BTS TRANSPORTATION PROBE DATA GUIDE: NON-LBS CELLULAR PROBE DATA

Cell phones directly produce two types of probe data, both of which leverage the spatiotemporal information derivable from the relative strength of a phone's connection to cell towers owned by its corresponding mobile phone carrier: event-driven call detail records (CDRs) and network-driven passive-signaling data. Both data types are available from any type of mobile phone, a side effect of mobile phone carriers' need to implement usage-based customer billing, optimize networks, and improve 911 emergency response rates [Hard et al. 2016; Cambridge Systematics, Inc. 2018; Zhao, Zhao, Koutsopoulos 2016]. While these location-detection methods bear some resemblance to the Global Positioning System (GPS)-based procedures underlying location-based services (LBS) sightings from smart phones, they are performed by the phone itself and do not depend on software-based applications (apps).

Developed in the 2000s and 2010s, cellular probe data, a collective term for both CDRs and passive-signaling data, were one of the earliest examples of nontransportation-specific big spatial data being harnessed for transportation-planning and -modeling purposes [H.R. 438]. As they proxy human movement vis-à-vis the traces left by people as they use their cell phones over the course of their daily lives, transportation specialists saw them as a novel, nonsurvey-based method to measure mobility patterns and flows. Cell phone companies, who primarily harvest these data from their devices to track their customers as part of their standard business practices, began selling them to transportation-oriented analytics firms, who converted, enriched, and sold them as transportation statistical products for planners and other mobility professionals.

Such work continued until 2018, when major mobile phone carriers abruptly stopped sharing data with analytics vendors due to privacy, policy, and public relations concerns. The analysts previously using these cell network–derived inputs subsequently switched to LBS location data that, while still sourced from cell phones, rely on more high-precision, GPS-derived position data emitted from the apps running on these devices. While the former inputs were provided by mobile phone carriers, the latter are typically sourced from smart phone app developers, who can theoretically pull data from devices from multiple carriers.

Despite these developments, mobile phone carriers are still presumed to produce and log cellularly derived probe data for internal purposes. As such, they remain a hypothetical alternative data source for regional and national trip analytics, an inference supported by the continued existence of transportation-oriented statistical products and research using these data in international markets, where they remain available [Macfarlane, Copley 2020]. In fact, a return to cellular probe data in the United States is made more attractive as LBS data become less available, constrained by stricter privacy settings and a growing number of app developers opting not to resell user location data.

Extracting location information from these forms of cellular probe data remains technically complex and involves working with data forms and standards unfamiliar to those outside the telecommunications industry. The only people with direct access to cellular probe data messages in their original form are data analysts at mobile companies and employees at analytics firms. Unaltered cellular probe data are not available to the public. The methodology for extracting location information from these messages, a task performed by the analytics companies, is also unknown to the public.

These challenges have been exacerbated by the fact that United States-based transportation planners have not worked with these data—in any format—since 2018, meaning that assumptions about the data, as well as corresponding techniques for analyzing the data, are potentially out-of-date and not useable with newer call records. For example, call records usually incorporate satellites for location detection in ways not done before [Blake 2025].

Fortuitously, standards for CDRs, the more widely known of the two forms of cellular location data, are still maintained and developed by the global consortium 3rd Generation Partnership Project [3GPP 2024]. Some technology vendors still implement these standards [Cisco 2025]. As such, information on cellular location data is still knowable, even if they are primarily used outside the United States; some literature, for instance, finds that CDRs, which describe interactions between a phone and a cellular network for a call, text, or data request, can be generated via network-management events [Hard et al. 2016].

1. CAPABILITIES

Cellular probe data offer distinct advantages for generating transportation statistics:

- They relay information on approximate device locations, which are mostly determined during calls, texting events, and data sessions (e.g., an individual cell phone's connections to its nearest mobile towers) through one of two methods: CDRs and passive-signaling data.
- They are available from any cell phone, offer broad spatial coverage, and have large sample sizes that can be valuable for regional and long-distance travel patterns.
- They are an early form of passive-transportation and mobility data with a long history that precedes widespread GPS adoption.

2. LIMITATIONS

Known limitations of cellular probe data for generating transportation statistics include the following:

- They lack GPS-level precision, with accuracy ranging from 250 feet in urban areas to 1–3 miles in rural regions.
- They are not suitable for high-resolution mode detection, short-distance travel, or safety analytics.[1]
- They are sparse (i.e., while spatially expansive, the precision of these sightings is relatively poor), possess variable spatial accuracy, and are difficult to ground truth (i.e., comparable large-scale origin–destination [OD] tables are not readily available).
- They have no native information on trip purpose, mode, and vehicle occupancy, all of which must be inferred.

[1] Cell data vendors typically recommend travel shed polygons be no smaller than 1 square mile, meaning short trips, such as walking to corner stores, bike trips, or other very short-distance travel may not be captured in the analysis.

3. VENDORS

U.S. cellular providers discontinued data access to analytical vendors in 2018, at which time LBS became the predominant source of probe data for transportation planners [Macfarlane, Copley 2020]. Products previously completed with cellular data (i.e., OD tables) were continued with LBS data as their primary source.

Current cellular data usage is limited to regions outside the United States, including Europe, Asia, and South America.

Interested data users in the United States would need to reach out directly to representatives from mobile phone carriers to determine the current or prospective availability of cellular probe data for transportation statistics and planning.

4. MARKETS

The primary markets for cellular probe data include the following:

- Advertising and retail
- Commercial site planning

Transportation is a secondary market for cellular probe data providers.

5. SCALE OF AVAILABILITY

Cellular probe data are theoretically available at any spatial scale, covering all parts of the United States with cell phone service. This circumstance characterizes their suitability in the following ways:

- They are best suited for regional OD matrices, long-distance trip capture, model validation (e.g., OD interchanges, screen line counts, proportion of trips by distance, special generators), and special generator analyses (e.g., trips to and from a sports stadium), with a higher potential for use at the nationwide level. A primary vendor of phone-data-derived products released a free dataset of county-to-county ODs in 2016 based on these data [Hard et al. 2016].
- They are not recommended, without supplemental data, for mobility studies, short trips, or modal analyses.
- They lack the spatial accuracy needed to associate events with specific road segments, so they cannot be map-matched to a network or accurately provide link-based operational characteristics (network speed, high-precision trip estimates or distances, stop detection, etc.).[2]

[2] Mobility studies, in this context, refer to speed studies, national performance measures, and congestion analyses—essentially road or link-based applications that require precision beyond cell data's spatial accuracy. While OD studies inherently have large error margins, they remain viable for large scales at which such error is acceptable, unlike mobility studies, which depend on precise network-level characteristics.

6. GENERAL DETAILS

The following subsections detail background information on how cellular probe data are generated, why they exist as a data type, and the pieces of information contained in their data points.

6.1. How Are Data Captured

The following subsections detail the generation, capture, conveyance, and protection of cellular probe data points.

6.1.1. Two Primary Data Types

The means by which cellular probe data points are generated depend on whether they are based on event-driven CDRs or network-driven passive-signaling data.

6.1.1.1. CDRs (Event Driven)

Cellular probe data from CDRs are generated through the following circumstances:

- CDRs are created when any device with a cell phone plan initiates or receives a call, sends or receives SMS (Short Message Service), or uses data.
- CDRs capture location, which is recorded as the location of nearby cellular antennae or towers during communication events (e.g., text, calls, and data transmissions).
- CDRs are also created during network-management events, when a device interacts with cellular infrastructure for network-optimization purposes, even without user-initiated communication.
- CDRs are available from all mobile phone carriers.

6.1.1.2. Passive-Signaling and Sighting Data (Network Driven)

Cellular probe data from passive signaling are generated through the following circumstances:

- Location is derived by the mobile phone carrier (or vendor, who converts carrier-sourced data ex-post-facto) based on signals sent from the device and its nearest cell tower(s) within the network of the device's mobile phone carrier or provider. These signals allow a device to determine the optimal cell towers from which to send and receive calls and texts. The relative location of the device in comparison to its towers, which have fixed locations, help the mobile phone carrier determine where the device is located.
- These data include handover data when a device switches between cell areas. The handover information does not inherently contain any geospatial information, although this context can be added by knowing the geographic locations of the towers on either side of the handover.
- These data have a higher sampling frequency than CDRs, with location updates occurring every 15–60 minutes.

- These data have better temporal coverage over time and persons than LBS data, which only produce device coordinates when a user is actively using their phone and its apps, but nevertheless, they require an end user to have an agreement with each mobile phone carrier for them gain access to the data produced by their users' devices. Both cellular probe data and LBS data produce user location information. Such information from LBS is gathered more situationally.

6.1.2. Trigger Mechanisms and Frequency

For cellular probe data derived from CDRs or passive signaling, active triggers occur whenever a device transmits a call, text, or data. Passive triggers, which apply only to those derived from passive signaling, include the passing of a regular amount of time (i.e., the device indicates its location on an interval) or the movement of a device between the areas of different cell towers.

6.1.3. Location Determination Technology

The location components of cellular probe data points are generated and defined under these conditions:

- CDRs record the cell tower and cell tower sector associated with the device location during the communication event. Cell towers typically have 3 sectors (120 degrees each) but can have 6 sectors in high-density areas.
- Device location is approximated to the coverage area of the servicing tower and tower sector (i.e., location is defined by a polygonal area, not a precise coordinate).
    - More advanced methods use cell-tower triangulation when device signals are received by multiple towers, although the resultant location would still be aggregated to a tower- or tower-sector-defined polygonal zone.
    - Single-tower connections use sector-based positioning, which is less accurate and assigns a device to a tower-sector coverage area. A single tower will have multiple antennae, each looking for signals in different sectors; the location of a device is determined by the relative strength of its connection to these antennae, which—in turn—help estimate the device's location within an antenna's sectors.
- Some techniques improve the accuracy of the location estimate for a device:[3]
    - Radio Signal Strength estimates distance by measuring how much a radio signal weakens as it travels from transmitter to receiver, allowing triangulation from multiple reference points.
    - Time Difference of Arrival calculates position by measuring the time differences for a signal to reach multiple receivers.
    - Angle of Arrival determines location by measuring the directional angle of incoming signals at multiple receivers using antenna arrays and then triangulating where the directional lines intersect.
- Accuracy varies significantly by geographic density of towers and tower placement, although this accuracy is obfuscated when individual sighting records are aggregated to a larger polygon zone (a step typically performed by the transportation-oriented data vendors responsible for converting sighting data into publicly available data products).
- GPS is not used in traditional cellular data.

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[3] Any of these techniques could have been used by the cell phone provider to estimate the location of the device (and are not typically documented).

6.1.4. Data Transmission

Cellular probe data points are transferred from a phone through the following procedures:

- All cellular data, along with accompanying metadata, are generated within the mobile phone carrier's network and then stored and analyzed for billing and operational purposes.
- Data are extracted, shared, and anonymized to third-party vendors, who would analyze metadata of the dataset to derive sightings and location information to estimate OD counts. Neither the vendor nor the end customer would ever work with the exact, raw call records originally emitted from the cell phone companies' users' phones.
- Real-time access to call data, whether by vendors or their customers, is not typically available due to the extensive postprocessing required to convert raw call data into the processed tables delivered to vendors.

Review Chapter 3 of *Cell Phone Location Data for Travel Behavior Analysis* [Cambridge Systematics, Inc. 2018] for more information on data transmission.

6.1.5. Identifiers and Privacy

Identifying information on the owner of a cellular probe device is protected by the following procedures:

- CDR-derived public products from vendors include tower identifiers (IDs) and timestamps but no unique user or device IDs (it is not known if such IDs are included in the data provided by the cell companies to data analytics vendors).
- Vendor products derived from cellular antennae data include locations aggregated to a user's defined geographies but no unique user or device IDs. Vendors never provide the disaggregate data and only provide data aggregated to custom-specified zones (polygons) as provided by customers in the course of a specific data purchase.
- Privacy concerns remain due to potential re-identification of a device owner, especially in low-density areas.[4]

6.1.6. Observation Unit

The unit of analysis for cellular probe data is defined as follows:

- The core unit is the device.
- Because of this characteristic, users of cellular probe data should be mindful of the following: One person may have multiple devices or share a device with others.
- Devices observed and presumed to have been traveling could represent drivers, passengers, or nontraveling users.
- All device sightings are aggregated to custom-specified polygonal zones, typically provided by customers in the course of a specific data purchase.
- No mode or occupancy indicator exists.

[4] Vendors typically do not exclude zones with insufficient data but will not process data below a certain traffic-analysis-zone size threshold. If smaller geographic units are required, customers must conduct postprocessing disaggregation to smaller traffic analysis zones using population, employment, or other weighting factors.

6.2. Why Does This Data Source Exist Originally and for Transportation

The following subsections provide background on the history, development, and application of cellular probe data, especially vis-à-vis the generation of transportation statistics.

6.2.1. Original Purpose

The development of cellular probe data was centered on the following goals:

- CDRs were created by mobile phone carriers for billing and customer-service records, although the exact contents, attributes, and elements of a raw, disaggregate CDR message—as logged internally by the cell phone company—are unknown. Similarly, whether all the contents of these messages were handed over to the transportation-oriented data vendors (who subsequently converted them to statistical products) is unknown.
- Passive-signaling data have been used by the same mobile phone carriers for network optimization and 911 compliance to geolocate origins of 911 calls from mobile devices (previously, 911 calls could only be traced to the address of the phone number) [FCC 2025]. As with CDR records, the exact contents of these data points, as used internally, are not known.
- Transportation applications have been secondary, even after the potential for mobility analysis was recognized in the mid-2010s [Hard et al. 2017].

6.2.2. Transportation Focus

The use of cellular probe data for transportation statistical purposes can be characterized as follows:

- CDRs and passive-signaling data were made available to intermediary vendors at the same time.
- CDR data were used initially but were found inadequate for many transportation applications due to the imprecise geographic data.
- Modern approaches, from parts of the world where both data sources are available to the transportation sector, combine CDRs with passive-signaling data to enhance their coverage.

6.3. Data Contents

The following subsections note the pieces of information contained in cellular probe data points, including those generated initially by the phone as well as those estimated during subsequent steps.

6.3.1. Core Attributes

Data elements available for all cellular probe data points, generated by default by the mobile phone, include the following:[5,6]

- Timestamp
- Cell tower ID and antenna sector
- Device ID (anonymized)
- Duration or type of communication event
- Basic network status (i.e., any service disruptions)
- Signal strength
- Network type (e.g., 2G, 3G, 4G)

6.3.2. CDR-Specific Attributes

Data elements that are uniquely available for CDR-derived cellular probe data points and generated by the mobile phone by default include the following:[7]

- Type of communication event (e.g., call, text, or data)
- Duration of communication event
- Called and calling party information (anonymized)

6.3.3. Passive-Signaling Attributes

Data elements that are uniquely available for passive signaling–derived cellular probe data points and generated by the mobile phone by default include the following:[8]

- Handover events between towers
- Location area of the tower and tower sector

6.3.4. Non-Universal Attributes

No specific, non-universal attributes are known for either type of cellular probe data.

Any additional attributes that may exist would have unknown units and formats not publicly disclosed by cellular providers or vendors.

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5 These core attributes represent the data received by vendors from cellular providers. Vendors transform these data into customer-requested products, such as OD tables. The actual data format received by vendors may not be tabular.

6 Cellular providers or vendors do not publicly disclose the specific units and formats for these core attributes (tower ID and sector, device ID, event duration and type, network status, signal strength, and network type).

7 Cellular providers or vendors do not publicly disclose the specific units and formats for these CDR attributes (communication event type, duration, and party information).

8 Cellular providers or vendors do not publicly disclose the specific units and formats for these passive-signaling attributes (handover events, location area data, and registration updates).

6.3.5. Derived Attributes

Cellular probe data elements that not inherently generated by the phone and require derivation or estimation by context include the following:

- Activity points (locations where a device remained for more than 5 minutes)
- Inferred trip ends from stable locations over time
- Home location (majority of nights 9PM–6AM)
- Work location (majority of days 9AM–5PM)
- OD flows between customer-specified polygonal zones (i.e., traffic analysis zones)

As cell phone providers no longer sell cell phone record data in the U.S. market, these derived attributes reflect legacy products that are no longer available and were by-products of customer requests for analytical products using the cell companies' data records. The degree to which these attributes could be presumed with modern-day cellular probe data is unknown.

6.3.6. Sample Characteristics[9]

The sample penetration of cellular probe data vis-à-vis the traveling American public is characterized as follows:

- CDRs show 50–180 network interactions per device per day.
- Passive-signaling data include more continuous updates (every 15–60 minutes).
    - The device will interact with the cellular network when it is not actively being used if it is still turned on.
    - Combined approaches (using multiple pieces of metadata from these two mechanisms) maxed out at a sample penetration rate of 15–25 percent of the population (per Airsage) [Hard et al. 2016].
- Children, the elderly, and those without cell phones are underrepresented.
- Sampling bias results from differences in usage patterns (CDR) or network design (passive signaling).
    - The trade-off between these data types is that CDRs could ping more frequently but only when being used and passive signaling was less frequent but continuous. Both were only available where there were towers.
    - For rural areas, a phone would still produce a recordable signal (as long as there was a tower), but the spatial accuracy of its location was much more variable compared to records produced in urban areas.

6.3.7. Data Quality

Documented concerns about the quality and usability of cellular probe data include the following:

[9] Devices do not directly produce sightings—rather, sightings are derived by cellular companies and vendors from device signals and network interactions.

- Data quality depends on how each mobile phone carrier processes their CDRs and passive-signaling messages, the density of cell towers, and how each person uses their phone:
  - CDR data often miss short trips due to sparse sampling (i.e., if all trips occur within a single-tower area, then no trips are observed).
  - Passive data provide better trip detection but still lack precision (the level of precision can vary depending on tower density, ranging from 1 square mile to much lower densities in rural areas [e.g., county to county]).
- Temporal granularity of vendor products derived from the original CDR and passive-signaling messages is coarse, typically 3-hour bins at a minimum, due to vendor data expansion to population requirements.
- Road network routes cannot be traced, and network-level directionality cannot be assigned.
- Freight and commercial vehicles are difficult to detect and are, therefore, underreported.
- Trip purpose is easily misclassified, especially in college towns and shift-work communities.
- Home locations can be determined via a variety of mechanisms depending on the quality and availability of each type of cellular probe data message [Yang et al. 2021].
- Cellular data are susceptible to edge effects and false positives in peripheral zone boundaries, where sightings produced on the edge of a tower's zone could easily be picked up by a different tower and obfuscate its actual location.
- They require zone aggregation and custom validation to calibrate the results. Custom validation and calibration typically involve using a matrix-fitting operation called Iterative Proportional Fitting, which fixes values in a matrix to a known total, such as traffic counts. The process is iterative because it estimates initial expansion weights. From the initial estimate, the resultant error is calculated, and the process then recalculates the weight using the error until it minimizes a specified minimum error [Chigoy 2018, Hard et al 2016]. If external validation data are not available, which may be the case in some areas of study, this step is not possible.
- Iterative zone development with vendors is used to optimize pricing and cellular data collection (i.e., if not enough data were found for some zones, the users might have to aggregate their zones to a larger area).

7. TEMPORAL AND SPATIAL SCALES OF THE DATA

The following subsections characterize the historical, temporal, and spatial coverage, availability, and precision of cellular probe data.

7.1. Temporal Coverage

Details on the historical penetration and availability of cellular probe data in the United States include the following:

- Cellular probe data were only utilized and available between the early 2010s and 2016.
  - Whether the historic cellular data (CDR or passive-signaling data) are archived or still available for analysis is unknown.
  - This location information, available from cellular probe data, was not native to the data obtained from cell phone providers. Instead, location was determined by the data analytics vendors who purchased these data and applied specialized algorithms to the available data messages' attributes to infer a phone's position.

- Presumably both data types are still being collected but are no longer sold to analytics companies. They are available in certain international markets.
- A customer typically purchased 3–12 months of data, the amount of time needed to build up detectable patterns from the collected cellular data.
- OD data could only be calculated for data for a window of at least 3 hours (minimum needed to establish statistically defensible activity patterns).

7.2. Temporal Resolution

The precision of temporal information generated with cellular probe data varies slightly based on whether they were derived from CDRs or passive signaling:

- CDRs are highly irregular and depend on communication events.
- Passive data are more regular (15–60-minute updates).
- Neither format allows for continuous tracking.
- For OD analysis, a 3-hour period is smallest time increment.

7.3. Spatial Coverage

Details on the geographic coverage and availability of cellular probe data in the United States include the following:

- Higher data density is available in metro areas due to denser tower distribution (CDR and passive data).
- Rural areas suffer from poor coverage and lower accuracy due to limited cell-tower locations. In rural areas, most coverage will be along highways.

7.4. Spatial Resolution

Details on the precision of spatial information generated with cellular probe data include the following:

- Urban areas' average resolution is 250–1,000 feet.
- Suburban areas' average resolution is 1,500–3,000 feet.
- Rural areas' average resolution is 1–3 miles.
- Triangulated positions are more accurate than single-sector positions.
- These resolutions are not precise enough for intersection-level or mode-separated analysis.

8. USE CASES OF THE DATA

The following subsections list documented use cases and applications of cellular probe data, with specific attention given to those related to transportation planning and statistics.

8.1. Transportation Use Cases

Examples of transportation-centric applications of cellular probe data follow:[10]

- OD matrix development (travel between customer-specified zones): The objective of this analysis was to understand trips between each OD pair, by time-of-day, and purpose.
- Long-distance travel analysis: The objective of this analysis was to determine trips between cities and/or states. This type of analysis typically required the vendor to implement custom trip algorithms to filter out interim trips.
- External survey data collection (external–internal and internal–external trips were better than external–external trips): The objective of this analysis was to study where trips entered and/or exited a study area. This analysis typically required the customer to postprocess the data from the vendor to determine which probable routes the trips took.
- Event impact studies and special generator analysis: The objective of this analysis was to study the ODs and home locations of persons traveling to an event (for example at sports complex).
- Travel demand model validation and calibration: The data were used to help determine if the magnitude of the travel demand model distributions between origins and destinations conformed to external data.

8.2. Nontransportation Use Cases

Examples of nontransportation applications of cellular probe data follow:

- Retail site planning and selection or location theory
- Outdoor (billboards) advertising placement
- Emergency response and 911 calls
- Tourism activity

[10] The actual application of the data was unique in each analysis as each dataset was aggregated to zones that were defined by the customer.

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