

Axle Factor User Guide

Viability of Vehicle Length in Estimating Vehicle Classification and Axle Factors

**Transportation Pooled Fund Study TPF-5(340), led by
Wisconsin Department of Transportation**

**Pooled Fund Partner State DOTs:
Georgia, Idaho, Illinois, Iowa, Kansas, Minnesota, New York, North Dakota,
Ohio, Pennsylvania, Texas and Utah**

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Table of Contents

Introduction	1
Method 1: Axle Factor Development – Data Needs	2
Step 1: Establish vehicle length class thresholds	2
Step 2: Collect length-based vehicle count data and axle count data.....	3
Step 3: Determine average axles for each length class.....	3
Step 4: Determine average axle factor for site (or class).....	3
Method 1: Example Axle Factor Applications	5
Axle factor application #1: find axle factor with only vehicle-length data	5
Axle factor application #2: find daily traffic volumes with axle counts.....	6
Method 5: Introduction	7
Method 5: Procedure Overview	8
Method 5: Technical Details	9
Method 5: Estimation Tool	10

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Introduction

Road tubes are widely used to collect count data because they are inexpensive and accurate enough to meet the needs of many travel monitoring applications. However, single-tube installations only measure axle counts which must be converted to annual average daily traffic (AADT) volume. The most common way to convert this data is to analyze axle-based classification data and determine the ratio of total vehicles to the axle count. Many agencies call this an “axle factor.” Such axle-based vehicle classification sites have historically been significantly costlier and require more maintenance than length-based traffic detection methods. Non-intrusive sensors, such as side-fire radar sensors, can cost-effectively collect vehicle length data, which can then be used to estimate axle factors.

The Final Report from Phase I of this Transportation Pooled Fundy Study (TPF-5(340)), published in October 2017, evaluated the accuracy of generating axle factors based on vehicle length and developed and evaluated methodologies to convert length-based vehicle data to axle-based classifications. Based on the results of the evaluation, the performance of the two recommended methods (Methods 1 and 5) were found to be within the expected limits of performance – within 2 percent error. Axle factor accuracy was found to not vary significantly depending on the roadway character, facility type, and number of travel lanes.

Method 1 uses collocated axle class and vehicle length data collected at “benchmark” sites to develop an average axle per vehicle class. This “seed” data is then applied to local sites to project axle factors for each local site. Method 5 uses algorithms to classify locally-collected vehicle length data into FHWA vehicle classifications as a precursor to developing the local axle factor.

Phase II of this project developed and evaluated an implementation plan for these methods. The purpose of this guide is to provide step-by-step instructions to implement Method 1 applications (converting length-based vehicle data into axle factor data) and an overview of how to implement Method 5.

Method 1: Axle Factor Development

Method one uses data collected at “benchmark” sites to develop an average number of axles per vehicle class. The following specific seed data is needed at these benchmark sites:

- *Vehicle count per length class data.* This data consists of vehicle counts for each vehicle length class or “bin”. Individual agencies have developed length bins to group vehicles. Many states use between three and six bins to distinguish vehicle classifications into categories such as motorcycles, passenger vehicles and different lengths of trucks.
- *Axle count per length class data.* This data consists of vehicle count data for each vehicle length class or bin. The vehicle length class bins used to collect axle count data must be the same bins definition used above.

Most traffic data collection sites do not collect both vehicle length data and axle count data. This is especially true if a temporary and/or limited-count data collection site is installed. The temporary installation of equipment to collect additional data may be required. Examples include a continuous count station with a collocated radar sensor or a radar sensor with a collocated road-tube installation.

While traffic data at one site can be used to develop axle factors, traffic data from multiple sites and for multiple days is preferred if the axle factor will be used for regionwide or statewide applications. In addition, the location of each site should be representative of the area in which the axle factor would be applied. The following lists site characteristics that should be considered in collecting seed data for axle factor conversion:

- Number of travel lanes (two, four, six)
- Location of traffic data collection stations (urban, suburban, rural)
- Roadway classification (freeway, expressway, arterial, collector)
- Commercial truck and/or recreational vehicle volumes

The following steps describe how seed data is collected and processed to create an axle factor that can be applied at other locations.

Step 1: Establish vehicle length class thresholds

If this is not already established by a governing agency, vehicle length class designations, or bins must be determined. Observation of vehicle types may be needed to identify natural bin boundaries. One possible example of a four-bin vehicle length class distribution is:

- Length Class #1: 1 to 6 feet
- Length Class #2: 7 to 29 feet
- Length Class #3: 30 to 44 feet
- Length Class #4: 45+ feet

Step 2: Collect length-based vehicle count data and axle count data

Length-based vehicle count data and axle count data must be collected at the same location to guarantee accuracy of the collected data. The length-based count data shall be collected and compiled in the bins that were established in Step 1.

While it is preferred that daily, or multiple day, counts be collected to analyze a more robust data set, time-of-day count data – such as AM and/or PM peak time periods – could be developed into axle factors. However, caution should be taken when using time-of-day count data to develop daily axle factors as time-of-day data is likely not representative of vehicle characteristics over the course of a day.

Step 3: Determine average axles for each length class

The length-based vehicle counts and axle counts collected in Step 2 can be used to determine an average axle count for each length class. Use the following equation to determine the average axles for each length class:

$$\text{Equation \#1: Average axles per length class} = \frac{\text{axle count per length class}}{\text{vehicle count per length class}}$$

Example: the following vehicle counts and axle counts were collected for each of the four length classifications in a 24-hour period at one data collection site. Using Equation #1, an average number of axles per vehicle class can be determined – see data in the right-most column.

Length Class	Vehicle Count	Axle Count	Average No. of Axles
Length Class 1	557	1,119	2.009
Length Class 2	70,515	141,841	2.012
Length Class 3	1,716	5,559	3.240
Length Class 4	5,488	26,550	4.838
SITE TOTAL	78,276	175,069	2.237

Step 4: Determine average axle factor for site (or class)

The axle factor for the site is determined by taking the inverse of the average axle per vehicle class equation, shown below:

$$\text{Equation \#2: Axle factor} = \frac{\text{vehicle count per length class}}{\text{axle count per length class}}$$

This equation can be used to determine the axle factor for all vehicles at a site or for a particular vehicle length class. The following shows the axle factor for all vehicles and all vehicle length classes for the example site.

Length Class	Vehicle Count	Axle Count	Average No. of Axles	Axle Factor
Vehicle Class 1	557	1,119	2.009	0.498
Vehicle Class 2	70,515	141,841	2.012	0.497
Vehicle Class 3	1,716	5,559	3.240	0.309
Vehicle Class 4	5,488	26,550	4.838	0.207
SITE TOTAL	78,276	175,069	2.237	0.447

These steps are used to determine the axle factors at benchmark sites. The next step in the process is to apply these factors to sites that only have axle factor or length data. This is explored in the next section.

Method 1: Example Axle Factor Applications

Once axle factors are determined for a site or a collection of sites, they can be applied to other locations that do not have the ability to collect pertinent traffic data. Two such examples are as follows:

- Application #1: Determine axle factor for a site where only vehicle-length data was collected.
- Application #2: Determine number of vehicles at a site where only axle counts were collected.

Axle Factor Application #1: given vehicle-length data find axle factors

Example: A count station along a roadway uses radar technology (e.g. Wavetronix) to collect vehicle length data. This roadway is scheduled for reconstruction and the roadway designer is developing a pavement design. The designer would like to use axle factor data at this location to aid in pavement design, but only vehicle-length data is collected. Two days of traffic data was compiled and is as follows:

- Length Class 1 Vehicle Count: 1,292 vehicles
- Length Class 2 Vehicle Count: 85,620 vehicles
- Length Class 3 Vehicle Count: 3,645 vehicles
- Length Class 4 Vehicle Count: 8,554 vehicles

Assuming that the traffic data collected in the Axle Factor Development Example presented earlier (i.e. seed data) is an appropriate application to this site, and the vehicle length class designations are the same for each site, the axle factor can be found for this site.

Solution: Using the average axles per vehicle class from the seed site, the number of axles at this site can be determined using Equation #1:

- Length Class 1 Axle Count = 1,292 vehicles x 2.009 axles per class = 2,596 axles
- Length Class 2 Axle Count = 85,620 vehicles x 2.012 axles per class = 172,267 axles
- Length Class 3 Axle Count = 3,645 vehicles x 3.234 axles per class = 11,788 axles
- Length Class 4 Axle Count = 8,554 vehicles x 4.838 axles per class = 41,384 axles
- Site Axle Count Total = 2,596 + 172,267 + 11,788 + 41,384 = 228,035 axles
- Average Axles per Vehicle = 228,035 axles / 99,111 vehicles = 2.301 axles per vehicle

Once the number of axles for each length class is derived, the site's axle factor can be determined using Equation #2:

- Length Class 1 Axle Factor = 1,292 vehicles / 2,596 axles = 0.498
- Length Class 2 Axle Factor = 85,620 vehicles / 172,267 axles = 0.497
- Length Class 3 Axle Factor = 3,645 vehicles / 11,788 axles = 0.309

- Length Class 4 Axle Factor = $8,554 \text{ vehicles} / 41,384 \text{ axles} = 0.207$
- Site Axle Factor = $99,111 \text{ vehicles} / 228,035 \text{ axles} = 0.435$

Axle Factor Application #2: given axle counts find daily traffic volumes

Example: A short-term (two day) road-tube count station was installed to collect axle counts. A total of 27,841 axles were counted on day 1 and 24,505 axles were counted on day 2. Instead of using default or historical statewide axle factor data in the conversion software to convert the axle counts, the analyst wants to use localized axle factor data.

Using the traffic data inputs and outputs identified in Axle Factor Application #1, find the daily traffic volume for this site.

Solution: Using the average axles per vehicle class from the seed site, the number of vehicles for each day at this site can be determined by dividing the number of axles by the average axles per vehicle:

$$\text{Day 1: } 27,841 \text{ axles} / 2.301 \text{ axles per vehicle} = 12,100 \text{ vehicles per day}$$

$$\text{Day 2: } 24,505 \text{ axles} / 2.301 \text{ axles per vehicle} = 10,650 \text{ vehicles per day}$$

Method 5: Introduction

The essence of Method 5 is the development of a statistical model based on the combined distribution of 14 axle classes (the 13 identified by the Federal Highway Administration (FHWA) plus an additional class of vehicles with unknown axle classes). The model is calibrated using a database of locations for which both the vehicle length and axle classes are known (this is called the calibration database). From the calibration procedure, the model estimates class length probability density functions (PDFs) for each axle class that are used to estimate the vehicle count of each axle class in a different dataset. This result is beneficial in situations which the vehicle count of each axle class is needed but only the vehicle length is known.

Method 5: Procedure Overview

The basis of Method 5 analysis is to distinguish an observed vehicle length distribution into the most likely component distributions per axle class. This process is similar to the way a spectral analysis breaks down a beam of light into its most basic color components. The result of this process is fourteen separate axle class estimates. A key feature of this methodology is that the base distribution has an initial (i.e. default) set of PDFs based on Long Term Pavement Performance (LTPP) national data and a robust amount of calibration data from Wisconsin DOT (WisDOT). Therefore, it is possible to obtain axle class estimates for a local site without calibration data; however, calibration is strongly encouraged if local calibration data is available. The estimation tool created for this project allows the user to adjust the default PDFs and input locally-collected axle classes distribution data. Figure 1 illustrates the inputs for the statistical model graphically. Steps A, B and C noted in the figure identify the sequence of using the PDF to develop length-based data.

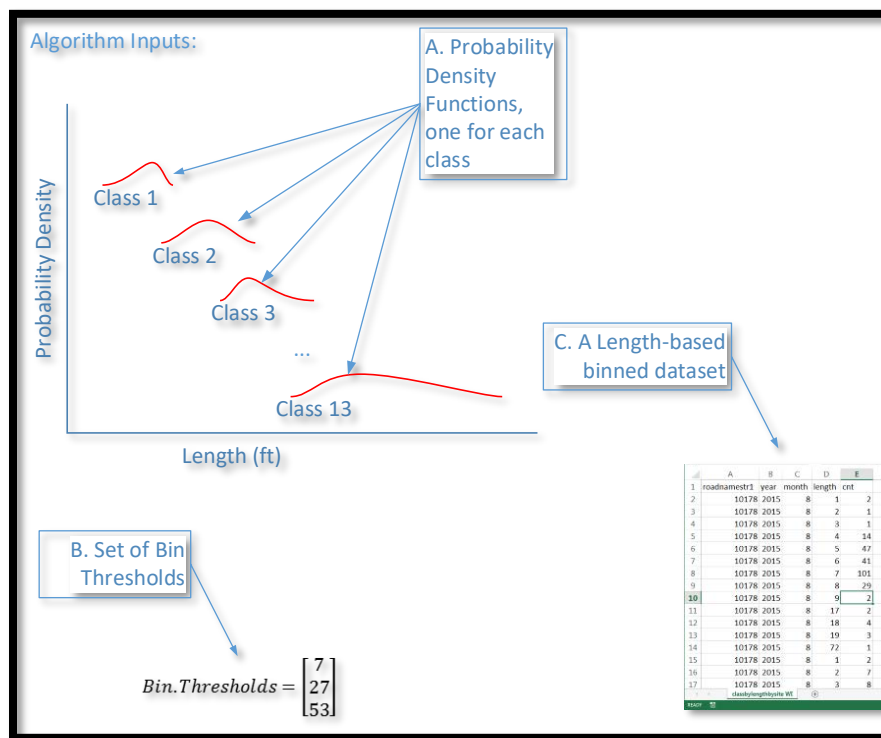


Figure 1. Inputs for Statistical Model

As with any statistical model, the accuracy of the results depends on how representative the local axle class distributions are inputted in the PDFs for parametric estimation. Therefore, calibration is encouraged if appropriate data is available. Another key assumption that could affect results is that the length distributions within each FHWA vehicle class are fixed, at least for the time period that is being analyzed. This may be a reasonable assumption for studies or analysis performed over a short period of time, such as 3-5 years. However, re-calibration of the default PDFs is recommended periodically so the methodology remains representative of the most-current vehicle fleet.

Method 5: Technical Details

The following discusses the technical details in determining the parameterized functions and the algorithm used to develop the vehicle length class estimates:

Let the observed distribution of vehicle lengths (*len*) at a site be defined as a PDF $g(len)$, such that for the total range of observed vehicle lengths in the PDF is the universe of observable events:

$$P(L_{min} < len < L_{max}) = \int_{L_{min}}^{L_{max}} g(x) \cdot dx = 1.0$$

The calibration procedure estimates this function empirically directly from the field data. Given that $g(len)$ is known, the absolute proportion of vehicles within a subrange of lengths $[L_1, L_2]$ can be obtained by modifying the limits of integration. This is convenient since the interval $[L_1, L_2]$ can be define as a bin or band of aggregation of length data. Let this bin of aggregation be bin_j , then,

$$P(bin_j) = \int_{L_{mjn}}^{L_{max}} g(x) \cdot dx$$

Conditional to a given class of vehicles, h_i , let the PDF be similarly defined as $f_{h_i}(len)$. This function is such that the proportion of vehicles of class h with lengths within bin_j is given by,

$$P(bin_j | class = h_i) = F_{ij}(len) = \int_{L_{mjn}}^{L_{max}} f_{h_i}(x) \cdot dx$$

$P(bin_j | class = h_i)$ is the conditional probability of vehicle lengths in the interval $[L_1, L_2]$ given that the vehicles come from class h . Therefore, given sufficient calibration data, a set of $f_{h_i}(len)$; $1 \leq i \leq 14$ can be developed.

The statistical model estimates a set of fourteen $P(class = h_i)$ (for i varying from 1 to 14) given the observed mixed density function $g(len)$ and the set of previously known class PDFs $f_{h_i}(len)$.

In this context, let $P(class = h_i) \times N = \theta_i$ be the number of vehicles of class h_i in the traffic stream (N is the number of vehicles in the dataset of analysis). Then, the global density function of lengths can be decomposed as follows,

$$g(len) \approx N^{-1} \cdot \sum_{j=1}^p \sum_{i=1}^{14} [\hat{\theta}_i \cdot \hat{F}_{ij}(len)]$$

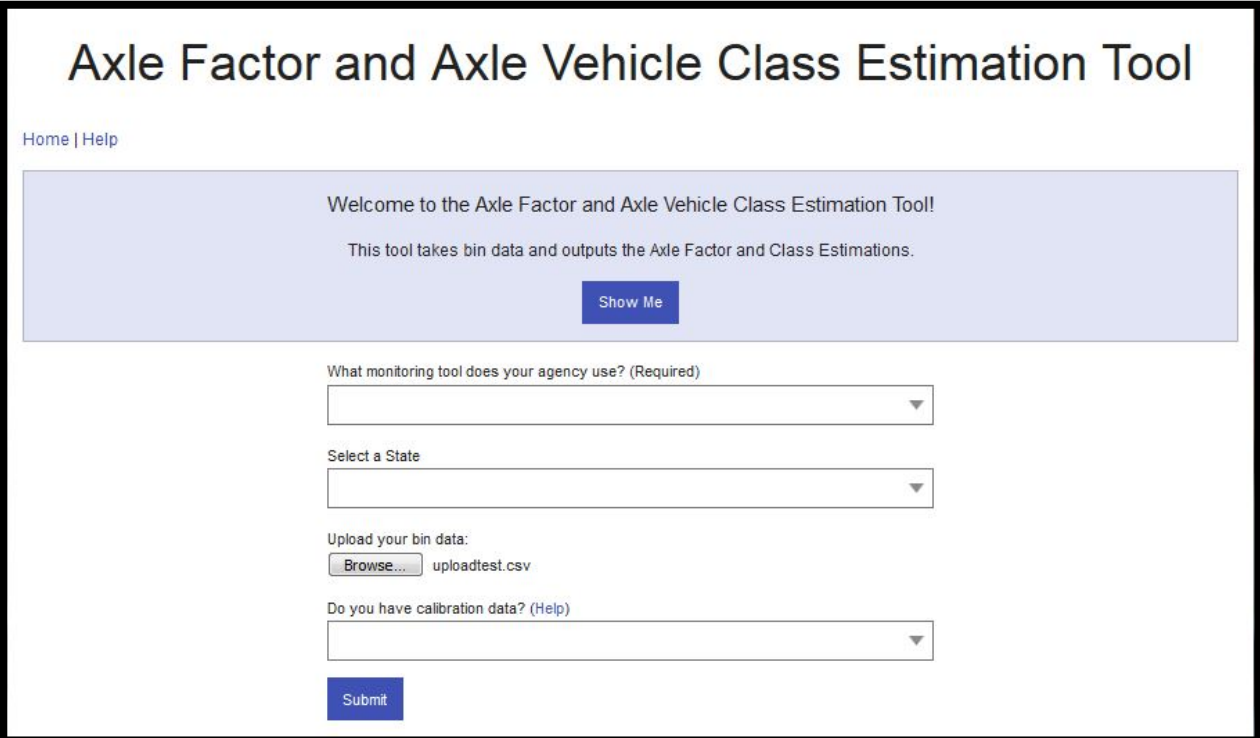
Where p is the number of bins of aggregation; $\hat{\theta}_i$ is the estimate of θ_i (obtained from non-linear optimization); and $\hat{F}_{ij}(len)$ is the estimate of $F_{ij}(len)$ obtained from the 14 axle class PDFs and the bin thresholds (each PDF was, in turn, constructed from the calibration data).

Method 5: Estimation Tool

The process to develop the PDFs and axle class estimates can be very intense and may not be user-friendly to analysts looking to use this method. Therefore, an axle vehicle class estimation software program, or “tool”, was developed to create and carry out the algorithms to produce the axle class estimates. The tool uses input data supplied by the analyst and the calibration data – either default or user-supplied – to calculate axle factor and axle class estimations. The tool outputs the data in tabular form that the user can export for their use.

As previously stated, vehicle class distribution data used for this analysis can use default PDFs based on previously collected LTPP national data and WisDOT local data to develop axle class estimates. However, if local calibration data is available, the estimation tool will produce axle factor and axle class estimates that are more representative of local conditions. Therefore, it is preferred to use local calibration data to develop axle factor and class estimates, if available.

The estimation tool can be accessed and run online, allowing for updates of the tool to be provided without sending software updates. Once loaded, an input screen is provided for the user to upload data to the estimation tool. A “help” hyperlink is provided throughout the input page for further guidance and instruction on information the software needs to function properly. Figure 2 illustrates the estimation tool page online.



The screenshot shows the web interface for the "Axle Factor and Axle Vehicle Class Estimation Tool". At the top, there is a navigation bar with "Home | Help". Below this is a light blue banner with the text: "Welcome to the Axle Factor and Axle Vehicle Class Estimation Tool! This tool takes bin data and outputs the Axle Factor and Class Estimations." A "Show Me" button is centered in the banner. The main form area contains several input fields: a dropdown menu for "What monitoring tool does your agency use? (Required)", a dropdown menu for "Select a State", an "Upload your bin data:" section with a "Browse..." button and a file named "uploadtest.csv", and another dropdown menu for "Do you have calibration data? (Help)". A "Submit" button is located at the bottom of the form.

Figure 2. Estimation Tool Input Page

The first data input is the database or data monitoring tool you use to tabulate the local data. This question has a pull-down that lists several options to choose from. Many options are third-party vendors that are common amongst state and local agencies; however, an “other” option is provided if the input data isn’t one of the previous options. If “other” is chosen, additional instructions are provided to ensure that the uploaded data is formatted in a manner that the software recognizes. A hyperlink to a sample upload file is provided to aid the user in formatting the input data correctly.

Depending on your selection for data monitoring tool that is used, a follow-up question appears to answer. The follow-up question may ask for the number of vehicle length intervals (“bins”) your data is summarized or what time interval (“aggregation”) you would like the output data summarized. If the number of bins is requested, the user will need to identify the vehicle length intervals used in their data collection process so the estimation tool can adjust accordingly. Figure 3 illustrates this input request from the estimation tool.

The screenshot shows a web form titled "Vehicle Length Inputs from Estimation Tool". At the top, there is a dropdown menu labeled "What monitoring tool does your agency use? (Required)" with "Other" selected. Below this is a yellow informational box stating: "We require a CSV file with the first row containing column names and the first column containing a row name. Here is a sample file for formatting your bin data [Sample file](#)." The next question is "How many vehicle length bins does your data have? (Required)" with the number "4" entered. This is followed by four pairs of input fields. Each pair consists of a field for the upper length bound (e.g., "Please put the upper length bound on bin 1 (Inclusive) (Required)") and a field for the column label (e.g., "Please input the column label on bin 1 (Required)"). Below these is a "Select a State" dropdown menu with "Wisconsin" selected. The next section is "Upload your bin data:" with a "Browse..." button and the filename "uploadtest.csv" displayed. At the bottom, there is a dropdown menu for "Do you have calibration data? (Help)" and a blue "Submit" button.

Figure 3. Vehicle Length Inputs from Estimation Tool

The second data input is a dropdown menu to select the state in which data was collected. If default calibration data is being used, this input is not important; however, as the estimation tool is refined in the future, it is possible that local calibration data may be stored within the tool for local use.

The third data input requests the collected data to be uploaded into the software program. Selecting the “Browse” icon will open a pop-up window that enables you to select the file to upload. Note that only one file can be uploaded into the database per estimation tool run, so grouping multi-day data into one file will be necessary.

The fourth data input is a yes/no response if local calibration data is available to supersede the default calibration data already stored in the software. If local calibration data is available and “yes” is selected as the response, the software will provide further instructions on how to upload the data.

Once data is inputted, the user clicks “submit” and the estimation tool performs the tasks and equations outlined previously. Once complete, the web page expands and the user will see the axle factor and axle class estimates for the time interval inputted (or specified, depending on database used for input). Rows consist of time intervals and columns provide the estimated axle factor and estimated volume based on FHWA vehicle classes. This data is provided in tabular format, but it can also be converted to a chart by selecting a hyperlink provided in the last column of each time interval. At the bottom of the page are two commands: “download results” as a CSV file, or “print/save PDF” allowing the results to be printed or converted to a PDF file, if available on the user’s computer. Figure 4 illustrates the output results.

As of this writing the tool is hosted only by TTI. Any questions regarding access or use of the tool should be directed to the Wisconsin DOT or the research team.

	Axle Factor	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Chart
18-Jan	0.4206	0	0	70163	0	29293	3488	0	0	2203	0	2874	2478	0	0	See Chart
18-Feb	0.4126	0	12142	63199	0	21953	4311	2017	0	7389	1	1440	1105	39	2	See Chart
18-Mar	0.4185	0	3482	75069	0	29318	4343	725	66	4346	5	2684	2157	2	1	See Chart
18-Apr	0.4158	0	0	73846	0	30622	4047	2	0	3776	0	3060	2546	0	0	See Chart
18-May	0.4146	0	8934	64559	0	23438	4312	1538	0	6336	0	1674	1391	1	15	See Chart
18-Jun	0.4157	0	3859	68105	0	26385	4055	729	0	4869	2	2352	1941	1	1	See Chart
18-Jul	0.4173	0	12487	69746	0	24321	4424	1721	2	6609	0	1663	1317	5	4	See Chart
18-Aug	0.4169	2	6235	73424	4	27761	4379	993	17	5365	4	2377	1929	2	6	See Chart
18-Sep	0.416	1	15169	64613	3	21493	4263	2011	0	7247	10	1069	822	103	696	See Chart
18-Oct	0.4163	0	6834	66048	0	24763	4228	1132	0	5421	0	1879	1591	2	2	See Chart
18-Nov	0.4125	1	10945	64015	1	22723	4328	1716	0	7220	0	1513	1252	32	3	See Chart
18-Dec	0.4167	0	0	77381	0	31937	3928	0	0	3577	0	3249	2718	8	0	See Chart

[Download Results](#)
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Figure 4. Data Outputs from Estimation Tool