U.S. Department of Transportation
National Highway Traffic Safety Administration

NHTSA

DOT HS 813 288 May 2022

Estimating Motorcycle Miles Traveled From State Vehicle Inspection Records

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Suggested APA Format Citation:

Kirley, B., Wang, Y., Foss, R., Harrell, S., & Goodwin, A. (2022, May). *Estimating motorcycle miles traveled from state vehicle inspection records* (Report No. DOT HS 813 288). National Highway Traffic Safety Administration.

Technical Report Documentation Page

<table>
<tr><td>1. Report No.
DOT HS 813 288</td><td>2. Government Accession No.</td><td>3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Estimating Motorcycle Miles Traveled From State Vehicle Inspection Records</td><td>5. Report Date
May 2022</td></tr>
<tr><td>6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Authors
Kirley, B., Wang, Y., Foss, R., Harrell, S., and Goodwin, A.</td><td>8. Performing Organization Report No.</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
UNC Highway Safety Research Center
730 Martin Luther King Jr. Blvd., Ste 300
Chapel Hill, NC 27599</td><td>10. Work Unit No. (TRAIS)</td></tr>
<tr><td>11. Contract or Grant No.
DTNH2211D00223L/0006</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
National Highway Traffic Safety Administration
Office of Behavioral Safety Research
1200 New Jersey Ave SE
Washington, DC 20590</td><td>13. Type of Report and Period Covered
Final Report
9/17/2016 – 3/16/2018</td></tr>
<tr><td>14. Sponsoring Agency Code</td></tr>
<tr><td colspan="3">15. Supplementary Notes
Dr. Kathryn Wochinger was the project manager for this project.</td></tr>
</table>

16. Abstract

Estimating vehicle exposure is difficult for any type of vehicle, and motorcycles are no exception. As motorcycle vehicle miles traveled (VMT) is based on traffic counts of sampled roadways supplemented with traffic modeling, a long-standing challenge of measuring motorcycle exposure is due to motorcycle characteristics in terms of size and type (smaller, lighter, single-axis) and use (recreational and weekend trips). This study sought to improve our understanding of this issue by examining use of motorcycle odometer readings as measures of VMT. The study used odometer data to calculate motorcycle mileage. The odometer data were part of motorcycle safety inspection records provided by three States — Hawaii, from 2013 to 2016; North Carolina, from 2012 to 2016; and Virginia, from 2012 to 2017. Mileage was computed for motorcycles that had more than one inspection record.

The results showed that mean annual mileage per motorcycle was consistent year-to-year for the periods studied, and motorcycles on average were ridden about 2,000 miles each year. This distance is lower than the mileage reported in self-report studies, suggesting that self-reports may be overestimations. Also, the annual motorcycle mileage was skewed, with a large proportion of motorcycles having been ridden for very few miles each year. The current study suggests that inspection records are valuable for revealing patterns of use, as they are a direct measure of distance ridden. The information in this report is presented to share research findings; it is not a recommendation to use this strategy for computing VMT. There are signification limitations to using odometer-based readings from inspection records to calculate VMT. First, this type of odometer data is not widely available, as few States require motorcycle safety inspections. Second, thousands of inspection records used in this study had missing or erroneous odometer data. Third, interpretation of odometer-based VMT is challenging because inspected motorcycles may have mileage accrued out-of-State, thereby limiting conclusions about State-based VMT.

<table>
<tr><td colspan="2">17. Key Words
motorcycles, motorcycle vehicle miles traveled, VMT, crash risk exposure, motorcycle safety inspection</td><td colspan="2">18. Distribution Statement
This document is available to the public from the DOT, BTS, National Transportation Library, Repository & Open Science Access Portal, rosap.ntl.bts.gov.</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
51</td><td>22. Price</td></tr>
</table>

Form DOT F 1700.7 (8.72) Reproduction of completed page authorized

Acknowledgements

The authors would like to acknowledge the following people for their assistance in obtaining motorcycle safety inspection data.

- Sgt. Kevin W.G. Satterfield, II, Virginia State Police
- Scott Haneberg, Hawaii Department of Transportation
- L. Paul Jelley, North Carolina Department of Motor Vehicles, License and Theft Bureau
- Eric D. Bellamy Sr., North Carolina Department of Transportation

Sincere thanks and appreciation are extended for their time, effort, and assistance on this project.

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Introduction

Annual motorcycle fatality and injury numbers are essential to understanding the status of motorcycle safety. A key data point in identifying trends in motorcycle safety is exposure in terms of the distance and riding conditions of motorcycle trips. Lacking reliable and accurate measures of exposure constrains the ability to assess trends in motorcycle riding and safety.

Obtaining exposure measures is challenging for all vehicle types, and motorcycles are no exception. In fact, the unique physical characteristics of motorcycles and motorcyclist travel patterns mean that traffic counting technologies must be capable of distinguishing motorcycles from other vehicle types, and traffic modeling must adjust for the travel patterns of motorcyclists (for example, more weekend trips and scenic drives).

Study Objective

Considering the historic challenges to estimating motorcycle miles traveled, this study sought to examine the use of motorcycle odometer data obtained from safety inspection records to estimate motorcycle mileage (exposure). The goal was to determine the feasibility, strengths, and weaknesses of using safety inspection data to estimate motorcycle miles traveled. The methodology was to acquire aggregate odometer readings from existing State motorcycle safety inspection data, use it as the basis for calculating motorcycle exposure, and compare it to estimates of vehicle miles traveled (VMT) based on the data in the USDOT Highway Statistics Series.[1]

Measures of Exposure

Motorcycle exposure is assessed in various ways, from indirect measures such as motorcycle registrations, licenses, and sales, and direct measures, such as self-reported mileage or odometer readings. An important measure of exposure is VMT, which is based on traffic counts which are then adjusted by growth in traffic. These measures are summarized below.

Indirect Measures of Exposure

Motorcycle Registration Records. The number of registered motorcycles is a commonly used as a proxy for motorcycle use. However, registration data are not direct measures of the exposure of motorcyclists to crash risk, for a variety of reasons. Many motorcyclists rely on a passenger vehicle as their primary means of transportation and use motorcycles more commonly for recreational purposes; similarly, in many States, motorcycles may be used during the warmer seasons. For example, a survey of motorcyclists in North Carolina found that 57% of motorcyclists rode exclusively for recreational purposes, 6% rode for task-related trips (e.g., work, school) and 37% made both recreational and functional trips (Kirley, Foss, & Goodwin, 2017). For these reasons, along with the fact that the number of motorcycles owned by individual riders varies, registration data are an indicator of motorcycle popularity, not exposure.

[1] The Highway Statistics Series consist of annual reports containing analyzed statistical information on motor fuel, motor vehicle registrations, driver licenses, highway user taxation, highway mileage, travel, and highway finance. Available at www.fhwa.dot.gov/policyinformation.

Vehicle Miles Traveled. VMT is the total number of miles traveled in a geographic region over a given period, usually a year. State departments of transportation conduct traffic monitoring programs that produce traffic counts for all vehicle types including motorcycles. State DOTs provide this data to the Federal Highway Administration (FHWA) for the Highway Performance Monitoring System (HPMS)[2] Measures of VMT are based on traffic counts that are adjusted to account for various factors such as growth in traffic.[3] The challenge with motorcycle VMT is that motorcycles differ from passenger vehicles in their physical characteristics (lower weight, less metal, smaller axle) and travel patterns (more recreational driving on weekends, on scenic routes, and at times in large groups). These differences influence the ability to count motorcycles, resulting in the long-standing concern that motorcycle travel is comparatively undercounted (for example, see TRB, 2007). Historically, the traffic counting technologies for passenger VMT were used for motorcycle VMT, an approach to counting traffic that makes sense overall in that these are the vehicle classes that make up the bulk of traffic volume on public roadways (Middleton et al., 2013). Traffic counting estimates have improved by expanding to full lane coverage and using piezoelectric sensors (FHWA, 2016a; S. Jessberger, personal communication, 2018; Middleton et al., 2013); nonetheless, the question remains whether a direct measure of motorcycle VMT is available and feasible for determining crash risk.

Direct Measures of Exposure

Self-Reports and Odometer Readings. Examples of direct measures of motorcycle exposure include motorcyclist self-reports on the distances they traveled and motorcycle odometer readings. Self-reported miles rely on the ability of riders to estimate this information accurately. Williams et al. (2017) compared self-reported mileage in one year to measured mileage in the following year for 91 motorcyclists participating in the Motorcycle Safety Foundation 100 Motorcyclists Naturalistic Study. Participants were asked to estimate how many miles they rode in the previous 12 months. Motorcycles were subsequently fitted with devices to capture both video and kinematic data. Participants reported an average annual mileage of 7,868 (ranging from 100 miles to 40,000 miles) whereas collected annual mileage averaged 4,847 miles (ranging from 65 miles to 21,696 miles), suggesting riders tended to overestimate the number of miles they rode annually. Odometer readings would provide information in the distance covered by a motorcycle but no information on the nature of a trip, type of road, or traffic conditions. Odometer readings would allow comparisons to VMT.

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[2] Information about HPMS is available at Highway Performance Monitoring System - Policy | Federal Highway Administration (dot.gov)

[3] The HPMS Field Manual provides detailed instructions on the requirements for HPMS data including VMT data. Available at www.fhwa.dot.gov/policyinformation/hpms/fieldmanual/

Method

Study States

This study required inspection data from States that met the following criteria:

1. Requiring all motorcycles to pass safety inspections, as some States exempt newly registered motorcycles from being inspected (which would likely bias estimates of VMT).
2. Having annual (instead of biennial) safety inspections.
3. Inspection data that had been in use for several years and were not in transition.
4. Having 5 years of digital inspection data.
5. Willingness to share data with the research team.

A review of websites for State DOTs and departments of motor vehicle found 16 States with motorcycle safety inspection programs. Information on the programs in each State was obtained from a variety of sources, including State DOT and DMV websites, news articles, census data, and motorcycle safety inspection stations within States. The features of interest included the following:

1. Are All Motorcycles Covered? Some programs have exemptions to their Motorcycle Safety Inspection Program. To obtain an accurate estimate of VMT, it is important that information is available about all motorcycles in the State. Several States exempt certain motorcycles from safety inspections (such as newer motorcycles). Any State that excluded more than a small fraction of motorcycles from the inspection requirement was eliminated from further consideration. This criterion is critical, and if a State program did not include all motorcycles, it was no longer considered a candidate.
2. Annual Versus Biennial Safety Inspections. States that require annual inspections were preferred over those with biennial inspections, because they would provide a more accurate picture of miles traveled in a single year.
3. Stability of the System. In several States the registration and inspection systems were in transition. For example, Texas was in the process of merging its inspection and registration systems, which could introduce irregularities across time. Hence, States whose inspection systems had not been stable for at least several years were eliminated from consideration.
4. Urban and Rural Roadways. Because riding differs in urban and rural areas, States where motorcycling involves a good mix of riding conditions were prioritized. At a minimum, the State's population needed to be well-distributed across urban, suburban, and rural areas.
5. Electronic Versus Paper Data. States with electronic data were prioritized because transferring 5 years of paper records to a digital format would be an enormous undertaking.

6. How Long Has the State Program Used Electronic Records? This criterion is important because it indicates the number of years of potentially available data for the study.

Table 1 summarizes the findings on the individual programs by the selection criteria. The States that did not meet criteria 1 through 6 listed above were no longer considered as candidates.

Table 1. Selection Criteria by State

State	All MCs covered?	Annual inspections?	System stable?	Urban & rural roadways?	Data stored electronically?	Electronic since…
Hawaii	Yes	Yes[1]	Yes	Yes	Yes	11/1/2013
Massachusetts	Yes	Yes	Yes	Yes	Yes	~ 1998
North Carolina	Yes[2]	Yes	Yes	Yes	Yes	11/1/2008
Virginia	Yes	Yes	Yes	Yes	Yes	2012
New York	Yes	Yes	Unknown	Yes	Unknown	
Maine	Yes	Yes	Yes	No		
New Hampshire	Unknown	Unknown	Unknown	No		
Rhode Island	Unknown	Unknown	Unknown	No		
West Virginia	Unknown	Unknown	Unknown	No		
Texas	Yes	Yes	No[3]			
Vermont	Yes	Yes	No[4]			
Louisiana	Unknown	No				
Pennsylvania	Yes	Yes[5]				
Delaware	No[6]					
Missouri	No[6]					
Utah	No[7]					

1. Inspections of new motorcycles are valid for 2 years. All other inspections are required annually.
2. Motorcycles more than 35 years old are exempt.
3. Was merging inspection and registration systems.
4. Was transitioning to electronic system.
5. Some motorcycles have a shortened inspection cycle to coincide with the vehicle registration due date.
6. Motorcycles in most recent five model years are exempt.
7. Only motorcycles age 4, 8, and > 10 years-old are inspected.

Four States were identified as good candidates for study — Hawaii, Massachusetts, North Carolina, and Virginia. These four States were contacted and asked to provide data from the annual motorcycle safety inspections. North Carolina, Hawaii, and Virginia provided the research teams with data from their annual motorcycle safety inspections.

Study Data

This section describes the size of each State's annual motorcycle safety inspection data provided for this analysis, the variables included, issues identified with the data, and steps taken to clean the data for analysis. Table 2 summarizes the datasets by State, years of inspections, number of inspections, number of motorcycles inspected, and the range of motorcycle model year.

Table 2. Study Data by State

State	Dates Dataset Covered	Number of Inspections	Number of Motorcycles	Motorcycle Model Year Ranges
North Carolina	1/1/12 – 12/31/16	982,852	335,876	1977 – 2017
Virginia	8/1/12 – 9/8/17	604,581	255,473	Pre-1950s – 2017
Hawaii	11/1/13 – 12/31/16	101,364	42,803	Pre-1950s – 2017

North Carolina

There were 11 variables in the dataset: Vehicle Identification Number (VIN), County, License Plate Number, Model Year (MY), Make, Model, Test (inspection) Start Date, Test Start Time, Test End Date, Test End Time, and Current Odometer Reading. North Carolina does not require safety inspections for vehicles more than 30 years old. North Carolina's inspection system requires motorcycle safety inspectors to enter information into the system manually, including the 17-character VIN.

The key variable of interest for this study was the Current Odometer Reading which was missing for 6,707 inspections (6.8%). About 1% of the odometer readings were extreme (e.g., over 100,000 miles, with the highest being 999,999), and were excluded from analysis. The dataset included 2,383 inspections for motorcycles not registered in North Carolina, per the values in the "County" variable, and these were excluded from analyses.

Every vehicle inspection was recorded as a "Pass" (n = 966,365), "Fail" (n = 9,715), or "Re-inspection" (n = 6,772). "Re-inspection" refers to an inspection that was passed following a failure, and the two inspections typically occurred close in time. The median time between a failed inspection and a re-inspection was 3 days; 95% occurred within 35 days.

Virginia

There were eight variables in the dataset, including VIN, Plate Number, MY, Make, Model, Date of Inspection, Inspection Result, and Current Odometer Reading. There were no missing data for the Current Odometer Reading variable. Unlike the data from North Carolina, the Virginia dataset only had records on passed inspections.

There were obvious invalid entries for some of the records and these records were deleted from the study set. For example, a record having an MY value of "809" or "9154" would be deleted, as would be a record having a Make and Model values for a non-motorcycle (such as "Ford Explorer" or "Jeep Liberty"). Likewise, some records had VINs that included illegal characters.

However, the proportion of these deleted records from the full data set was relatively small, with records having invalid MY accounting for less than 0.1%; records with invalid Make and Model variables accounting for less than 0.1%; and records with invalid VINs accounting for 3.56%.

Hawaii

There were 11 variables in the dataset, including Vehicle Number, Vehicle Type, Insurance Expiration Date, Model Year, Make, New Vehicle Indicator, Gross Vehicle Weight, a Mileage Measure Indicator (miles or kilometers), Current Odometer Reading, Inspection Date, and a Re-inspection Indicator.

The Hawaii Department of Transportation did not provide VINs, but had a unique identifier referred to as "Vehicle Number," precluding the possibility of examining the quality of the data entry for the original VIN variable. There were no missing data for the Current Odometer Reading variable. The Odometer Reading was reported in kilometers or miles, and for analysis purposes, odometer reading data were converted to miles.

Hawaii identified 9,630 vehicles as "new" vehicles, which were not newly manufactured but newly owned. In Hawaii, inspections of vehicles classified as "new" are valid for 2 years, with subsequent inspections required annually. Because the Hawaii dataset included approximately 3 years of data, all "new" vehicles with only one inspection in the dataset were excluded from further analysis. This dataset did not contain failed inspections, but 23% of the inspections were categorized as "re-inspection[s]" considered to be inspections that passed "after a failure." (A motorcycle that is not registered in Hawaii will also fail an inspection in Hawaii.)

Common Issues Across the Data Sets

Extensive data exploration determined which data should be included or excluded from the analyses. For example, there were motorcycles that appeared to have had 3 or more inspections within a single year (as many as 6 in North Carolina, 5 in Virginia, and 22 in Hawaii). Some of these inspections seemed to be duplicate "passed" inspection records having the same date, and some occurred within a few days or weeks. Hence, these inspection records were excluded, as their validity was questionable. Sensitivity analyses were conducted to assess the impact of this decision. Because they accounted for less than 1% of the inspected population in all three States, the results were virtually the same whether they were or were not included in the analyses. Other examples of erroneous data were odometer readings lower than those recorded during previous inspections.

Table 3 shows examples of three motorcycles with irregular odometer readings across inspections; inspection records with irregular readings were also excluded from the final data set.

Table 3. Examples of Irregular Odometer Readings

	Inspection 1 Date, Odometer Reading	Inspection 2 Date, Odometer Reading	Inspection 3 Date, Odometer Reading
Motorcycle 1	Oct. 24, 2014	July 31, 2015	Aug. 5, 2016
	93,135	60,221	95,185
Motorcycle 2	Jan. 4, 2012	Sep. 20, 2012	Aug. 27, 2013
	4,684	5,622	133
Motorcycle 3	Nov. 21, 2013	Nov. 12, 2014	Dec. 9, 2015
	50,036	8,359	9,176

Motorcycle 1's odometer reading from the second inspection is problematic as it generates negative mileage between the first and second inspections, and a seemingly legitimate (though extreme) difference between the second and third inspections. However, neither calculation is a valid indicator of miles traveled by the motorcycle. Similarly, the odometer readings for Motorcycle 2 and Motorcycle 3 show negative mileage. Motorcycle 2's odometer reading in the third inspection is lower than the previous readings, and Motorcycle 3's odometer reading is higher than the readings in the subsequent inspections. Each of these motorcycles were excluded from the final data set. Although such problems are often easy to spot when visually inspecting a series of readings for a single motorcycle, there is no consistently valid algorithm to identify and correct the many possible erroneous calculations across a series of five or more readings for several hundred thousand motorcycles. Consequently, when such problems were identified by the existence of a negative mileage calculation, we excluded the entire case (i.e., all odometer readings for that motorcycle) from the analyses.

The inspection data included odometer readings of "0" (zero) miles. Records with "0" miles in the first inspection were coded as missing, and records of subsequent inspections with "0" miles were excluded from analysis, as this would result in negative mileage.

Extreme odometer values were present in all three datasets and included readings greater than 200,000 miles. Further, there were some records showing mileage between inspections that exceeded 100,000 miles, an amount that is unusually large for a motorcycle in a year. Such differences were likely the result of data errors in at least one record, and records for such motorcycles were excluded.

In establishing cut-off points to define outliers in annual mileage, we considered excluding the top 0.5%, the top 1%, as well as vehicles with annual mileage of 20,000, 25,000, and 30,000 miles. However, none of these cut-off points made appreciable differences in the annual mileage estimates. Thus, we decided to exclude the top 1% of annual mileage calculations as erroneous outliers. For example, in the Hawaii data, the 99th percentile in odometer reading differences between two adjacent years ranged from 15,582 to 20,467. Using the 99th percentile to delineate outliers, as opposed to using a mileage for a cut-off, enabled a consistent approach to analyses in the States and across time.

Figures 1 to 3 show the total number of safety inspection records for North Carolina, Virginia, and Hawaii, and the numbers of exclusions due to missing data, atypical inspection patterns, negative mileage, and extreme mileage. In summary, 297,874 inspection records from North Carolina, 239,529 records from Virginia, and 24,680 records for Hawaii were retained for analysis. See Appendices A to C for additional information on the inspection data for North Carolina, Virginia, and Hawaii.

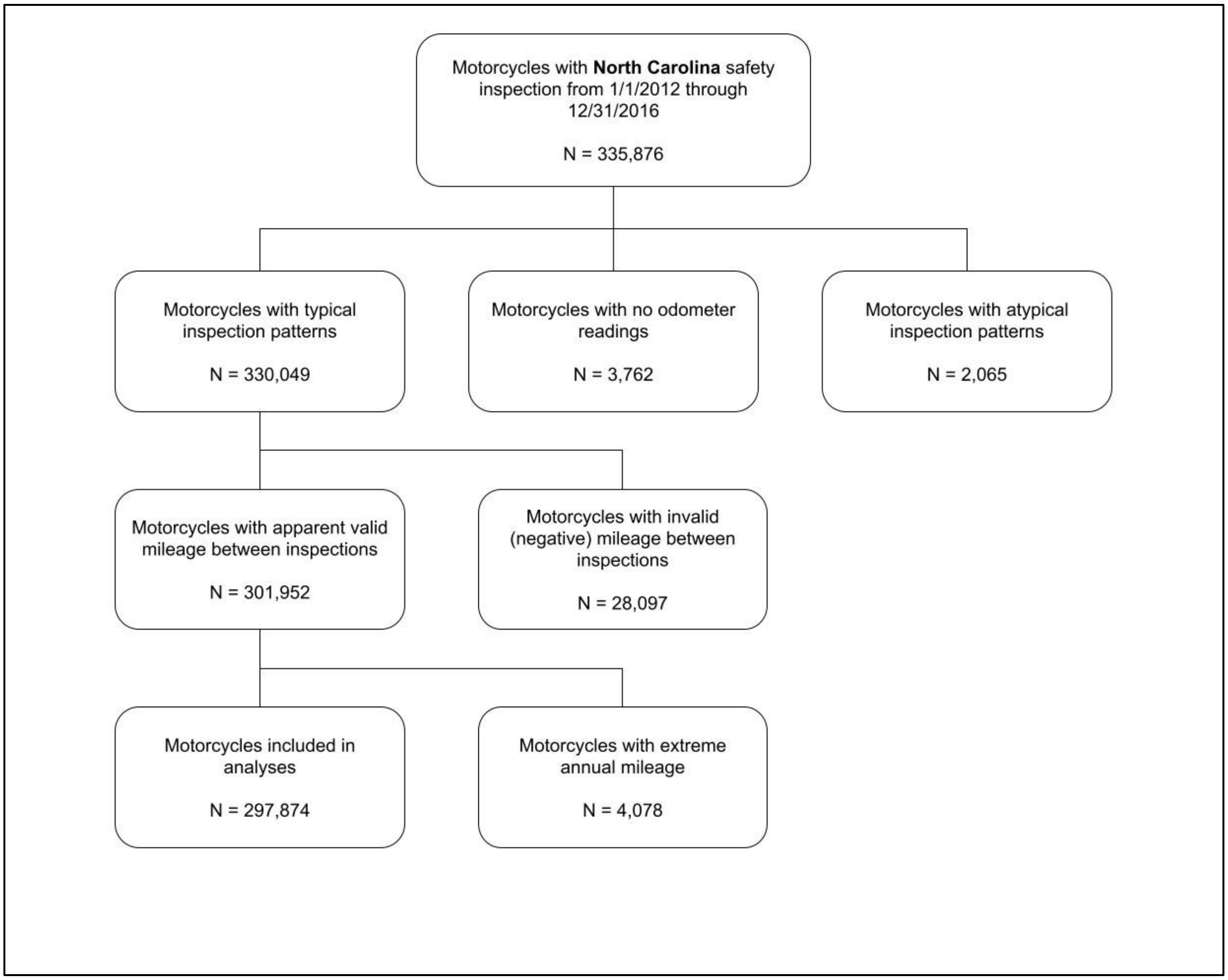

Figure 1. North Carolina Inspection Record Selection[4]

[4] In North Carolina, public-owned motorcycles, and scooters with engine sizes smaller than 50 cubic centimeters do not require an inspection. Scooters with larger engines are classified as motorcycles and do require an inspection.

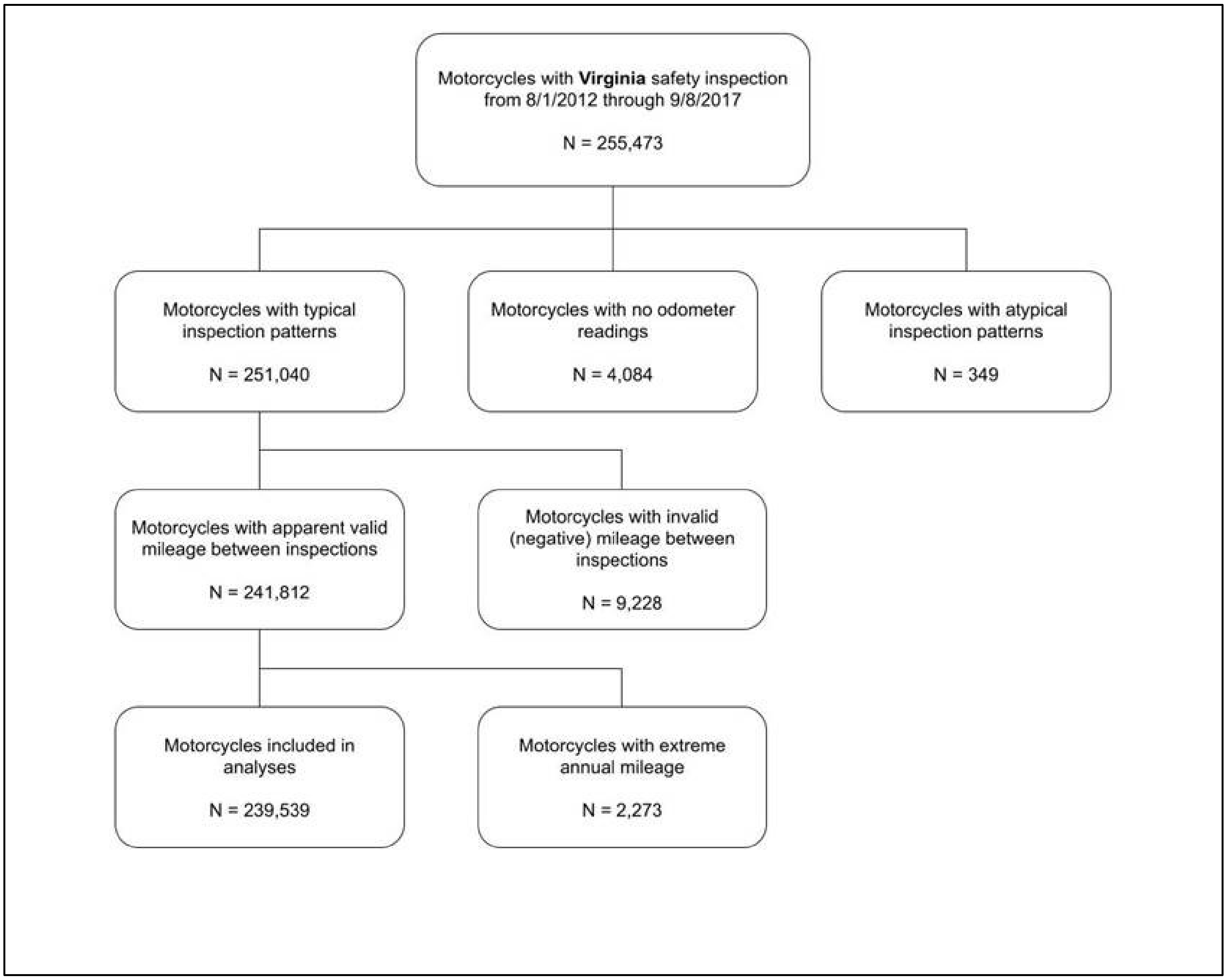

Figure 2. Virginia Inspection Record Selection

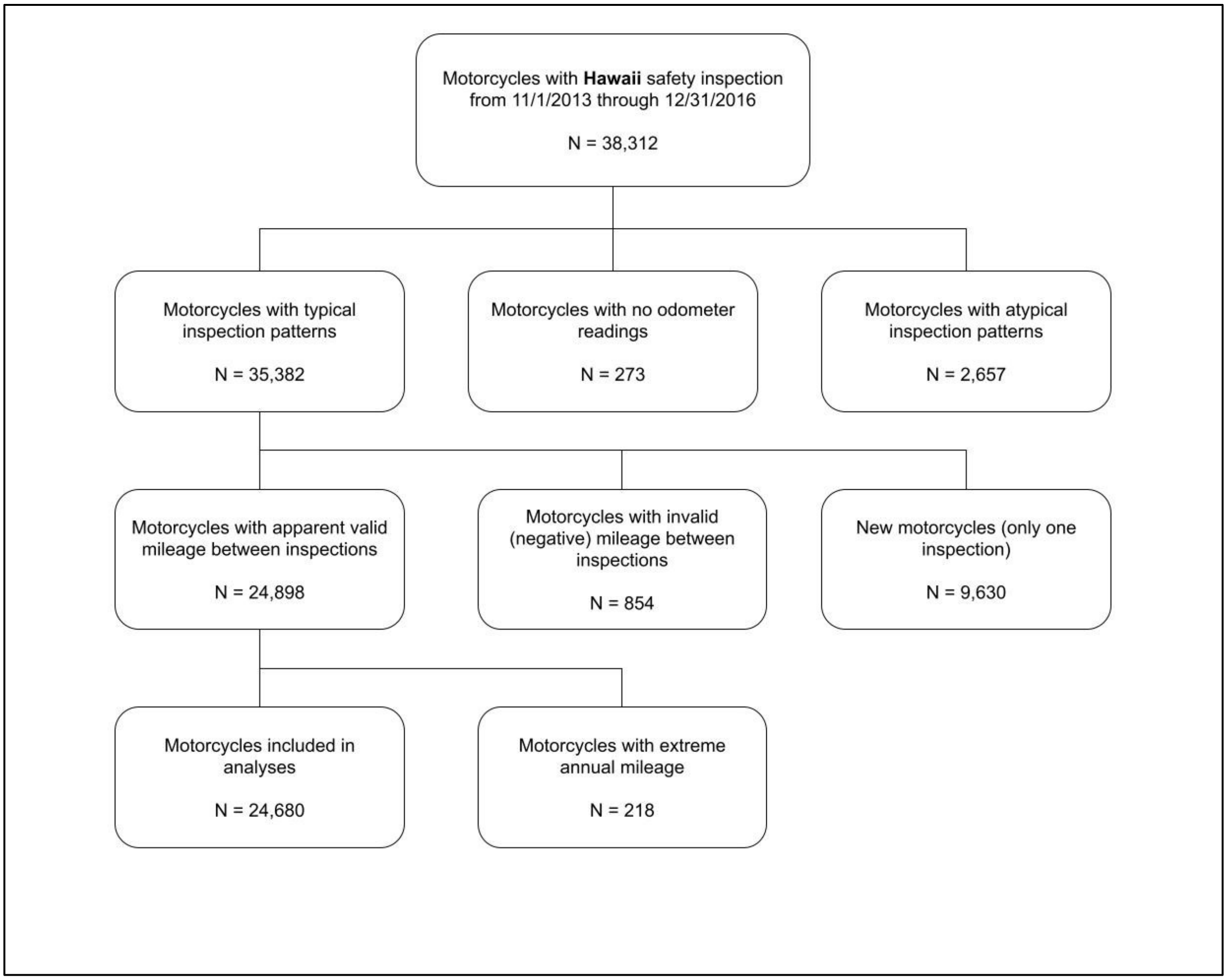

Figure 3. Hawaii Inspection Record Selection

Estimating Mileage Within a Calendar Year

To estimate annual VMT from odometer data, we allocated the calculated mileage within the calendar year between inspections. Two approaches were used.

Method 1. Assign mileage based on differences between adjacent inspections – these typically occurred approximately 1 year apart but were sometimes separated by 2 years or more.

Method 2. Assign mileage based on differences between the very first and the very last inspections available for each motorcycle within the period for which data were available.

Method 1 assumed that motorcycle riding was evenly distributed across months of a year. The assumption that motorcycle riding is distributed across months of the year is more sensible for Hawaii, than it is for North Carolina and Virginia, due to their colder winters. Method 2 assumed that motorcycle riding was evenly distributed across different years. Method 1 allowed using as many data points as possible, but Method 2 focused solely on the first and last data points for each motorcycle, to see if a simpler approach would be adequate to make VMT estimations.

Method 1: Differences Between Adjacent Inspections

With this method, we first calculated the mileage and number of days between all adjacent inspections. In the hypothetical example in Table 4, a hypothetical motorcycle had four inspections between 2013 and 2017, with the mileage between inspection 1 on March 31, 2013, and inspection 2 on August 15, 2014, being 5,000 miles, over a period of 501 days.

Table 4. Mileage Traveled by Hypothetical Motorcycle

	Inspection 1	**Inspection 2**	**Inspection 3**	**Inspection 4**
Dates		8/15/2014 – 3/31/2013	7/1/2016 – 8/16/2014	4/1/2017 – 7/1/2016
Mileage	n/a*	15,000-10,000 = 5,000	18,000-15,000 =3,000	19,500-18,000 =1,500
Days Between Inspections	n/a	501	685	273

*n/a = not applicable

Next, these miles were assigned proportionally to each calendar year. For example, 55% of the 5,000 miles between Inspections 1 and Inspection 2 would be assigned to 2013 (275 out of 501 days), and 45% would be assigned to 2014 (226 out of 501 days). Similarly, the 3,000 miles traveled between Inspection 2 on August 15, 2014, and Inspection 3 on July 1, 2016, would be assigned as: 20% assigned to 2014 (138 out of 685 days), 53% assigned to 2015 (365 out of 685 days), and 27% assigned to 2016 (182 out of 685 days). Finally, 67% of the 1,500 miles traveled between Inspections 3 and 4 would be assigned to 2016 (183 out of 273) and 33% would be assigned to 2017 (90 out of 273 days). This process was repeated for each motorcycle, providing an estimate of mileage for either part of a year or for a full year. See Figure 4 for a visual representation.

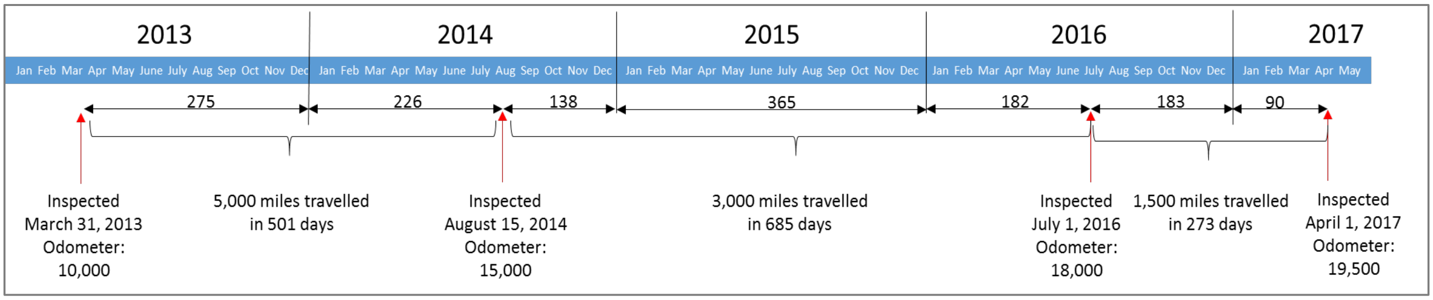

Figure 4. Method 1: Assigning Mileage Between Adjacent Inspections to a Calendar Year

Method 2: Differences Between the First and Last Inspections

With this method, we used only the first and last inspection for individual motorcycles, based on the assumption that motorcycle riding activities are evenly distributed across different calendar years.

Continuing with the previous hypothetical example, we would first calculate the mileage difference and number of days between the first and last inspections. In this case, 9,500 miles (19,500 – 10,000) were accumulated in 1,462 days (March 31, 2013, to April 1, 2017). These miles would then be then assigned proportionally to each calendar year. In this example, 19% of the total miles would be assigned to 2013 (275 out of 1,462 days), 25% (365 out of 1,462 days) would be assigned to 2014, 25% (365 out of 1,462 days) would be assigned to 2015, 25% (365 out of 1,462 days) would be assigned to 2016, and 6% would be assigned to 2017 (90 out of 1,462 days) as shown in Figure 5. This process was repeated for every motorcycle, providing an estimate of mileage for either part of a year or for a full year.

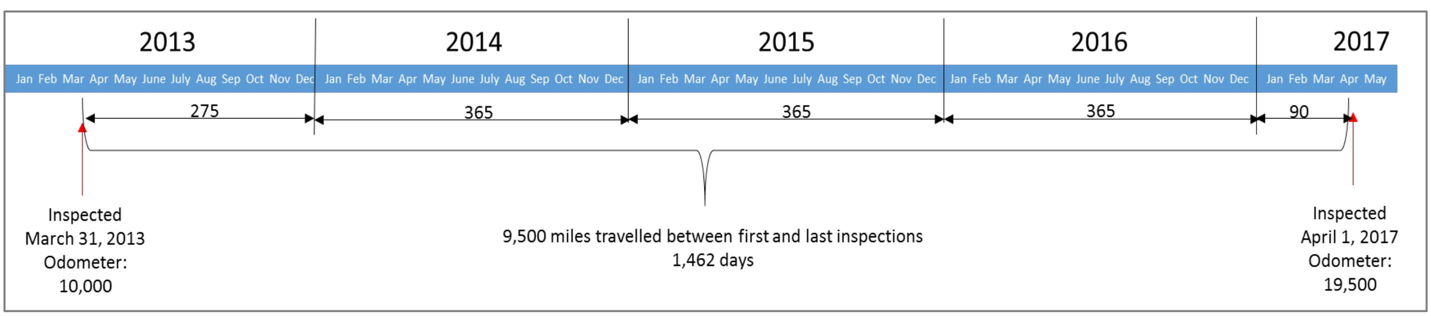

Figure 5. Method 2: Assigning Mileage Between First and Last Inspections to a Calendar Year

Computing Mean Annual Mileage per Motorcycle

As mileage for partial or full calendar year was computed for all motorcycles for which odometer reading data were available (with either method), motorcycles with different inspection schedules contributed to the same calendar year. For example, in Method 1, information on Calendar Year 2013 in NC could be provided by the following on the next page.

- Group 1: motorcycles inspected in 2012 and next in 2013
- Group 2: motorcycles inspected in 2013 and next in 2014
- Group 3: motorcycles inspected in 2012 and next in 2014
- Group 4: motorcycles inspected in 2012 and next in 2015
- Group 5: motorcycles inspected in 2012 and next in 2016
- Group 6: motorcycles inspected in 2013 and next in 2015
- Group 7: motorcycles inspected in 2013 and next in 2016

For motorcycles with inspections in adjacent years, for example from 2013 to 2014, we assumed their mileage assigned to 2013 represents miles accumulated in the latter half of 2013, and their mileage assigned to 2014 represents miles accumulated in the first half of 2014. We make this assumption because these inspections occurred, on average, 12 months apart. A motorcycle with an April-to-April inspection could hypothetically "balance out" another motorcycle with an August-to-August inspection, so that overall, these motorcycles provided half-year information for 2013 and half-year information for 2014.

For motorcycles with inspections that spread over 2 calendar years or more, for example, between 2013 and 2015, which accounted for a relatively small proportion of the sample, we only used mileage for the year with full-year information (in this case, 2014) in annual mileage estimation. We were not able to incorporate information for 2013 and 2015 for these motorcycles because there was not an obvious pattern for the partial years. Therefore, only information from Group 1 to Group 5 would be used to estimate 2013 mean annual mileage. For the same reason, in Method 2, we used only groups that provided full year information for a calendar year. Further, when we had data for a half year or a full year for a motorcycle, we felt comfortable assuming the mileage ridden was evenly distributed across the months or the years during this period. However, it was too risky to assume the reverse. That is, when we only had information for less than 6 months of a year, we did not assume the information represented the whole year.

To calculate mean annual mileage per motorcycle for each calendar year, the mean annual mileage for each group was first computed, then the means across groups were pooled together to generate the mean annual mileage for the whole sample. Specifically, the pooled mean annual mileage was calculated using the following equation.

$$\bar{Y}_j = \frac{\bar{m}_{1j} * n_{1j} + \bar{m}_{2j} * n_{2j} + \ldots + \bar{m}_{ij} * n_{ij}}{n_{1j} + n_{2j} + \ldots + n_{ij}}$$

Where:

$\bar{Y}_j$ = mean annual mileage per motorcycle during Calendar Year j
i = group associated with Calendar Year j
$\bar{m}_i$ = mean annual mileage assigned to a Calendar Year j associated with Group i
n_i = number of motorcycles within Group i

Results

North Carolina

In total, 297,874 North Carolina motorcycles contributed information for 962,095 inspections. The aggregate number of inspections for each year is indicated in Table 5. On average, 192,419 inspections were recorded each year. Some motorcycles had more than one inspection within the same calendar year. For example, in 2012, 183,087 motorcycles had one inspection and 7,434 of those had a second inspection within the same year.

Table 5. Number of Inspections by Year, North Carolina

	1st inspection	2nd inspection	Total
2012	183,087	7,434	190,521
2013	184,221	8,168	192,389
2014	183,457	8,095	191,552
2015	185,122	8,495	193,617
2016	185,145	8,871	194,016
Total			962,095

Estimation Method 1 – Mean Annual Mileage per Motorcycle Based on Differences Between Adjacent Inspections

Method 1 consisted of calculating the mileage and number of days between all adjacent inspections and then assigning these miles proportionally to each calendar year, as shown in Table 6. For the motorcycles that had consecutive inspections in 2012 and 2013 (n=106,329), 898 miles were assigned as the average mileage to the first half of 2013. For the motorcycles with consecutive inspections in 2013 and 2014 (n=104,820), 1,047 miles were assigned to the second half of 2013. For the motorcycles that had an inspection in 2012 and one in 2014 (n=15,820), the part of their mileage that was assigned to 2013 is 1,583 miles. For the motorcycles that had an inspection in 2012 and one in 2015 (n=3,124), 954 miles were assigned to 2013. Finally, for the motorcycles that had an inspection in 2012 and one in 2016 (n=1,552), 830 miles were assigned to 2013.

Table 6. Average Mileage by Motorcycle Groups Having Adjacent Inspections, North Carolina, Method 1

	2013		2014		2015	
	Mileage	N	Mileage	N	Mileage	N
2012/2013 (2013 first half)	898	106,329				
2013/2014 (2013 second half)	1,047	104,820				

	2013		2014		2015	
	Mileage	**N**	**Mileage**	**N**	**Mileage**	**N**
2013/2014 (2014 first half)			859	104,820		
2014/1015 (2014 second half)			1,011	105,280		
2014/2015 (2015 first half)					797	105,280
2015/2016 (2015 second half)					1,069	108,339
2012/2014	1,583	15,820				
2012/2015	954	3,124	954	3,124		
2012/2016	830	1,552	830	1,552	830	1,552
2013/2015			1,585	15,369		
2013/2016			1,021	2,996	1,021	2,996
2014/2016					1,667	14,956

Pooling these motorcycles, the mean distance traveled in 2013 was 1,898 miles, calculated as:

$$\overline{Y}_{2013} = \frac{898 * 2 * 106{,}329 + 1{,}047 * 2 * 104{,}820 + 1{,}583 * 15{,}820 + 954 * 3{,}124 + 830 * 1{,}552}{106{,}329 + 104{,}820 + 15{,}820 + 3{,}124 + 1{,}552} = 1{,}898$$

Using the same procedure, the mean annual mileage per motorcycle calculated using Method 1 was 1,821 miles for 2014 and 1,839 miles for 2015.

Estimation Method 2 – Mean Annual Mileage per Motorcycle Based on Differences Between the First and Last Inspections

Method 2 calculated mileage based on the very first inspection and the very last inspection for each vehicle, with the assumption that motorcycle riding is evenly distributed across different calendar years. There were 15 exhaustive and mutually exclusive combinations for the first and last inspections in the North Carolina dataset, as shown in Table 7.

Table 7. Combinations of First and Last Inspection Times, North Carolina

2012-2012	2013-2013	2014-2014	2015-2015	2016-2016
2012-2013	2013-2014	2014-2015	2015-2016	
2012-2014	2013-2015	2014-2016		

2012-2015	2013-2016			
2012-2016				

For example, motorcycles in the 2012-2012 combination had their first inspection in 2012 and their last inspection in 2012. Similarly, motorcycles in combination 2013-2015 had their first inspection in 2013 and their last inspection in 2015.

With this method, only motorcycles contributing to full year estimates for 2013, 2014, and 2015 were included. For example, 2,889 motorcycles had their first inspection in 2012 and their last inspection in 2014. These motorcycles contributed information only to the full year of 2013, but not the full year of 2012 or 2014. Similarly, 3,303 motorcycles had their first inspection in 2012 and their last inspection in 2015. These motorcycles contributed full year data to 2013 and 2014, but not to 2012 and 2015. Table 8 shows the average miles contributed by each group of motorcycles providing data for the period indicated.

Table 8. Mileage Computed for Each Group and Year, North Carolina Data, Method 2

	2013		**2014**		**2015**	
	Mileage	**N**	**Mileage**	**N**	**Mileage**	**N**
2012/2014	2,676	2,889				
2012/2015	1,557	3,303	1,557	3,303		
2012/2016	1,703	6,718	1,703	6,718	1,703	6,718
2013/2015			2,130	111,926		
2013/2016			1,727	21,848	1,727	21,848
2014/2016					2,096	8,088

Pooling these motorcycles with various inspection schedules, the mean annual mileage per motorcycle was calculated to be 1,883 miles in 2013, 2,036 miles in 2014, and 1,804 miles in 2015, as follows:

$$Y_{2013} = \frac{2{,}676 * 2{,}889 + 1{,}557 * 3{,}303 + 1{,}703 * 6{,}718}{2{,}889 + 3{,}303 + 6{,}718} = 1{,}883$$

$$Y_{2014} = \frac{1{,}557 * 3{,}303 + 1{,}703 * 6{,}718 + 2{,}130 * 111{,}926 + 1{,}727 * 21{,}848}{3{,}303 + 6{,}718 + 111{,}926 + 21{,}848} = 2{,}035$$

$$Y_{2015} = \frac{1{,}703 * 6{,}718 + 1{,}727 * 21{,}848 + 2{,}096 * 8{,}088}{6{,}718 + 21{,}848 + 8{,}088} = 1{,}804$$

The mean average mileage calculated using each method is shown in Table 9. Overall, the mean annual distance traveled in North Carolina using Method 2 was like that using Method 1.

Table 9. Mean Annual Mileage per Motorcycle, North Carolina

	Method 1	**Method 2**
2013	1,898	1,883
2014	1,821	2,036
2015	1,839	1,804

Virginia Inspections

From 2012 to 2017 there were 239,529 Virginia motorcycles that contributed information to 595,143 inspections. The aggregate number of inspections for each year is shown in Table 9. For years in which complete data were available (2013 to 2016), an average of 118,945 inspections were recorded each year. Some motorcycles had more than one inspection in the same calendar year; for example, in 2012, 213 of the 31,609 motorcycles had a second inspection in the same year.

Table 10. Number of Inspections by Year, Virginia Data

	Inspection 1	**Inspection 2**	**Total**
2012	31,609	213	31,822
2013	120,703	2,314	123,017
2014	117,663	2,133	119,796
2015	117,008	2,245	119,253
2016	111,553	2,160	113,713
2017	86,457	1,085	87,542
Total			**595,143**

Note: 2012 only included inspections conducted between August 1, 2012 and December 31,2012, and 2017 only included inspections conducted between January 1, 2017 and September 8, 2017. Hence, 2012 and 2017 included fewer inspections than other years.

Estimation Method 1 – Mean Annual Mileage per Motorcycle Based on Differences Between Adjacent Inspections

The same process undertaken for the North Carolina data was applied to the Virginia data to compute mean annual mileage per motorcycle considering the portion of the year for which each motorcycle contributed data. Table 10 shows the average miles contributed by the subset of motorcycles providing data for the time indicated.

Table 11. Mileage Computed for Each Group and Calendar Year, Virginia Data, Method 1

	2013		2014		2015		2016	
	Mileage	**N**	**Mileage**	**N**	**Mileage**	**N**	**Mileage**	**N**
2012/2013 (2013 1st half)	1,690	12,761						
2013/2014 (2013 2nd half)	1,197	62,226						
2013/2014 (2014 1st half)			1,079	62,226				
2014/1015 (2014 2nd half)			1,133	60,948				
2014/2015 (2015 1st half)					1,024	60,948		
2015/2016 (2015 2nd half)					1,160	58,889		
2015/2016 (2016 1st half)							1,065	58,889
2016/2017 (2016 2nd half)							1,270	27,269
2012/2014	1,322	7,340						
2012/2015	906	1,308	906	1,308				
2012/2016	745	489	745	489	745	489		
2012/2017	641	233	641	233	641	233	641	233
2013/2015			1,212	16,150				
2013/2016			845	3,676	845	3,676		
2013/2017			746	1,462	746	1,462	746	1,462
2014/2016					1,143	14,412		
2014/2017					825	3,149	825	3,149
2015/2017							1,293	13,849

Estimation Method 2 – Mean Annual Mileage per Motorcycle Based on Differences Between the First and Last Inspections

There were 21 exhaustive and mutually exclusive combinations for first and last inspection in the Virginia dataset, as shown in Table 11. With these combinations, full year estimates were available for 2013, 2014, 2015, and 2016, shown in Table 12.

Table 12. Combinations of First and Last Inspection Times, Virginia Data

2012-2012	2013-2013	2014-2014	2015-2015	2016-2016	2017-2017
2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	
2012-2014	2013-2015	2014-2016	2015-2017		
2012-2015	2013-2016	2014-2017			

2012-2016	2013-2017				
2012-2017					

Table 13. Mileage Computed for Each Group and Calendar Year, Virginia Data, Method 2

	2013		**2014**		**2015**		**2016**	
	Mileage	**N**	**Mileage**	**N**	**Mileage**	**N**	**Mileage**	**N**
2012/2014	2,676	2,889						
2012/2015	1,557	3,303	1,557	3,303				
2012/2016	1,703	6,718	1,703	6,718	1,703	6,718		
2012/2017	1,700	7,356	1,700	7,356	1,700	6,356	1,704	7,356
2013/2015			2,130	11,926				
2013/2016			1,727	21,848	1,727	21,848		
2013/2017			1,818	29,081	1,818	29,081	1,823	29,081
2014/2016					2,096	8,088		
2014/2017					2,176	9,536	2,182	9,536
2015/2017							2,811	7,996

The mean annual mileage using Methods 1 and 2 is shown in Table 13.

Table 14. Summary of mean annual mileage per motorcycle for Virginia

	Virginia	
	Method 1	**Method 2**
2013	2,266	1,817
2014	2,033	1,775
2015	1,991	1,844
2016	2,064	2,017

Hawaii

The data showed that 24,680 motorcycles contributed information from 81,132 inspections. The aggregate number of inspections by year is shown in Table 14. For the years in which complete data were available (2014 to 2016), there was an annual average of 25,826 inspections.

Table 15. Number of Inspections by Year in Hawaii

	Inspection 1	**Inspection 2**	**Total**
2013	3,014	641	3,655
2014	20,666	5,533	26,199
2015	20,291	5,612	25,903
2016	19,993	5,382	25,375
Total			81,132

Note: 2013 only included inspections conducted between November 1, 2013 and December 31, 2013. Hence, 2013 included fewer inspections than other years.

Estimation Method 1 – Mean Annual Mileage per Motorcycle Based on Differences Between Adjacent Inspections

The same process undertaken for the North Carolina and Virginia data was applied to the Hawaii data to compute mean annual mileage per motorcycle considering the portion of the year for which each motorcycle contributed data. Table 15 shows the average miles contributed by the subset of motorcycles providing data for the time indicated.

Table 16. Mileage Computed for Each Group and Calendar Year, Hawaii Data, Method 1

	2014		2015	
	Mileage	**N**	**Mileage**	**N**
2013/2014 (2014 first half)	1,741	1,014		
2014/2015 (2014 second half)	1,052	11,551		
2014/2015 (2015 first half)			993	10,551
2015/2016 (2015 second half)			986	10,472
2013/2015	1,893	896		
2013/2016	1,780	142	1,780	142
2014/2016			1,726	3,430

Estimation Method 2 – Mean Annual Mileage per Motorcycle Based on Differences Between the First and Last Inspections

There were 10 exhaustive and mutually exclusive combinations for first and last inspection in the Hawaii dataset. With these combinations, full year estimates are available for 2014 and 2015. The mean mileage was calculated for 2014 and 2015 using Method 1 and Method 2. As found with the North Carolina and Virginia data, estimates using Method 1 were similar to those using Method 2.

Table 17. Combinations of First and Last Inspection Times, Hawaii Data

2013-2013	**2014-2014**	**2015-2015**	**2016-2016**	
2013-2014	2014-2015	2015-2016		
2013-2015	2014-2016			
2013-2016				

Table 18. Mileage Computed for Each Group and Calendar Year, Hawaii Data, Method 2

	2014		2015	
	Mileage	**N**	**Mileage**	**N**
2013/2015	3,081	594		
2013/2016	1,850	1,263	1,850	1,263
2014/2016			1,922	9,633

Table 19. Summary of Mean Annual Mileage per Motorcycle, Hawaii Data

	Hawaii	
	Method 1	**Method 2**
2014	2,064	2,244
2015	1,943	1,914

Estimating Total VMT

Total annual VMT was estimated for each State under study by multiplying the mean annual mileage per motorcycle by the number of registered motorcycles in a year. Table 20 shows, by State and year, the number of registered motorcycles,[5] the mean annual mileage estimated with both Method 1 and Method 2, and the computed total annual VMT based on odometer readings and the FHWA Highway Statistics Series. The estimated annual VMT by State and vehicle type can be calculated from Tables VM-2 "Vehicle Miles of Travel by Functional System" and VM-4 "Distribution of Annual Vehicle Distance Traveled" of FHWA's Highway Statistics Series. Table VM-2 shows the total miles traveled on each road type by State. Table VM-4 shows the percentage that different vehicle types contribute to total mileage by road type. Calculating the FHWA-based estimate of total motorcycle VMT for each State involves the following steps:

1. Calculate the proportion of total mileage contributed by motorcycles for each road type,
2. Multiply this value by the total mileage on each road type to get the total number of miles traveled by motorcycles on each road type (FHWA, 2014, 2015, 2016b, 2016c, 2017); and
3. Sum the values for individual road types to calculate total number of motorcycle miles traveled.

Table 20. Total Annual VMT Estimates Based on Odometer Readings Versus FHWA Estimates

	North Carolina	**Virginia**	**Hawaii**
2013			
Registered motorcycles [1]	191,162	190,456	
Mean annual mileage per motorcycle (Method 1)	1,898	2,266	
Mean annual mileage per motorcycle (Method 2)	1,883	1,817	
Estimated total VMT based on odometer readings	362,825,476	431,573,296	
FHWA estimated total VMT	713,175,164	288,948,888	
2014			
Registered motorcycles [1]	188,675	200,558	37,771
Mean annual mileage per motorcycle (Method 1)	1,821	2,033	2,064
Mean annual mileage per motorcycle (Method 2)	2,036	1,775	2,244
Estimated total VMT based on odometer readings	343,577,175	407,734,414	77,959,344
FHWA estimated total VMT	730,548,536	280,528,583	112,695,322
2015			
Registered motorcycles [1]	192,034	204,089	32,831

[5] Registered motorcycle data were provided to UNC by State DOTs separately from the inspection data.

	North Carolina	Virginia	Hawaii
Mean annual mileage per motorcycle (Method 1)	1,839	1,990	1,943
Mean annual mileage per motorcycle (Method 2)	1,804	1,844	1,914
Estimated total VMT based on odometer readings	353,150,526	406,137,110	63,790,633
FHWA estimated total VMT	622,003,233	261,497,166	138,123,304
2016			
Registered motorcycles [1]		202,766	
Mean annual mileage per motorcycle (Method 1)		2,064	
Mean annual mileage per motorcycle (Method 2)		2,017	
Estimated total VMT based on odometer readings		418,509,024	
FHWA estimated total VMT		Unavailable[2]	

1. Registered motorcycle data were provided by each State, separately from the inspection data.
2. Table VM-4 was not available for 2016.

Table 20 reveals notable differences in the VMT values derived from the FHWA Highway Statistics Series and the VMT values based on the odometer data recorded on inspection records. It is not clear why the VMT values vary as much as they do. One obvious difference is that the FHWA Highway Statistics Series (from the Highway Performance Monitoring System[6]) cover all traffic including from out-of-State vehicles, whereas the VMT estimated from odometer readings is based only on motorcycles registered in the State and that were inspected. An examination of the sources for these differences would be a worthy pursuit, as it could help determine the accuracy of the estimates and identify ways to improve measures of VMT.

[6] The HPMS is a continuing database of national level highway information system that includes data on the extent, condition, performance, use and operating characteristics of the nation's highways. See www.fhwa.dot.gov/policyinformation/hpms.cfm.

Summary and Discussion

The goal of the present study was to examine the feasibility of using safety inspection data to estimate motorcycle VMT, with the objective of computing annual VMT using State odometer data from motorcycle safety inspections, and comparing the computed VMT based on odometer readings from motorcycle safety inspections to estimates of VMT based on FHWA's Highway Statistics Series described above.

Study Data. Three States, Hawaii, North Carolina, and Virginia, provided 3 years of vehicle inspection records for the purpose of this study. Analyses of mileage were conducted for motorcycles having inspection records deemed valid; records with erroneous odometer readings were dropped (see Figures 1 to 3 for a breakdown of the selection). Hawaii's final dataset had 81,132 inspection records for 24,680 motorcycles from 2013 to 2016; North Carolina's final dataset had 962,095 inspection records for 297,874 motorcycles from 2012 to 2016; and Virginia's final dataset had 595,143 inspection records for 239,549 motorcycles from 2012 to 2017.

Mean and Median Mileage. The analysis found a mean mileage of about 2,000 miles per year in each of the study States, but the median mileage in each study State was less than 1,000 miles per year. This distance is lower than the annual mileage in self-report studies. For example, Williams et al. (2017) reported an annual mileage of 4,847 miles among a convenience sample of motorcyclists in the 100 Motorcyclists Naturalistic Study. As the current study examined odometer readings for most motorcycles in each study State, the sample in each State likely included both frequent and infrequent riders. The findings suggest that the annual motorcycle mileage within each study State was skewed, with many motorcycles having been ridden only a few miles each year. Also, of note, the number of motorcycles inspected each year was smaller than the number of motorcycles registered in the State.

Comparisons to FHWA Highway Statistics. As shown in Table 19 above, the VMT estimates based on odometer readings differ from the VMT estimates derived from FHWA data. The FHWA-derived VMT is higher than the odometer-based VMT for both North Carolina and Hawaii, but it is lower than the odometer-based VMT for Virginia. In addition to being inconsistent in direction of difference, they are also inconsistent in the size of the difference by study State. For example, the 2014 FHWA-derived estimate for total VMT for motorcycles in North Carolina at 730,548,536 miles was more than double the odometer-based VMT estimate of 343,577,175 miles; while in Virginia the FHWA-derived VMT estimate of 280,528,583 miles was much lower than the odometer-based estimate of 407,734,414 miles. It is not clear why the VMT estimates vary as much as they do. One obvious difference is that the FHWA Highway Statistics Series (from the Highway Performance Monitoring System) cover all traffic including from out-of-State vehicles, whereas the VMT estimates based on odometer readings is based only on motorcycles registered in the State and that were inspected. Also, the FHWA estimates are based on information provided by each State and, as noted, there is variation in the way individual States count vehicle traffic and estimate motorcycle traffic. Transportation engineers and planners typically estimate VMT for passenger vehicles using various combinations of traffic counts obtained at fixed and mobile counting stations, as well as several 'adjustments' to account for various unmeasured but important factors (i.e., growth in travel, travel on roads where counts are not made, or at times when counts are not collected). While the FHWA VMT for motorcycles was relatively consistent across years within a State (likely reflecting a consistent methodology), the fact that States use their own approach to calculate motorcycle miles traveled complicates comparisons across States.

Limitations of Inspection Data

The findings suggest that the analysis of motorcycle safety inspection records provides valuable information about motorcycle exposure, but there are complications and limitations of this approach, including the following.

Cross-Border Riding. The odometer data reflect miles ridden by the motorcycles registered in a State, but not strictly the miles the registered motorcycle traveled *in that State*. Thus, miles ridden by a motorcyclist outside of their registered State will be included in the VMT calculation. Likewise, the odometer data do not include the miles traveled by motorcycles registered out-of-State, or miles from unregistered motorcycles.

Missing Odometer Data and Duplicate Inspections. The data recorded on safety inspection forms are not intended as a source for VMT, and this may have impacted the reporting of odometer data. Both the completeness and quality of the data were problematic in that there were missing or erroneous values in many cases (as shown in Figure 1, Figure 2, and Figure 3). Noteworthy also, the number of motorcycles inspected each year was lower than the number of registered motorcycles in a State.

In addition to missing inspections, there were instances of duplicate, or nearly duplicate, inspection entries. Some appear to reflect repeat inspections within a short period (a few minutes, hours, or days of the preceding one). This could represent initial failures followed by a successful inspection or an erroneous entry fixed by starting a new record for the same motorcycle. This problem can be generally handled by ignoring all but one inspection record but doing so when working with hundreds of thousands of records is time-consuming and complicated.

Inspection Schedules for Individual Motorcycles. As inspections occur throughout the year, the time of inspection of an individual motorcycle rarely lines up with a calendar year. Consequently, the calculated mileage (the difference in mileage between two adjacent inspections) is assigned across two years. This assignment of mileage to calendar year assumes that the amount of riding is constant across times of year, which is not likely.

Weaknesses in Data Recording Systems. Observations of inspections conducted in a North Carolina inspection station/location illustrated issues with data entered manually, which likely apply in other locations and States. For example, manually entering the VIN dramatically increases the potential for error. The data were not checked against previous entries for that vehicle to identify possible inaccuracies nor did the system have built-in quality checks for length or valid characters. While these examples are specific to the North Carolina process, based on the identified data quality issues it is likely that other States have similar systems.

Missing or Incorrect Data. The inspection data sets included missing or obviously incorrect information, particularly with VINs, odometer readings and the make/model of motorcycles. VINs are lengthy, complicated numbers and prone to entry errors. Incorrect VINs will result in subsequent difficulty in matching inspection records by VIN, and vehicle misclassification.

Errors in Odometer Data. Odometer readings were missing in many motorcycle inspection records or recorded as zero. In either case, the error precluded the ability to use the inspection record as a source. Other problems included clearly erroneous odometer readings, such as excessively high mileage, extreme differences from one year's reading to the next, or readings that declined from a previous inspection. These kinds of errors could be identified through algorithms. These problems raise the question of the presence of unidentifiable errors, that is, incorrect odometer readings that appear legitimate.

Some erroneous odometer readings appear to reflect human error, for example, by including too many repeating digits (e.g., 111,024 instead of 11,024). In some cases, it appeared the tenths of a mile value on an odometer was entered, though the system expects only whole miles. It also seems likely that for motorcycles with a trip meter, the trip reading was sometimes recorded instead of the total mileage. When visually inspecting a series of readings for a single motorcycle, such errors can often be spotted, and sometimes corrected with a reasonable guess about what is wrong. However, writing computer code to identify and correct the many kinds of errors that occur, in the automated fashion necessary when handling hundreds of thousands of records, is a daunting undertaking and beyond the scope of the present project.

Limited Availability of Inspection Data

Only 16 States require safety inspections for motorcycles, and some States exempt large numbers of vehicles from regular inspection which could bias the data. For example, newer vehicles are exempt from mandatory inspections in Delaware and Missouri, and the current analyses indicate that newer motorcycles are ridden further than older vehicles.

Improving Inspection Data

Inspection-based odometer readings have some strengths, but limitations must be overcome for the approach to be useful. The structure of the vehicle inspection system and the database that contains inspection records could ensure reasonable completeness and record high-quality data. A system with rudimentary quality control could prevent common errors encountered in this project. To resolve this, inspection record systems could:

- Populate the inspection record with pre-existing data to be used by the motorcycle safety inspector, and to include previous odometer readings.
- Reject blank or zero odometer entries and those lower than the previous inspection.
- Reject or provide feedback to the inspector when entered data are impossibly out-of-range or indicate a discrepancy, allowing the user an opportunity to fix an entry before final submission. For example, the system would question an entry that suggests the motorcycle was ridden more than 10,000 miles since the last inspection, asking the user to confirm the entry and include an explanatory note in an open-entry field (e.g., the owner of this motorcycle recently rode it on a 3-month trip around the United States); and,
- To facilitate data quality management by the State, each record could include an identifier for the inspection station or inspector.

Discussion

The information in this report is presented to share research findings, and it is not a recommendation to use this strategy for computing VMT for the following reasons. First, this type of odometer data is not widely available, as few States require motorcycle safety inspections. Second, thousands of the inspection records used in this study had missing or erroneous odometer data. Third, the interpretation of odometer-based VMT is challenging because inspected motorcycles may have mileage accrued out-of-State, thereby limiting conclusions about State-based VMT. As shown, it is possible to calculate motorcycle distance traveled using odometer data from safety inspections, however, limitations preclude its use as a regular source of VMT data. In contrast, current approaches to measuring VMT have improved due to advances in traffic monitoring tools and methods (FHWAa, 2016; Middleton et al., 2013). The current study found inspection records to be valuable for revealing patterns of use, as it is a direct measure of distance ridden. For example, that many motorcycles were ridden very infrequently, with a mean annual mileage of about 2,000 miles and a median mileage of less than 1,000 miles per year. The results suggest that there is more to be understood about motorcycle travel patterns and there is a need for ongoing research to improve measures of motorcycle VMT.

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Appendix A: Mileage Estimates, North Carolina Data

1) Mileage based on differences in odometer readings between inspections in adjacent years: The differences in odometer readings between inspections in 2012 and 2013, between 2013 and 2014, between 2014 and 2015, and between 2015 and 2016 are presented in the table below. The time lapse between inspections across years is also computed.

Table A-1. Descriptive Statistics of the Difference in Odometer Readings From Inspections in Adjacent Years

		Mileage				
	N (# Motorcycle)	Median	Mean	Std Dev	Minimum	Maximum
2012-2013 mileage	107510	1139	2054	2523	0	18167
2013-2014 mileage	106344	1061	1914	2303	0	14485
2014-2015 mileage	106604	976	1816	2243	0	14691
2015-2016 mileage	109200	958	1910	2609	0	23105
# of Days in 2012-2013	107510	372	380	58	4	728
# of Days in 2013-2014	106344	373	379	58	14	728
# of Days in 2014-2015	106604	365	372	60	8	727
# of Days in 2015-2016	109200	369	376	60	24	728

2) Mileage assigned proportionally based on inspections in adjacent years: It appears that inspections tend to take place a year apart for these motorcycles. Therefore, it is assumed that, overall, half of the mileage belonged to the first half of the year and half of the mileage belonged to the second half of the year. For example, for the 106,329 motorcycles that had an inspection in 2012 and an inspection in 2013, it is assumed that they traveled half of the 2,049 miles, or 1,025 miles, in 2012 and half of that in 2013. The table below presents descriptive statistics of mileage assigned to different time periods.

Table A-2. Descriptive Statistics of Mileage Assigned to Different Periods, North Carolina

		Mileage				
	N (# of Motorcycles)	Median	Mean	Std Dev	Minimum	Maximum
2012e	106,329	567	1,146	1,565	0	17,806
2013b	106,329	430	898	1,301	0	16,963
2013e	104,820	519	1,047	1,402	0	13,654
2014b	104,820	407	859	1,215	0	13,601
2014e	105,280	480	1,011	1,395	0	14,367
2015b	105,280	369	797	1,153	0	13,767
2015e	108,339	472	1,069	1,614	0	21,012
2016b	108,339	360	838	1,331	0	19,874

Note: "e" (ending) means second half of the year; "b" (beginning) means first half of the year.

3) Mileage assigned proportionally for inspections that skip a calendar year or more: For vehicles that skipped a calendar year between inspections, mileage was assigned proportionally, based on the assumption that riding was even across all months of a year and across all years. For example, if a motorcycle had one inspection on September 1, 2012, and the next one on March 31, 2014, without an inspection in 2013, and the odometer reading difference was 3,000 between these two inspections that occurred 18 months apart, the mileage assigned to 2012 was 3/18 of 3,000, or 500; the mileage assigned to 2013 was 12/18 of 3,000, or 2,000, and the remaining 3/18, or 500 miles, was assigned to 2014 for this motorcycle. In actual computation, the exact dates were used to generate the numerator and the denominator for the allocation weights (so assignment is based on days rather than whole months).

Table A-3. Descriptive Statistics of the Difference in Odometer Readings From Inspections in 2012 and Next in 2014, North Carolina

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2012	15,820	308	696	1,035	0	12,146
2013	15,820	897	1,583	1,942	0	16,748
2014	15,820	238	502	756	0	8,653

Table A-4. Mileage Assigned to Years With Inspections in 2012 and Next in 2015, North Carolina

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2012	3,124	165	489	934	0	10,376
2013	3,124	368	954	1,559	0	14,277
2014	3,124	368	954	1,559	0	14,277
2015	3,124	128	384	762	0	12,376

Table A-5. Mileage Assigned for Motorcycles With Inspections in 2012 and Next in 2016

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2012	1,552	126	441	836	0	8,715
2013	1,552	284	830	1,490	0	12,612
2014	1,552	284	830	1,490	0	12,612
2015	1,552	284	830	1,490	0	12,612
2016	1,552	106	345	681	0	8,440

Table A-6. Mileage and Days Assigned for Motorcycles With Inspections in 2013 and the Next in 2015, North Carolina

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2013 mileage	15,369	320	693	1,002	0	10,069
2014 mileage	15,369	917	1,585	1,907	0	17,341
2015 mileage	15,369	240	501	740	0	9,519
% of days allocated to 2013	15,369	0.24	0.24	0.11	0.00	0.50
% of days allocated to 2014	15,369	0.55	0.58	0.11	0.34	1.00
% of days allocated to 2015	15,369	0.18	0.19	0.09	0.00	0.49

Table A-7. Mileage and Days Allocated for Motorcycles With Inspections in 2013 and Next in 2016, North Carolina

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2013 mileage	2,996	167	518	1,060	0	15,309
2014 mileage	2,996	383	1,021	1,795	0	19,807
2015 mileage	2,996	383	1,021	1,795	0	19,807
2016 mileage	2,996	139	400	740	0	7,715
% of days allocated to 2013	2,996	0.18	0.17	0.07	0.00	0.31
% of days allocated to 2014	2,996	0.34	0.35	0.04	0.26	0.49
% of days allocated to 2015	2,996	0.34	0.35	0.04	0.26	0.49
% of days allocated to 2016	2,996	0.14	0.14	0.06	0.00	0.31

Table A-8. Mileage and Days Allocated for Motorcycles With Inspections in 2014 and Next in 2016, North Carolina

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2014 mileage	14,956	306	739	1,182	0	14,366
2015 mileage	14,956	880	1,667	2,247	0	25,867
2016 mileage	14,956	225	519	859	0	12,625
% of days allocated to 2014	14,956	0.25	0.24	0.11	0.00	0.50
% of days allocated to 2015	14,956	0.55	0.58	0.11	0.34	1.00
% of days allocated to 2016	14,956	0.17	0.18	0.09	0.00	0.50

Appendix B: Mileage Estimates, Virginia Data

1) Mileage based on differences in odometer readings between inspections in adjacent years: Mileage, indicated by the differences in odometer readings between inspections from 2012 to 2013, 2013 to 2014, 2014 to 2015, 2015 to 2016, and 2016 to 2017 are presented in the table below.

Table B-1. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings From Inspections in Adjacent Years, Virginia

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2012-2013	12,761	1,303	2,360	2,983	0	22,849
2013-2014	62,226	1,350	2,282	2,676	0	19,232
2014-2015	60,948	1,272	2,162	2,507	0	16,299
2015-2016	58,889	1,274	2,231	2,660	0	18,541
2016-2017	42,724	1,312	2,295	2,792	0	23,032
# of Days in 2012-2013	12,761	374	368	51	12	507
# of Days in 2013-2014	62,226	383	389	48	42	726
# of Days in 2014-2015	60,948	384	390	49	22	708
# of Days in 2015-2016	58,889	385	392	50	29	720
# of Days in 2016-2017	42,724	379	382	46	27	614

As indicated in Table A-8, motorcycles in Virginia traveled between 2,162 to 2,360 miles between one inspection and another in the following year, although the median is about 1,300 miles. Except for the time lapse between 2012 and 2013, which is about 12 months, the time lapses for other years are about 13 months with a standard deviation of about 7 weeks.

2) Mileage assigned proportionally based on inspections in adjacent years: The same procedures used with the North Carolina data are employed to assign mileage to different time periods for motorcycles in Virginia. Results are presented in Table B-1.

Table B-2. Descriptive Statistics of Mileage and Days Assigned to Different Time Periods, Virginia

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2012e	12,761	356	664	880	0	13761
2013b	12,761	897	1,690	2,226	0	22,598
2013e	62,226	649	1,197	1,556	0	17,457
2014b	62,226	586	1,079	1,426	0	17,711
2014e	60,948	605	1,133	1,465	0	15,026
2015b	60,948	556	1,024	1,336	0	14,358
2015e	58,889	600	1,160	1,540	0	15,737
2016b	58,889	565	1,065	1,423	0	16,623
2016e	27,269	689	1,270	1,649	0	19,053
2017b	27,269	518	934	1,190	0	13,592

Note: "e" (ending) means second half of the year; "b" (beginning) means first half of the year.

Except for 2012e, which represents 30% of the time in 2012, and 2013b, which represents about 70% of the time in 2013, all other partial years represent about half of a year. It appears that on average motorcycles accumulate between 1,000 and 1,200 miles in half a year. In contrast, 1,690 miles is assigned to the first half of 2013, which corresponds to 70% of time of the year.

3) Mileage assigned proportionally for inspections that skip a calendar year or more. Next, the same procedure was used for the Virginia data as was used for the North Carolina data (Appendix A) to assign mileage to different years proportionally for inspections that skip a calendar year or more.

There were 7,340 motorcycles that had one inspection in 2012 and then the next in 2014.

Table B-3. Mileage Differences and Days Assigned Proportionally for Inspections That Skip a Year, Virginia

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2012	7,340	134	288	441	0	5,296
2013	7,340	674	1,322	1,824	0	16,905
2014	7,340	208	432	690	0	8,841
% of days allocated to 2012	7,340	0.16	0.15	0.06	0.00	0.29
% of days allocated to 2013	7,340	0.63	0.63	0.09	0.42	0.96
% of days allocated to 2014	7,340	0.21	0.22	0.08	0.00	0.48

Table B-4. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings From Inspections in 2012 and the Next in 2015, Virginia

		Mileage				
	N (# of Motorcycles)	Median	Mean	Std Dev	Minimum	Maximum
2012	1,308	88	223	356	0	3,580
2013	1,308	370	906	1,405	0	11,545
2014	1,308	370	906	1,405	0	11,545
2015	1,308	141	382	631	0	5,194
% of days allocated to 2012	1,308	0.10	0.10	0.04	0.00	0.17
% of days allocated to 2013	1,308	0.37	0.37	0.03	0.29	0.48
% of days allocated to 2014	1,308	0.37	0.37	0.03	0.29	0.48
% of days allocated to 2015	1,308	0.15	0.16	0.06	0.00	0.31

Table B-5. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings From Inspections in 2012 and the Next in 2016, Virginia

		Mileage				
	N (# of Motorcycles)	Median	Mean	Std Dev	Minimum	Maximum
2012	489	73	201	334	0	2,404
2013	489	311	745	1,112	0	6,503
2014	489	311	745	1,112	0	6,503
2015	489	311	745	1,112	0	6,503
2016	489	120	340	542	0	3,912
% of days allocated to 2012	489	0.08	0.07	0.03	0.00	0.12
% of days allocated to 2013	489	0.27	0.27	0.02	0.23	0.32
% of days allocated to 2014	489	0.27	0.27	0.02	0.23	0.32
% of days allocated to 2015	489	0.27	0.27	0.02	0.23	0.32
% of days allocated to 2016	489	0.13	0.12	0.05	0.00	0.24

Table B-6. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings From Inspections in 2012 and the Next in 2017, Virginia

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2012	233	71	172	285	0	2,009
2013	233	306	641	1,010	1	7,436
2014	233	306	641	1,010	1	7,436
2015	233	306	641	1,010	1	7,436
2016	233	306	641	1,010	1	7,436
2017	233	92	221	383	0	2,808
% of days allocated to 2012	233	0.06	0.06	0.02	0.00	0.09
% of days allocated to 2013	233	0.21	0.21	0.01	0.20	0.25
% of days allocated to 2014	233	0.21	0.21	0.01	0.20	0.25
% of days allocated to 2015	233	0.21	0.21	0.01	0.20	0.25
% of days allocated to 2016	233	0.21	0.21	0.01	0.20	0.25
% of days allocated to 2017	233	0.08	0.08	0.03	0.00	0.14

Table B-7. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings From Inspections in 2013 and the Next in 2015, Virginia

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2013	16,150	194	469	783	0	9,770
2014	16,150	597	1,212	1,681	0	17,669
2015	16,150	204	436	671	0	8,324
% of days allocated to 2013	16,150	0.21	0.21	0.09	0.00	0.49
% of days allocated to 2014	16,150	0.56	0.57	0.10	0.35	1.00
% of days allocated to 2015	16,150	0.21	0.21	0.08	0.00	0.50

Table B-8. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings From Inspections in 2013 and the Next in 2016, Virginia

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2013	3,676	165	401	654	0	7,455
2014	3,676	394	845	1,188	0	9,277
2015	3,676	394	845	1,188	0	9,277
2016	3,676	145	348	566	0	5,868
% of days allocated to 2013	3,676	0.16	0.16	0.06	0.00	0.32
% of days allocated to 2014	3,676	0.34	0.35	0.03	0.25	0.50
% of days allocated to 2015	3,676	0.34	0.35	0.03	0.25	0.50
% of days allocated to 2016	3,676	0.15	0.15	0.06	0.00	0.32

Table B-9. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings From Inspections in 2013 and the Next in 2017, Virginia

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2013	1,462	128	374	635	0	5844
2014	1,462	297	746	1138	0	8534
2015	1,462	297	746	1138	0	8534
2016	1,462	297	746	1138	0	8534
2017	1,462	98	272	460	0	4183
% of days allocated to 2012	1,462	0.13	0.12	0.04	0.00	0.24
% of days allocated to 2013	1,462	0.26	0.26	0.02	0.22	0.33
% of days allocated to 2014	1,462	0.26	0.26	0.02	0.22	0.33
% of days allocated to 2015	1,462	0.26	0.26	0.02	0.22	0.33
% of days allocated to 2016	1,462	0.10	0.10	0.04	0.00	0.18

Table B-10. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings From Inspections in 2014 and the Next in 2016, Virginia

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximu m**
2014	14,412	189	441	682	0	7,431
2015	14,412	569	1,143	1,560	0	17,699
2016	14,412	188	404	618	0	9,201
% of days allocated to 2014	14,412	0.22	0.22	0.09	0.00	0.49
% of days allocated to 2015	14,412	0.55	0.57	0.10	0.34	0.99
% of days allocated to 2016	14,412	0.21	0.21	0.08	0.00	0.49

Table B-11. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings From Inspections in 2014 and the Next in 2017, Virginia

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximu m**
2014	3,149	134.53	390.7 7	726.12	0.00	8,482.44
2015	3,149	329.87	824.9 4	1,362.6 9	0.30	1,4371.78
2016	3,149	329.87	824.9 4	1,362.6 9	0.30	1,4371.78
2017	3,149	107.08	299.7 0	554.11	0.13	6,283.69
% of days allocated to 2014	3,149	0.16	0.16	0.06	0.00	0.32
% of days allocated to 2015	3,149	0.35	0.35	0.03	0.28	0.47
% of days allocated to 2016	3,149	0.35	0.35	0.03	0.28	0.47
% of days allocated to 2017	3,149	0.13	0.13	0.05	0.00	0.24

Table B-12. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings From Inspections in 2015 and the Next in 2017, Virginia

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2015	13,849	180	468	817	0	10,053
2016	13,849	585	1,239	1,788	0	19,612
2017	13,849	159	359	573	0	7,210

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
% of days allocated to 2015	13,849	0.22	0.22	0.10	0.00	0.48
% of days allocated to 2016	13,849	0.58	0.60	0.11	0.38	1.00
% of days allocated to 2017	13,849	0.19	0.18	0.08	0.00	0.39

Appendix C: Mileage Estimates, Hawaii Data

1) Mileage based on differences in odometer readings between inspections in adjacent years: Mileage, indicated by the differences in odometer readings between inspections from 2013 to 2014, from 2014 to 2015, and from 2015 to 2016 are presented in Table C-1, below.

Table C-1. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings Between Inspections in Adjacent Years, Hawaii

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2013-2014	1,014	1,001	1,933	2,603	0	20,467
2014-2015	10,551	1,203	2,050	2,435	0	17,832
2015-2016	10,472	1,065	1,887	2,270	0	15,582
# of Days in 2013-2014	1,014	366	326	108	2	421
# of Days in 2014-2015	10,551	380	390	75	2	726
# of Days in 2015-2016	10,472	382	393	76	5	724

As indicated in Table C-1, motorcycles in Hawaii traveled around 2,000 between one inspection and another in the following year, although the median is a little over 1,000 miles. Except for the time lapse between 2013 and 2014, which is right about 12 months with a standard deviation of about 15 weeks, the time lapses for other years are about 13 months with a standard deviation of about 11 weeks.

2) Mileage assigned proportionally based on inspections in adjacent years: The same procedures used with the North Carolina and Virginia data are employed to assign mileage to different time periods for motorcycles in Hawaii. Results are presented in the table below.

Table C-2. Descriptive Statistics of Mileage Assigned Proportionally Based on Inspections in Adjacent Years, Hawaii

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2013e	1,014	84	187	271	0	1,837
2014b	1,014	888	1,741	2,375	0	20,189
2014e	10,881	505	1,052	1,473	0	16,538
2015b	10,551	482	993	1,412	0	14,760
2015e	10,472	463	986	1,399	0	13,409
2016b	10,472	419	896	1,284	0	12,309

Note: 'e' (ending) means second half of the year; 'b' (beginning) means first half of the year.

Except for mile2013e, which represents 14% of the time in 2012, and mile2014b, which represents about 84% of the time in 2014, all other partial years represent about half of a year. It appears that on average motorcycles accumulate about 1,000 miles in half a year, and during the first 10 months (84%) of 2014, an average motorcycle ride about 1,749 miles.

2) Mileage assigned proportionally for inspections that skip a calendar year or more: Next, the same procedure used for North Carolina and Virginia data is used to assign mileage to different years proportionally for inspections that skip a calendar year or more.

Table C-3. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings Between Inspections in 2013 and the Next in 2015, Hawaii

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2013	896	58	150	243	0	2,684
2014	896	919	1893	2,605	1	20,845
2015	896	141	665	1,463	0	13,735
% of days allocated to 2013	896	.06	.06	.03	0	.14
% of days allocated to 2014	896	.76	.74	.15	.47	.99
% of days allocated to 2015	896	.17	.20	.16	0	.50

Table C-4. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings Between Inspections in 2013 and the Next in 2016, Hawaii

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2013	142	63	144	197	0	1,012
2014	142	1,083	1,780	2.015	5	9,449
2015	142	1,083	1,780	2,015	5	9,449
2016	142	202	556	944	1	5,572
% of days allocated to 2013	142	.03	.03	.02	0	.07
% of days allocated to 2014	142	.43	.42	.05	.32	.49
% of days allocated to 2015	142	.43	.42	.05	.32	.49
% of days allocated to 2016	142	.10	.13	.10	0	.33

Table C-5. Descriptive Statistics of Mileage Differences and Days Assigned in Odometer Readings Between Inspections in 2014 and the Next in 2016, Hawaii

		Mileage				
	N (# of Motorcycles)	**Median**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
2014	3,430	222	665	1,165	0	11,579
2015	3,430	913	1,726	2,278	1	23,570
2016	3,430	191	668	1,236	0	12,489
% of days allocated to 2014	3,430	.19	.20	.13	0	.49
% of days allocated to 2015	3,430	.55	.60	.15	.33	.99
% of days allocated to 2016	3,430	.18	.19	.13	0	.50

DOT HS 813 288
May 2022

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15551-050222-v3a