in average vehicle ownership per household based on vehicle sharing. This reduction in ownership and an accompanying shift to vehicle sharing within each household, in the most extreme hypothetical scenario, could reduce average ownership rates by 43%, from 2.1 to 1.2 vehicles per household. Conversely, this shift would result in a 75% increase in individual vehicle usage, from 11,661 to 20,406 annual miles per vehicle. (This increase in mileage does not include the additional miles that would be generated during each "return-to-home" trip.) However, given the number of current unknowns regarding sufficient gaps between trips, future self-driving-vehicle implementation, self-driving-vehicle acceptance, and possible vehicle-sharing strategies within households, these results serve only as an upper-bound approximation of the potential for household sharing of completely self-driving vehicles.

17. Key Words autonomous vehicles, self-driving vehicles, driverless vehicles, vehicle sharing, vehicle demand, vehicle ownership, vehicle usage, National Household Travel Survey, NHTS			18. Distribution Statement Unlimited
19. Security Classification (of this report) None	20. Security Classification (of this page) None	21. No. of Pages 16	22. Price

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Introduction

With the anticipated introduction of self-driving vehicles in the coming years, some scientific reports and news articles have suggested that a potential consequence of self-driving vehicles would be an increase in overall demand for vehicles, with a subsequent increase in overall traffic volume (e.g., Anderson, Kalra, Stanley, Sorensen, Samaras, and Olumatola, 2014; Bloomberg, 2014; Litman, 2014). Furthermore, consumers in several countries have also expressed doubts about the chances that self-driving vehicles would reduce congestion or travel time (Schoettle and Sivak, 2014). Indeed, if individuals who are currently unable, unwilling, or prohibited from operating a vehicle become users of self-driving vehicles, increased demand for vehicles and increased traffic volumes might occur. However, it is not clear if this necessarily means more individual vehicles on the road compared with today's traffic volume.

The anticipated increase in traffic volume is based on the current pattern of vehicle ownership and usage that exists in the U.S. and many other developed nations. However, a potential benefit of completely self-driving (level 4) vehicles (U.S. DOT, 2013) would be the possibility of having such vehicles operate in an unoccupied, "return-to-home" mode (or any other location), acting as a form of shared family or household vehicle. This innovative functionality could *reduce* the number of vehicles needed within a single household by allowing sharing of vehicles in situations where it is not currently possible. (For a related analysis examining the possibility of reduced household vehicle ownership using public car-sharing programs, see Martin, Shaheen, and Lidicker [2010].)

To illustrate the self-driving vehicle sharing concept, consider the following example. A household has two drivers, A and B. Driver A requires a vehicle for commuting to work by 8:00 a.m. and home again at 5:00 p.m. Driver B normally runs errands during the day while driver A is at work, returning home after each errand. The level 4 self-driving vehicle "return-to-home" mode would involve the vehicle performing the following basic actions:

1) Drop driver A off at work by 8:00 a.m.
2) Return home to driver B for an errand from 10:00 a.m. to 11:00 a.m.
3) Take driver B on a second errand from 2:00 p.m. to 3:00 p.m.
4) Return to work location of driver A by 5:00 p.m. for commute home.

To examine the existing potential for reductions in the number of vehicles required within a household using level 4 self-driving vehicles, we analyzed data from the latest National Household Travel Survey (NHTS), a periodic survey administered by the Federal Highway Administration (FHWA) that documents the travel and transportation-related habits of people in the U.S. using detailed questionnaires and travel logs. (For details regarding the general administration of the NHTS, see U.S. DOT [2011a].) These data contain comprehensive information about each trip made by a person within a selected household, including the exact start and stop times of each trip. Specifically, the start and stop times of all trips for drivers within a household were analyzed for this study to determine the extent of trip overlap within each household.

Based on this analysis, a possible reduction in household vehicle ownership (based on sharing of self-driving vehicles) is presented and discussed. An analysis of vehicle usage rates, with both the current vehicle ownership rate and the calculated hypothetical minimum rate, is also presented.

Method

Data

The 2009 National Household Travel Survey (NHTS) data files (U.S. DOT, 2011d) were downloaded and analyzed. The following SAS data files were used:

- *Household file*. Used for calculating or identifying household-level information (e.g., number of vehicles or drivers per household). The weight variable for households and vehicles (the same weight is used for both) was applied for all household-level and vehicle-level tabulations, including the final results for the calculated minimum number of vehicles required within each household.
- *Person file*. Used to determine the total annual miles driven by each driver within a household. (The final annual-miles tabulation was weighted by the person weights in this file.)
- *Travel day trip file*. Used for the main analysis to identify the specific trip start and end times and the corresponding person for each recorded trip within a household. (No weights were applied to the subsequent calculations of overlapping trips, as those tabulations are appropriately summarized at the household level using the household weight variable.)

Table 1 describes the data files and the specific NHTS variables used in the current analysis. (For a complete summary of the variables contained in the latest NHTS data files, see U.S. DOT [2011b]). The following selection criterion was applied to include the appropriate records for the analysis:

- Drivers only (no passengers) who used a privately operated vehicle (POV) for some portion of at least one trip on the travel day for which data were recorded within a household were included in the analysis. (Only records within the *Travel day trip file* with DRVR_FLG = 01 were included.)

Table 1
Data files and NHTS variables used in the current analysis.

NHTS data file	File name[†]	Record level	Variables used in the current study	Sample size	Weight sum
Household file	hhv2pub	One record per household	HOUSEID: unique household identifier used to link or merge data files (contained in each file) DRVRCNT: number of drivers per household HHVEHCNT: number of vehicles per household WTHHFIN: weight for household- and vehicle-level tabulations	150,147	113,101,330
Person file	perv2pub	One record per person	YEARMILE: total annual miles driven by each driver WTPERFIN: person-level weights	351,275	283,053,872
Travel day trip file	dayv2pub	One record per travel day per person-trip	STRTTIME: trip start time ENDTIME: trip end time PERSONID: person identification number TDTRPNUM: travel day trip number (per person) DRVR_FLG: identifies the driver on a trip when equal to "01" VMT_MILE: calculated trip distance for drivers only on each trip	1,167,321	392,022,844,962 (not directly used in this analysis)

[†] SAS data files (.sas7bdat) (U.S. DOT, 2011d).

Data weights

A description of the purpose and application of the different NHTS weights that are listed above is presented in the NHTS *User's Guide* (U.S. DOT, 2011a):

> *The weights reflect the selection probabilities and adjustments to account for nonresponse, undercoverage, and multiple telephones in a household. To obtain estimates that are minimally biased, weights must be used.... Because the weighting also involved adjustments for demographic factors, such as household size, race and ethnicity, tabulations without weights may be significantly different than weighted estimates and may be subject to large bias. Estimates of the totals are obtained by multiplying each data value by the appropriate weight and summing the results.*

In Table 1, the *Sample size* represents the number of actual records contained in each data file, while the *Weight sum* corresponds to the representative U.S. population of that record type (household, person, etc.) as a whole. For example, the *Household file* contains just over 150 thousand records, representing approximately 113 million U.S. households. Analogously, the *Person file* contains just over 351 thousand records, representing approximately 283 million U.S. individuals. Although this analysis does not contain any direct summaries of travel-day, trip-level tabulations, the nearly 1.2 million trip records that were analyzed from the *Travel day trip file* represent approximately 390 billion person-trips within the U.S.

Analysis

Trip overlap and household vehicle requirements

The primary measure of interest was to determine how many different drivers within a household had trips that did (or did not) overlap. However, the available NHTS data files, while containing the required information, do not allow for straightforward comparisons of trip start and end times for individual drivers within each household due to their current structure. Using the data within the NHTS *Travel day trip file*, a new data file was assembled by transforming multiple records per travel day per person-trip into a single record per household. (Records within each household were identified and linked by the HOUSEID variable.) This was accomplished with macros that performed the following transformations to build the new data file:

- New variables were created in the new data file using names with unique identifiers for the start and end times for each person with a trip taken as a driver within a household. For each person (PERSONID) and trip (TDTRPNUM) combination when the person was the driver, the new variables were created with the following naming structures:

  Person1Trip1_START, Person1Trip2_START,… Person[i]Trip[j]_START

  Person1Trip1_END, Person1Trip2_END,… Person[i]Trip[j]_END
- The maximum person count [i] was 11; the maximum trip count [j] was 27.
- The resulting variables were populated with the corresponding trip start time (STRTTIME) and end time (ENDTIME) for each unique person and trip combination within that household.

- The new data file contained 123,974 records (one record per usable household), representing approximately 90 million households within the U.S. as a whole.
- This new file contained information on 748,807 total trips, representing approximately 230 billion person-trips.

A separate macro was developed to perform the task of examining the newly created data record for each household to compare each person and trip combination against each additional person and trip combination within the household. For hypothetical drivers A and B, two individual trips were considered to be overlapping if their start times and end times satisfied the following conditions:

$$(End\ time\ of\ trip)_{Driver\ B} > (Start\ time\ of\ trip)_{Driver\ A}$$

AND

$$(Start\ time\ of\ trip)_{Driver\ B} < (End\ time\ of\ trip)_{Driver\ A}$$

This comparison was made for every household that had one or more drivers who recorded using privately operated vehicles (POV) for trips in their survey record. If a trip for one driver ended exactly (to the minute) when a trip for another driver in the household started, these trips were *not* considered to be overlapping.

The basic assumption, given the selection criterion that was used, was that each household included in the analysis would require at least one vehicle as a minimum (baseline) condition. When making the trip comparisons within a household, each time the macro encountered a conflict between two unique person-trips, one additional vehicle was added to that household's required vehicle count. (This new household-level variable was weighted by WTHHFIN.)

Vehicle usage

To determine the likely effect of increased vehicle sharing on the annual usage of the remaining vehicle(s) within a household, we calculated the expected average annual usage rates (in miles) based on (1) the current situation and (2) with vehicle sharing of self-driving vehicles based on the results of the first analysis. The annual usage rate for the vehicle(s) in a household can be estimated using the following formula (the specific NHTS variable names are shown in the second equation):

$$\frac{Drivers}{Household} \times \frac{Annual\ miles}{Driver} \div \frac{Vehicles}{Household} = \frac{\boldsymbol{Annual\ mileage}}{\boldsymbol{Vehicle}}$$

$$DRVRCNT \times YEARMILE \div HHVEHCNT = \frac{\boldsymbol{Annual\ mileage}}{\boldsymbol{Vehicle}}$$

Results

Trip overlap and household vehicle requirements

Table 2 shows a comparison of the actual number of vehicles currently available per household[1] versus the minimum required based on the current analysis of overlapping trips. In this analysis, 83.7% of households had no trips that overlapped or conflicted. For 14.7% of households analyzed, there were two drivers with overlapping trips that created a conflict requiring two vehicles. Less than 2% of households had drivers with overlapping trips requiring 3 or more vehicles.

Table 2
Vehicles per household – currently available versus minimum required.

Vehicles	Percent of households	
	Currently available	Minimum required
1	31.9	83.7
2	41.6	14.7
3 or more	26.5	1.6

Based on the distributions shown in Table 2, the weighted average number of vehicles available per household is currently 2.1, dropping to 1.2 with the hypothetical minimum levels. In other words, a shift in ownership corresponding to these minimum levels would result in a 43% reduction in the average number of vehicles per household.

[1] Calculated from the *Household file* (HHVEHCNT weighted by WTHHFIN) using the same households selected for inclusion in the current analysis.

Vehicle usage

Table 3 shows the differences in annual vehicle usage between the current situation and a hypothetical scenario involving a shift to the minimum vehicle-availability levels calculated above. Assuming the same number of drivers per household and the same annual mileage for drivers in both scenarios, the reduction in vehicle ownership from 2.1 to 1.2 vehicles per household would result in an increase from 11,661 annual miles per vehicle to 20,406 annual miles per vehicle (an increase of 75%). The total annual vehicle miles per household are the same in both scenarios—24,488 miles. (These calculations do not take into account the additional mileage accrued when an unoccupied vehicle travels in the "return-to-home" mode.)

Table 3
Vehicle usage (annual miles) – current levels versus calculated minimum levels.

Scenario	Drivers per household[2]	Annual miles per driver[3]	Vehicles per household	Annual miles per vehicle
Current situation (without self-driving)	1.9	12,888	2.1	11,661
Calculated minimum (with level 4 self-driving)			1.2	20,406

For comparison, the total annual person miles of travel (PMT) per household averaged 33,004 miles in 2009 (U.S. DOT, 2011c). While the current data do not allow us to determine the extent to which nondrivers in a household would become self-driving-vehicle users, household members travel a total of approximately 8,500 miles on average each year (for all trips completed as a nondriver using any mode of travel) in addition to the vehicle miles of travel (VMT) from drivers in the household (33,004 - [1.9 x 12,888] = 8,517). An increase in the percentage of these nondriver trips utilizing self-driving-vehicles would (1) increase the average minimum vehicle demand per household and/or (2) increase the average annual miles per vehicle.

[2] The average number of drivers within the households included in this analysis was 1.9 drivers (DRVRCNT weighted by WTHHFIN).
[3] The average annual mileage for the drivers in this analysis was 12,888 miles (YEARMILE weighted by WTPERFIN).

Discussion

The results we presented in this analysis are strictly an upper-bound approximation of the maximum possible effects of self-driving vehicles on reductions in household vehicle ownership. This is the case because several factors make such an estimate more challenging and were not accounted for in this preliminary analysis. These factors include (but are not limited to):

- Feasibility of vehicle sharing based on the proximity of trips and destinations
- Overall timing of trips
- Specific purpose of individual trips
- General willingness (or lack-thereof) of individuals to share vehicles within a household
- Current drivers may increase their annual mileage when using self-driving vehicles
- Self-driving vehicles may lead to current nondrivers becoming vehicle operators or users, thus increasing the total number of "drivers" per household
- Additional mileage from the "return-to-home" trips

One of the dominant factors limiting these results to simply an upper-bound approximation relates to the uncertainty of what constitutes an acceptable gap (in time) between trips determined not to overlap in this analysis. While we were able to perform general comparisons for overlapping trip times, the detailed data needed to check for realistic travel time between each required location during these gaps were not available. Consequently, it is realistic to assume that a substantial portion of these nonoverlapping trips would not allow vehicle sharing with self-driving vehicles due to travel time between destinations that is larger than the available gap.

In the hypothetical scenario outlined in this analysis, the potential reduction in vehicle ownership per household would include a correspondingly large increase in vehicle usage, consequently increasing wear-and-tear and required maintenance frequency, while reducing the average vehicle life span (in total years on the road). Given the current average on-road vehicle age of 11.4 years (U.S. DOT, 2014) and the assumption that the underlying scrappage rate are largely functions of overall wear-and-tear and total mileage, then a 75% increase in annual mileage per vehicle could reduce this average on-road age to approximately 6.5 years.[4] (Failure to keep pace with the increased maintenance requirements could further shorten a vehicle's service life in terms of total miles.)

One possible silver lining to decreased vehicle life span (in years) involves the more rapid introduction of new technology into the on-road fleet, and the consequent benefits for road safety. In the hypothetical scenario we describe in this analysis, with an average turnover rate that is 75% faster for these vehicles, the rate at which new self-driving technology would be replaced or updated in the on-road fleet would nearly double (versus current average vehicle age and annual usage rates).

[4] These calculations do not take into account the effect of the additional mileage accrued when an unoccupied vehicle travels in the "return-to-home" mode.

Conclusions

In this report we presented an analysis of the potential for reduced vehicle ownership within households based on sharing of completely self-driving vehicles that employ a "return-to-home" mode, acting as a form of shared family or household vehicle. An examination of the latest U.S. National Household Travel Survey (NHTS) data shows a general lack of trip overlap between drivers within a majority of households, opening up the possibility for a significant reduction in average vehicle ownership per household based on vehicle sharing. This reduction in ownership and an accompanying shift to vehicle sharing within each household, in the most extreme hypothetical scenario, could reduce average ownership rates by 43%, from 2.1 to 1.2 vehicles per household. Conversely, this shift would result in a 75% increase in individual vehicle usage, from 11,661 to 20,406 annual miles per vehicle. (This increase in mileage does not include the additional miles that would be generated during each "return-to-home" trip.) However, given the number of current unknowns regarding sufficient gaps between trips, future self-driving-vehicle implementation, self-driving-vehicle acceptance, and possible vehicle-sharing strategies within households, these results serve only as an upper-bound approximation of the potential for household sharing of completely self-driving vehicles.

References

Anderson, J. M., Kalra, N., Stanley, K. D., Sorensen, P., Samaras, C., and Olumatola, O. A. (2014). *Autonomous vehicle technology. A guide for policymakers*. Available at: http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-1/RAND_RR443-1.pdf

Bloomberg. (2014, July 21). *Self-driving cars will mean more traffic*. Available at: http://www.businessweek.com/articles/2014-07-21/self-driving-cars-will-mean-more-traffic

Litman, T. (2014). *Autonomous vehicle implementation predictions. Implications for transport planning*. Available at: http://www.vtpi.org/avip.pdf

Martin, E., Shaheen, S. A., and Lidicker, J. (2010). Impact of carsharing on household vehicle holdings: Results from North American shared-use vehicle survey. *Transportation Research Record: Journal of the Transportation Research Board, 2143*, 150-158. Available at: http://trb.metapress.com/content/qn6630211676kq63/fulltext.pdf

Schoettle, B. and Sivak, M. (2014). *Public opinion about self-driving vehicles in China, India, Japan, the U.S., the U.K., and Australia* (Technical Report No. UMTRI-2014-30). Ann Arbor: University of Michigan Transportation Research Institute. Available at: http://deepblue.lib.umich.edu/bitstream/handle/2027.42/109433/103139.pdf

U.S. DOT [United States Department of Transportation]. (2011a). *2009 National Household Travel Survey user's guide (version 2)*. Available at: http://nhts.ornl.gov/2009/pub/UsersGuideV2.pdf.

U.S. DOT [United States Department of Transportation]. (2011b). *2009 NHTS - Public use codebook, version 2.1*. Available at: http://nhts.ornl.gov/2009/pub/Codebook.pdf.

U.S. DOT [United States Department of Transportation]. (2011c). *Summary of travel trends. 2009 National Household Travel Survey.* Available at: http://nhts.ornl.gov/2009/pub/stt.pdf.

U.S. DOT [United States Department of Transportation]. (2011d). *2009 NHTS - version 2.1, February 2011 [SAS Windows binary (.sas7bdat) files]*. Available at: http://nhts.ornl.gov/download.shtml.

U.S. DOT [United States Department of Transportation]. (2013). *Preliminary statement of policy concerning automated vehicles*. Available at: http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf

U.S. DOT [United States Department of Transportation]. (2014). *National Transportation Statistics. Table 1-26: Average age of automobiles and trucks in operation in the United States.* Available at: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_26.html.