Origin-Destination Validation - Literature Review and Recommendations

TETC Transportation Data Marketplace Data Validation

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4/19/2023

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TETC Transportation Data Marketplace
Data Validation

Literature review and recommendations for structuring a volume validation program

TDM-VAL-3

Data Categories: Origin-Destination

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The Eastern Transportation Coalition is a partnership of 17 states and the District of Columbia focused on connecting public agencies across modes of travel to increase safety and efficiency. Additional information on the Coalition, including other project reports, can be found on the Coalition's website: www.tetcoalition.org

Executive Summary

The purpose of this report is to communicate the strategy the TETC Validation Team recommends for evaluating the Origin-Destination (OD) datasets sold through the TDM marketplace. To this end, it identifies relevant OD validation strategies from the literature, makes recommendations about how to structure the validation program, and proposes the framework for an initial validation activity for 2023. The document is structured as follows:

Section 1, titled *TDM Origin-Destination Data Expectations*, reviews the OD data expectations defined in the RFP.

Section 2, titled *Literature Review,* performs a brief overview of OD validation research, focusing in particular on a subset of more recent studies that investigate the quality of probe-based OD data. These studies are reviewed with an eye for relevant evaluation strategies, error measures, and other learnings that might prove useful for TETC validation purposes.

Section 3, titled *Recommendations*, presents a preliminary path forward for TETC OD validation, seeking to build off the learnings from previous studies and align the evaluation process with the expectations outlined in the RFP.

Section 4, titled *Proposed Initial Validation Activity*, provides a concrete example of what an initial OD validation activity, tentatively scheduled for 2023, might look like.

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Background

This report marks the third validation activity for The Eastern Transportation Coalition (TETC) Transportation Data Marketplace (TDM), which encompasses six transportation data items (Travel Time/Speed, Volume, Waypoint, Origin-Destination, Freight, Conflation Services) and 12 data vendors. Whereas the VPPII (Vehicle Probe Project Phase II, the precursor to TDM) validation program focused on quantifying vendor travel time/speed data accuracy via travel time field measurements and well-established analysis methods, the TDM program will need to develop new validation techniques that are appropriate for the new data items sold within the TDM. As such, the TDM validation reports will contain a broader range of topics and analysis; each report will summarize a discrete "validation activity" – not necessarily quantitative evaluation of vendor data based on comparison with field measurements. Reports may also include literature reviews of best practices for evaluating new types of data, methodological development of validation processes, descriptive analyses of new datasets, and Quality Assurance / Quality Control procedures to sanity check emerging datasets.

Based on guidance from the Validation Technical Advisory Committee (TAC), the validation team was tasked with reviewing existing methods for evaluating OD data and proposing a strategy for evaluating OD data sold through the TDM marketplace. This validation report is structured as a technical memo to the TAC containing a detailed literature review of best practices for quantifying OD data quality and recommendations about how to structure the OD validation process. These recommendations – which were reviewed by the TAC and other key stakeholders – will be used to guide the initial OD validation activity later in 2023.

TDM Origin-Destination Data Expectations

Origin-Destination data is one of the six core data items in the Transportation Data Marketplace. However, in contrast to Travel Time and Speed data, which had been studied extensively by the Coalition validation team since 2008 and has well defined accuracy measures, OD datasets are new to the TDM and have not yet been evaluated for accuracy and quality. Validation of OD data is further complicated by lack of a qualified reference source, or ground truth in most cases. Relevant expectations from the TDM RFP[1] (Section 5, pg. 93-96), are listed below in Sections 1.1 and 1.2. Although data quality is not explicitly covered in this section, RFP respondents were made aware that all TDM data is subject to data quality review.

Source Data, Processing and Use Cases

Unlike Travel Time/Speed and Volume datasets, for which the RFP outlined many mandatory reporting and data quality requirements, the OD section of the RFP is more open-ended and asks vendors to explain their data products. The Source Data, Processing and Use Cases section (Section 5.2, starting on pg. 93 of the RFP) asks vendors to describe the following:

- Source data used to create the OD tables (e.g., GPS, LBS, Telecommunications)
- Method used to transform the source data into the OD product, and whether the resulting OD tables are scaled up to represent the overall population.
- The spatial granularity with which data can be delivered (e.g., Census blocks/tracts/block groups, counties, zip codes, user-defined zones)
- How region boundaries are handled (e.g., will OD data for a region consider trips that begin outside of the region to originate from the zone boundary or the true origin?)
- Whether segment level/select-link OD is supported
- Whether intersection-level OD is supported
- The extent to which home locations are identified/used in OD, versus the extent to which PII controls mask the actual home location.
- Temporal aggregation and data availability
- Whether modeling and/or data fusion processes are used (and if so, a description of the process)

Formatting, Privacy and Licensing Restrictions

This section (5.3, starting on pg. 95 of the RFP) asks vendors to explain their data format and delivery mechanism, comment on how privacy is handled, and describe any licensing restrictions.

[1] Traffic Data Marketplace RFP (link)

Literature Review

Historically, Origin-Destination (OD) flows were estimated primarily from travel surveys [1]–[3]. While these datasets contain important information about travel behavior, survey-based methods tend to be time-consuming and expensive to acquire and are usually limited by small sample sizes. Over time, other sources have been introduced alongside – and sometimes in place of – surveys, including point-based re-identification sensors (e.g., Bluetooth, Automatic License Plate Recognition cameras) and more recently, data obtained from passively-acquired GPS, Location Based Services (LBS), and Cell phone data records.

The emergence of large-scale, passively collected commercial OD data, as can be procured through the TDM, provides an opportunity for travel patterns to be acquired at scale and at a much lower cost than traditional methods. These datasets may be useful for various purposes, including building and validating travel demand models, as well as gaining general insight into travel behavior [4], [5]. Given the potential benefits, there is interest in understanding the data quality of such sources.

Existing OD validation strategies tend to fall into two categories: (i) comparative evaluations, where commercial OD data is compared to a reference dataset – and (ii) internal quality checks, which can be conducted by looking at other aspects of data quality, including checking for anomalies and other inconsistencies. The sections below discuss each of these approaches, drawing from studies that were deemed most relevant to the TETC OD validation task.

Comparative Evaluation

Comparative evaluation involves systematically evaluating the commercial OD data with benchmark datasets. Benchmark datasets include (i) other OD trip matrices, for which direct comparisons can be made, and (ii) OD trip attributes (e.g., trip length distribution, travel time distribution) that can be obtained from other sources. While the latter benchmark source -- trip attribute datasets -- may be easier to acquire than OD matrices, the corresponding trip level information may not be available for the commercial OD data that is subject to evaluation. The use cases of each are explored and summarized below, followed by a discussion of the spatial and temporal considerations that are relevant for both.

Comparison with other OD matrices

Other OD datasets can be utilized to evaluate the commercial OD flows at local, state, or national scale, based on the spatial coverage and aggregation level of the data. In general, these benchmark OD datasets can be obtained from the following sources:

- **Traditional and "Next Generation" Surveys**
  Traditional travel surveys and other related sources provide the origin and destination locations of *individual trips*, which can subsequently be used to derive OD matrices for comparison with commercial OD data. As an example, the 2017 National Household Travel Survey (NHTS) provides valuable information on the US population's trips [6], and although the exact locations of the trip ends are not publicly available, it is possible to make a request

for this information at some aggregated levels (e.g., census block groups). Additionally, state and local agencies often conduct regional travel surveys (e.g., Maryland Statewide Household Travel Survey [7]), which provide trip-level information at a more localized level. Note that household surveys can have small sample sizes, so comparisons may need to focus on aggregated zones.

Additionally, the Next Generation National Household Travel Survey (NextGen NHTS) program launched by the Federal Highway Administration provides a national-level multimodal origin-destination matrix, derived from passively collected mobile device location data [4]. Although the source of the location data may have considerable overlap with what commercial OD vendors (i.e., the data vendors to be validated through the TETC validation program) are using, this dataset may provide opportunities for comparison. It is worth noting that as of now, the national NextGen NHTS program provides the trips at a high-level geographic area, with the US partitioned into just 583 metropolitan statistical areas zones. While these zones may be too large for certain applications, more granular data will be available in the future as part of the pooled fund studies for specific regions.

- **Re-identification sensors**
  Re-identification technologies such as Automatic License Plate Recognition (ALPR), toll tag information, and Bluetooth reidentification data have been used to extract OD data at small spatial scales [8], [9]. These systems work by detecting and then later re-identifying vehicles at different sensor locations within a study area, thus providing the endpoints for individual trips that can be used to extract OD patterns [10]. However, because these sensors are 'point-based', they cannot easily capture OD patterns between large geographies, and thus are most suitable for relatively small study areas.

- **Calibrated demand models**
  Many regional travel studies have generated OD matrices using calibrated travel demand models such as a gravity model, the opportunity model, or the gravity-opportunity models [11]–[13]. Although OD matrices derived from such models may theoretically be utilized for validation purposes, caution should be exercised when doing so. As an example, the developers of the travel demand model of the Metropolitan Washington Council of Governments (MWCOG) mentioned that although the model is calibrated to have a satisfactory match between the observed trip-length distribution and the trip-length distribution inferred from the model, the OD level information generated by the model is not validated and not recommended for direct use [14]. As such, when using any travel demand model results for this purpose, it is important to carefully consider the appropriate spatial scale.

- **Mode-specific datasets**
  Although obtaining OD trip data from *vehicle trips* is difficult, local and federal transportation agencies often collect transit and air travel trip information that can be used to derive mode-specific ODs. Examples of such datasets include the Airline Passenger and Freight Traffic (T-100) data, the Airline Origin and Destination Survey (DB1B) data, and the National Transit Database (NTD).

- **Commercial OD datasets provided by other vendors**
  Several data vendors provide commercial OD data using different underlying data sources, strategies and implementations. Although any one vendor's OD data may not be considered a benchmark dataset per-se, comparisons between multiple vendors' offerings may be useful to understand whether there is general agreement among the industry.

When comparing OD matrices, several accuracy measures can be calculated to identify how close the commercial data is to other known datasets. Note that several of these measures use the term “difference” instead of “error” to communicate that benchmark datasets do not perfectly represent ground truth conditions.

Percentage Difference (PD) and Mean Censored Absolute Percentage Difference (MCAPD) were used in [8] and [15], with Cools et al considering MCAPD greater than 5% as the threshold of inaccuracy. The GEH statistic, defined as $\sqrt{\frac{2(M-C)^2}{M+C}}$ where M and C are the estimated and observed hourly volumes, respectively, is another accuracy measure that has been applied to quantifying differences in OD pair volumes [16]–[18]. Typical GEH acceptance thresholds used in practice are “less than 5 is OK”, “10 or more is not OK” and “at least 85% of the values in a dataset should have GEH less than 5 [16]. Other studies quantified differences between OD matrices using the coefficient of determination (R^2) [19], mean normalized error (MNE) and root mean squared normalized error (RMSNE) [20], root mean square error (RMSE) and mean absolute error (MAE) [21], and root mean square (RMS) difference [22], with the latter also using scatter plots to visualize observed and estimated traffic volumes.

Comparison with trip attributes

In cases where OD data providers provide trip-level information (i.e., the trip records that underpin the OD matrices, often consisting of start/end time, trip distance, etc.), the corresponding attribute information, including travel time and trip length distributions, can be compared to other reference data sources. Note that this closely mirrors how many traditional planning models are calibrated (or internally validated); travel time and trip length distributions produced by the model – often separated by mode and trip purpose – are compared with reference sources to test for a satisfactory match.

As an example, Alexander et al (2015) performed validation of the OD travel patterns by trip purpose and time of day by aggregating raw trip records to the town level and comparing the distributions with available ground-truth datasets, including the 1991 Boston Household Travel Survey [23]. This analysis also involved comparing the spatial distribution of home-work flows to those obtained from 2006-2010 Census Transportation Planning Products (CTPP), which they found to be highly correlated. Likewise, the Next Generation National Household Travel Survey used several trips datasets for internal validation purposes, including the 2017 traditional NHTS for comparing daily trip rate and miles traveled per person, Airline Passenger and Freight Traffic (T-100) data, the Airline Origin and Destination Survey (DB1B), the National Transit Database, and Highway Performance Monitoring System (HPMS).

In practice the comparison between travel time, trip length, or trip rate distributions are often done visually – see [24], [25] for example, but such comparisons could also be formalized via statistical testing (e.g., chi-square test, t-test or Kolmogorov-Smirnov (KS) tests). Regardless of the specific approach, it is often useful to break the comparisons out by time of day, travel mode, and separate trips with different characteristics (e.g., short-distance vs long-distance).

Spatial and Temporal Considerations

Each of these validation strategies requires considering spatial and temporal factors. Since many of the datasets are only available for a specific region, or a specific geographical level such as a county or a traffic analysis zone (TAZ), the commercial OD data should also be aggregated/disaggregated in a like manner -- either by the OD data vendors or by the consumers such as the DOT or MPO. Similarly, comparison of the commercial OD data with the benchmark datasets gathered from ALPRs or Bluetooth reidentification datasets is likely to be limited by the study area of the benchmark dataset to the intersection/corridor level. Thus, it is essential to inquire of data vendors the level of geography aggregation or specificity they can support – or, as an alternative approach, have the vendor provide the underlying trip data to allow the consumer to map to a desired custom geography.

In addition to considering the geographical coverage and level of detail, the temporal granularity of vendor OD data should match the benchmark sources. Benchmark datasets are available for a specific time interval. For instance, the 2017 National Household Travel Survey (NHTS) was conducted from April 19, 2016, through April 25, 2017, with the intent of reflecting an 'average day' during this period. To be able to compare the commercial OD data for dates other than what NHTS covers, markup factors can be used to convert the 2017 trip count to the required year. It should be acknowledged that the travel behavior of the people during the time that the benchmark dataset was conducted might be different from the time interval of the commercial OD data. As an extreme example, the travel behavior of people during the COVID-19 pandemic is clearly different from the travel behavior of the US population reported by the 2017 NHTS [5]. However, differences from year to year due to population growth (but without a major outside influence like a pandemic) may be satisfactorily accounted for by markup factors.

Internal Quality Checks

In addition to accuracy, which was covered in the section above, other aspects of data quality can be investigated without the use of benchmark/reference datasets. Note that many of these strategies require more information than may be conveyed by vendors in the TDM marketplace. Nonetheless, these examples from the literature are instructive for thinking about how to test the reasonableness of commercial OD datasets.

- **Unreasonable OD Pairs by Mode**: Since several OD pairs are not accessible with a specific mode of transportation, those OD pairs should be investigated for any impossible trip. For example, a trip originating on an island in Hawaii with a destination in the contiguous United States is not feasible by vehicle [26], while a walking trip where the distance between the origin and destination is greater than a specific threshold such as 25 miles is not acceptable. Air trip lengths should also exceed a certain minimum distance threshold [26].

- **Purpose and Location Consistency**: The trip purpose and the type of destination should be consistent [27]. For instance, if the purpose of a trip is a dining trip, a valid restaurant point of interest (POI) should be observed at the destination. As another example, if at the OD level, there is an air trip associated with the specified OD pair, there should be an airport at both origin and destination of the OD.

- **Travel Time Validation**: Travel time between the origin and destination of a trip should be within an acceptance interval, given the mode, route, and time of day [27].

- **Dwell Time Validation**: Time spent at the destination should be reasonable, given the destination and trip purpose [27].

- **Trip Chaining Consistency**: At the trip level, the departure time of any given trip of a person should be after the arrival time of the previous trip of the same person. The destination of the previous trip and the origin of the next trip should be consistent [27].

- **Time-of-Day Validation**: trips should be occurring at logical times. For example, it is unlikely for an elementary school trip type to leave home late at night [27].

- **Flow Conservation**: At any given basic freeway without any off-ramp or on-ramp, the traffic volume upstream should be consistent with the volume downstream. Also, there should not be any U-turns on the road when it is not allowed. The percentage of these occurrences can be utilized to measure the validity of the dataset (7).

- **Road Accessibility to Certain Vehicle Types**: On certain roads at certain times, trucks may not be allowed to maneuver. This can be tested to see if the truck volumes are zero (7).

- **Symmetry of OD matrices:** Most trips are circular, in which traveler leaves home, travels to a destination such as work, shopping, or even a distant location, and then returns home later. Such behavior induces symmetric trip behavior – typically as many trips from A to B as from B to A. A non-symmetric OD matrix may warrant further investigation.

In addition to these types of reasonableness tests, Turner et. al [28] highlight other aspects of traffic data quality that are worth considering, which Venkatanarayana and Fontaine [8] later use in the context of assessing OD data. Such considerations include:

- **Data Timeliness**: The extent to which vendors deliver the data to the consumer in a timely manner (e.g., the number of months between the time that the data is collected and the time that it is available to the consumer) [8], [28].

- **Data Coverage**: The percentage of the study area that is covered by the dataset [8], [28]

- **Data Accessibility/Usability**: The ease with which the dataset can be obtained and queried to meet customer use cases [8], [28].

- **Data Biases**: The extent to which the sample data represents the overall population. While it is not easy to quantitatively evaluate such biases in commercial OD data, it is instructive to gather information from data vendors about where the data comes from and what strategies are used to reduce the effect of potential biases.

- **Data Privacy**: Key considerations include whether the data could be used to identify individual people/vehicles/trips, and what steps (if any) are taken to obscure exact trip origins and destinations. While this is the data vendor’s responsibility, it may be useful to ask vendors to explain how they handle such concerns.

Recommendations

After reviewing the existing literature, the TDM validation team makes the following recommendations:

- **Recognize that benchmark OD datasets are hard to acquire – particularly for vehicle trips and for large spatial geographies.** In contrast to Travel Time/Speed and Volume datasets, for which reference data can be collected for reference purposes, benchmark datasets for vehicle OD trips data tend to be limited -- particularly for large spatial geographies. As such, a more diverse set of approaches will be needed to effectively evaluate data quality.

- **Investigate vendor OD data quality through both *systematic comparisons* and *internal reasonableness checks*.** In cases where high quality benchmark data can be acquired – usually for limited spatial scales or for specific travel modes, accuracy measures should be computed to quantify agreement with a trusted source. However, even when trusted benchmark data does not exist, comparative methods can be used to check for agreement between vendors, and with other available (non-benchmark) data sources, and additionally each vendor's data can be checked for internal consistency.

- **Request that vendors respond to a series of questions to help clarify their OD data products.** Although OD vendors responded to several open-questions in during the RFP process (the questions listed above in Sections 1.1 and 1.2), the responses – and answers to other emerging questions – are not easily accessible to State DOTs who are interested in buying OD data. Organizing this information and seeking responses to follow-up questions would help provide clarity and actionable information to potential customers.

- **For an initial validation activity, consider conducting a side-by-side systematic comparison of all vendors' vehicle trip OD to test for agreement at different spatial scales,** ranging from the state level to more granular geographies such as census areas / corridors / intersections (see Section 4 below). Where possible, reference (benchmark) datasets should be included in the comparison. Advantages of this strategy include:

    - Learning whether there is general agreement on vehicle travel patterns within industry (amongst different vendors), and if so, whether it is consistent at different spatial scales.

    - Including reference OD or secondary datasets as additional points of comparison to gain additional insight. At a minimum this can be done at the corridor/intersection level by deploying short-term Bluetooth/ALPR/Re-id/emerging video processing techniques or utilizing data from tolling facilities. Reference data from larger geographies can be used if relevant surveys or other sources can be identified. Comparison against modeled results from planning activities is also encouraged.

    - Testing different accuracy measures and statistical methods from the literature to quantify agreement between data sources.

- **Recognize the need to continuously revise and improve validation methods***.* It is expected that the first few validation efforts will provide many learning opportunities. Based on these findings and feedback from State DOTs and data vendors, it will likely be necessary to refine the methodology to improve the validation process.

In the longer term, the validation team also recommends incorporating the following into the OD validation process:

- **Evaluate non-vehicular travel modes – such as transit and air travel, which often have good reference datasets that may be easier to validate.** While vehicle trip datasets are hard to ground truth, local and federal transportation agencies often collect trip information that can be used for validation purposes. Promising reference datasets dealing with air and transit modes include the previously mentioned Airline Passenger and Freight Traffic (T-100) data, the Airline Origin and Destination Survey (DB1B) data, and the National Transit Database (NTD).

Proposed Initial Validation Activity

The Coalition validation team proposes the following structure for an OD validation activity to be conducted in 2023, using North Carolina as an example. This will cover state, metro area, and corridor/intersection-based OD -- three different geographic scales of interest.

Scale #1: State level (Macro)

Given a target state, vendors will be asked to provide origin and destination data on a scale representative of movement between counties or major cities/metro areas within the state and to adjoining states (specific geography will be determined by the validation team in coordination with the TAC). Trips that start or end outside the state may be assigned to the other state's geography or simply bucketed as 'external'.

- **Spatial Granularity**: One of the following spatial geographies will be chosen by the validation team, pending the scope/goals of the validation and availability of reference data.
    - **County**
    - **Core Based Statistical Area (CBSA).** One or more counties with an urban core having 10k+ population.
    - **Metropolitan Statistical Area (MSA)**. A subset of CBSA where urban cores have 50k+ population.

Figure 1 shows an example of MSAs in North Carolina. For context, there are 100 counties, 41 CBSAs, and 17 MSAs in the state.

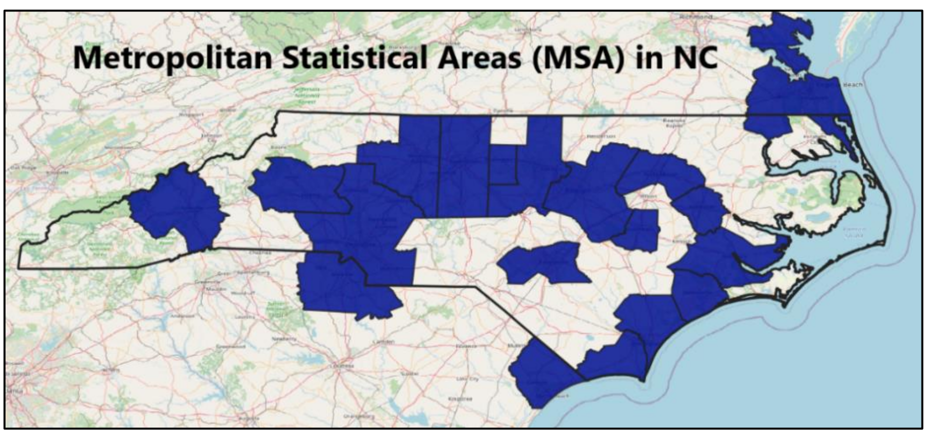

Figure 1 – Metropolitan Statistical Areas (MSA) in North Carolina.

- **Time Period**: A year, season, month, weekday or weekend during a specified calendar year (to be specified).

- **Reference/comparative datasets**: State data models, NHTS Next-Gen, state survey data, and comparison between vendors

Scale #2: Metropolitan Area

Given a target metropolitan area (likely MSA), vendors will be asked to provide origin and destination data on a scale representative of movement between census tracts or similar scale geographies (specific zone geographies to be determined by the validation team in coordination with the TAC). This will capture typical movements for trip ODs throughout the metro area, and to adjoining areas. Note that trips that start or end outside the target MSA may be assigned to their specific geography or simply bucketed as ‘external’.

- **Spatial Granularity**: One of the following spatial geographies will be chosen by the validation team depending on the scope/goals and availability of reference datasets.
  - **Census Tract**
  - **Census Block Group**.
  - **Traffic Analysis Zone**

Figure 2 shows an example of Census Tracts within the Raleigh-Cary MSA. There are 224 Census Tracts and 569 Census Block Groups in this MSA.

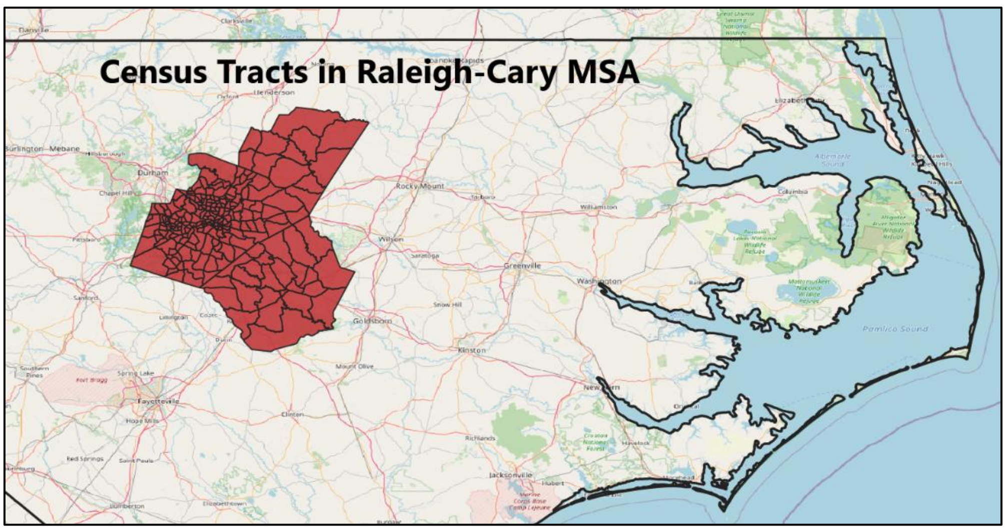

Figure 2 – Census Tracts in Raleigh-Cary MSA.

- **Time Period**: A year, season, month, weekday or weekend during a specified calendar year (to be specified).

- **Reference/comparative datasets**: Metropolitan data models, survey data, NHTS Next-Gen (if available) and comparison between vendors.

Scale #3: Corridor / Intersection Level (Micro)

For smaller geographic extents such as intersections, segments, or corridors, vendors will be asked to provide an analysis of vehicle movements. There are several different approaches that fall under this category.

Corridor Analysis

Given a small geographic study area, vendors will be asked to provide origin and destination data between custom-defined zones on a scale representative of movement along a corridor. The intent is to capture intersection-to-intersection movements in an urban area and understand turning movements (traffic exiting and merging) along a corridor. Initial efforts would likely target multi-lane facilities such as freeways for major arterials.

- **Spatial Granularity**: Custom zones representing intersections or roadway locations
- **Time Period:** Representative weekday, weekend, or week (possibly also broken out by peak period)
- **Reference/Comparative Datasets:** Field data collection (e.g., Bluetooth, ALPR), traffic control data if instrumented, and comparison between vendors.

Intersection Turning Movements

At individual intersections, vendors will be asked to provide turning movements – minimally indicative of an average weekday and weekend. Minimally, this would include approach volumes from each leg, and the anticipated turning movements (through, left, right) from each leg to every other leg.

- **Spatial Granularity**: Intersection and corresponding legs
- **Time Period:** Representative weekday, weekend, or week (possibly also broken out by peak period)
- **Reference/Comparative Datasets:** Field data collection (e.g., camera with video analytics), traffic intersection data, and comparison between vendors

Pass-through Analysis or Select Link Analysis

Given a target geography (likely MSA), vendors will be asked to provide origin-destination data for trips **that pass through a specific zone or roadway link**. Note that although the OD data reported will be for a larger geographic scale (e.g., census tract for an MSA), the intent is to gain insight into the patterns of trips that pass through specific roadways.

- **Spatial Granularity**: Census tract (or appropriate) *for trips passing through zone/segment*
- **Time Period:** Representative weekday, weekend, or week (possibly also broken out by peak period),
- **Reference/Comparative Datasets:** Comparison between vendors and possibly against link analysis results from travel demand model.

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