T-Mobile USA, Inc.

Methodology for T-Mobile Drive Tests to Verify Compliance with T-Mobile/Sprint Merger Commitments

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I. INTRODUCTION

The Commission's order approving the license transfers associated with the merger of T-Mobile US, Inc. ("T-Mobile") and Sprint Corporation adopted as conditions commitments made by the Applicants in their *ex parte* filing dated May 20, 2019.[1] As described in the Order, one of those commitments requires T-Mobile to meet certain 5G network build-out commitments.[2] To verify the coverage area and speeds of its 5G service to determine compliance with the build-out commitments, T-Mobile committed to conducting a drive test utilizing a methodology mutually agreed to by T-Mobile and the Wireless Telecommunications Bureau ("Bureau").[3]

This document describes the methodology agreed to by T-Mobile and the Bureau, which T-Mobile will utilize to conduct drive tests following the third and sixth anniversaries of the merger's closing.

As described herein, T-Mobile will drive dense drive routes covering populated areas and major and minor roads. T-Mobile will drive approximately 1 million miles, more than five times the industry average (approximately 220,000), resulting in extensive testing in both urban and rural areas.

Stationary and mobile speed measurements will be taken in 500-meter grids that cover about 99.5% of the population, including 98% of the rural population. Approximately five million speed measurements, more than ten times the industry average (approximately 500,000), will be taken at different locations and in diverse network conditions to quantify delivered speeds. Measured data will be mapped to unique 500-meter grids in Census blocks containing population across the entire country, and the population of each Census block will be associated with the average speed across all speed-tested grids in the Census block. Note the population reference is derived from the 2016 Pitney Bowes study, which provides population at the Census block level based on the 2010 U.S. Census but updated based on more recent information.[4]

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[1] *Applications of T-Mobile US, Inc. and Sprint Corporation*, Memorandum Opinion and Order, Declaratory Ruling, and Order of Proposed Modification, WT Docket No. 18-197, FCC 19-103 (Nov. 5, 2019) ("Order").

[2] *Id.* at App. G, Att. 1.

[3] *Id.*

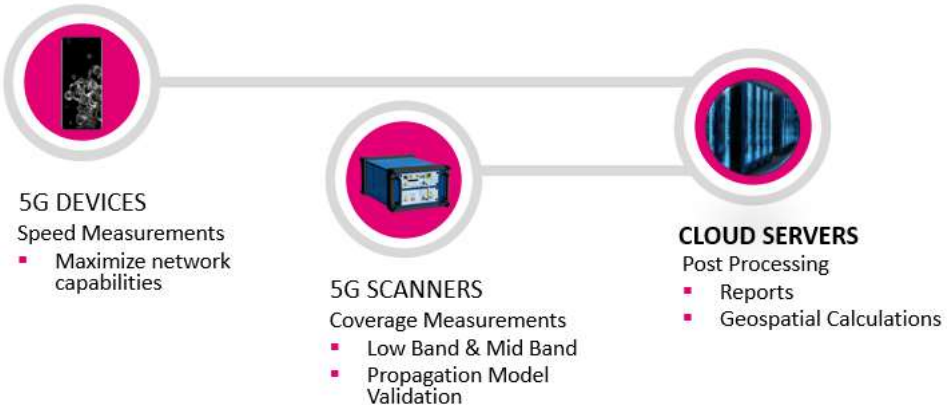
[4] *See* Letter from Nancy Victory, Counsel to T-Mobile, and Regina Keeney, Counsel to Sprint, to Marlene H. Dortch, Secretary, FCC, WT Docket No. 18-197, at 5-6 (filed May 20, 2019).

II. DRIVE TEST ROUTES

T-Mobile will set the routes to be driven throughout the country. The drive test routes will extensively cover the United States. These routes will go beyond just interstates and highways and T-Mobile will ensure that both rural and urban areas are covered. Dense drive routes will cover not only populated areas but extend to major and minor roads. Approximately 1 million miles will be driven (more than five times the industry known drive test norms), across the continental U.S., Hawaii and Puerto Rico. Along the drive routes, approximately five million speed measurements will be collected in both urban and rural areas. Note the below are not final drive routes.

III. DRIVE TEST EQUIPMENT & PLAN

Data will be collected using T-Mobile-Certified 5G devices as well as scanners to collect coverage measurements for both low- and mid-band independently. All drive tests will be performed during regular business hours to capture network performance and radio conditions under load. To calculate covered population, T-Mobile will make use of an RF propagation model to compute RSRP (Reference Signal Received Power) based on its ordinary course methodology at the time of the test. These types of predictions are used in ordinary business course to drive network investment. T-Mobile will provide these values with its test results. Coverage predictions are then overlaid into GIS mapping, with Census data, to calculate the population covered. Specifically, T-Mobile has chosen to work with address/population weighted block centroids licensed through Pitney Bowes as the most accurate method for tracking where people are. In Census Blocks where the coverage prediction covers the weighted centroid, the entire Census Block population will be counted toward the commitment metric; in Census Blocks where the coverage prediction does not cover the weighted centroid, none of the Census Block population will be counted toward the commitment metric.



Measurement Setup. Equipment setup will typically be comprised of one or more devices with a scanner configured to a standalone PC or with a logging software application on the device. Software installed on a PC or device is configured to run a specific test sequence. The test terminals (MS/UE) are usually positioned in the middle of the cabin, at the median of the side window's height, and equally spaced from each other. The scanner will have external antennas for receiver and GPS at the vehicle rooftop.

Measurement Instrumentation. General instrumentation is a third-party PC screen with route, levels, and message flow, with specific alerting on events. Internet-based servers are utilized for any specific throughput protocol testing (FTP/TCP/UDP). These servers are hosted in the public cloud, but third-party hosting or optional edge servers may also be utilized.

Changes in the next 3 to 6 years. The equipment models, hardware and software, are likely to change over the next 3 to 6 years due to technological improvements and T-Mobile will use the best available tools to support the latest network capabilities in use at that time.

Data Collection

Data Collection Methodology. All the scanner data will be collected with an external antenna, on-street/outdoor levels at vehicular speeds varying generally between 25-60 mph. The speed measurements performed will be in-car for both stationary and mobile measurements.

Data Collected. Devices (UE) can report all Layer2 and Layer3 information processed via the wireless chipset via streaming data flow or with certain information available within the device. A scanner is programmed to search only for selected frequencies and technologies, recording file logs typically for location (GPS), signal level, technology, serving cell/sector characteristics, signal quality, antenna paths, and other technology-specific signal embedded characteristics.

Synchronization Process of Data Collection. Both the phone and scanner will be connected to the same drive test software, so the measurements are automatically correlated and timestamped.

Data Collection Logistics and Mechanics

Logistics. The drive test team will continuously measure coverage through scanner equipment independently for both low- and mid-bands and manually trigger speed measurements when stopping at measurement locations and will initiate mobile speed tests when moving away from the stationary tests locations and the vehicle reaches the speed of surrounding traffic. There will not be a requirement to have separate teams for separate tasks, just separate teams covering different geographical areas, although T-Mobile may use separate teams if it is more efficient. There are no plans to drive roads in both directions or multiple times by design, but it may happen to some degree to cover intended grids.

Tracking Measured Sites. The drive testing software indicates the cell in which the speed measurement is being performed, which provides visibility to the drive test team.

Site outages. There will be a centralized support team to coordinate and communicate with drive test teams in case of planned or unplanned network outages that may affect areas being tested. All speed measurements are to be performed during regular business hours to capture network performance and radio conditions under load and avoid the network maintenance window.

Datasets and Samples

Deliverables. Apart from the shapefiles of low- and mid-band coverage areas, T-Mobile will provide: 1) scanner data export in no more than 4-second increments with measured RSRP per band along with its location coordinates; 2) speed measurements export with download speed values, test start and end location coordinates, RSRP of serving cell, network load for serving cell within hour of test, and bandwidth of serving cell and sector; 3) looked up speed measurements export with grid location, network load for dominant cell, and bandwidth of serving sector. Non-conforming results will also be provided to the Bureau with the exception of tests that fail due to equipment failure or human error.

Sample Requests. With continuous technology evolution, the output formats could change from today's examples. T-Mobile will provide a sample file to the Bureau before initiating the actual drive test.

Delivery Method. The datasets will be delivered to the Bureau in the same manner that large confidential data sets have been shared with FCC in previous engagements.

Speed Test Measurements. T-Mobile will make use of well-known industry speed measurement applications (*e.g.*, Ookla). The process will work as follows: 1) the application requests data from the server and measures the amount of bytes received; 2) depending on the type of application, it opens one or multiple connections to the server; 3) as data is transferred, the application aggregates the number of bytes transferred on all connections. Key parameters that will be collected to ensure the validity of the tests are technology type, site, frequency band, and signal information. There is no set file size for a test. By default, a continuous stream is used for the throughput test, which floods the connection with as much data as it can handle.

Test Parameters Collected

5G Network Features Visibility. The drive test software has visibility into the use of certain network features that are reported on layer 2 or layer 3 messages. The impact of such features is reflected in the results of the speed tests.

Collection of Data. Measurement location coordinates, frequency band(s), deployed channel bandwidth(s), and associated RSRP will be collected by the drive test software from the device on system information block (SIB) or layer 3 messages.

RSRP Scanner vs. Speed Measurement. The RSRP from the speed measurement may differ from a scanner because the latter will be using an external antenna and is not collected in network connected mode.

GPS Signal Challenges. External antennas for GPS provide great conditions for multiple satellite signal availability. In very dense urban areas, T-Mobile utilizes a GNSS dead-reckoning system that utilizes GPS in conjunction with direct auto-integration through automotive serial port to output a standard accurate GNSS signal output for the data collection software.

Site Loading and Correlation with Measurement

Sector Load Determination. Sector loading is measured from well-established network counters used for many purposes in the ordinary business course and are very reliable for determining usage of all subscribers connected to the sector. The sector load is not interpolated and is measured at every hour by the network. In cases of speed look up, the busy hour load of the dominant cell in the grid will be used, reflecting a worst-case scenario. The dominant cell is the cell sector that best covers the untested grid.

Correlation to Speed Measurement. Speeds are measured at the time of the measurement. The cell used and timestamp will be recorded for every speed measurement. During post processing, this information will be used to find the sector load value from the hourly network metrics.

Guidelines for Assessing and Processing Data. As part of the standard process of drive testing programs, the following is considered: 1) pre-drive verification of equipment, configuration, and sequence of testing; 2) set-up of alerts for issues with network performance during data

collection; 3) on-call support in case of issues; 4) system validation of log files collected; and 5) automated route acceptance, based on post-processing of drives against expected routes.

Handling Non-conforming Results. General validation revolves around route validation and performance versus expected. Failed tests will be validated for equipment issues. Discrepancies from expected performance will be checked against equipment and network issues. If the root cause of the non-conforming tests are immediately resolved, the retest(s) can be executed immediately and will use similar, if not the exact same, test conditions. At the post-processing phase, non-conforming results will be checked against network performance, key performance indicators (KPIs) at the time of fault, expected coverage, network outages/degradation, and capacity constraints.

IV. COVERAGE ASSUMPTIONS AND DATASETS

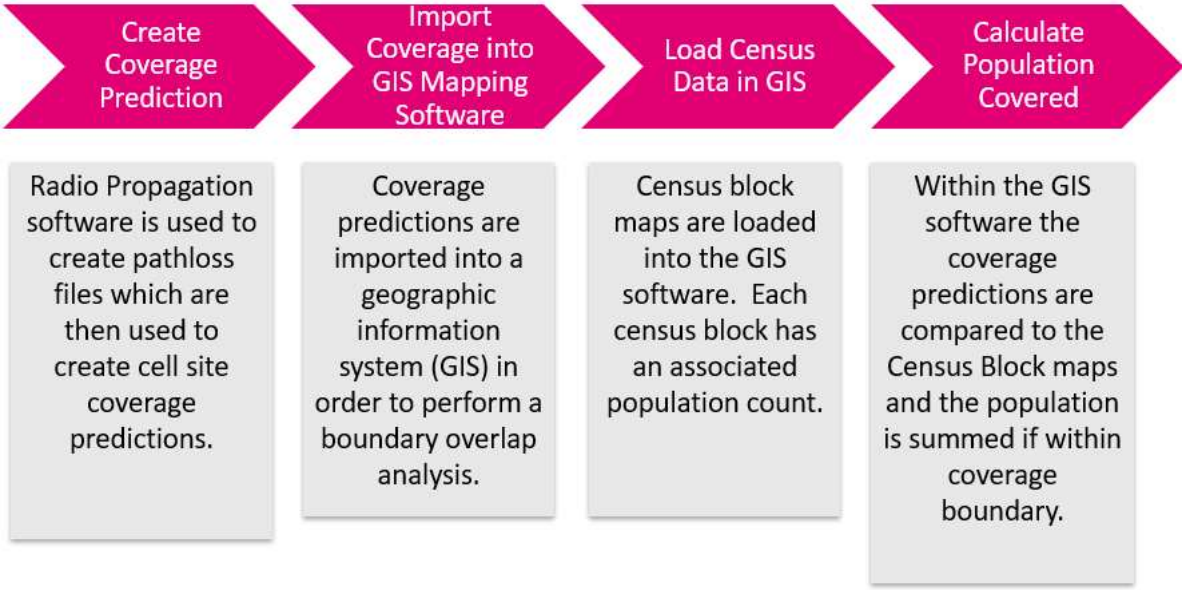
Assumptions. Beside link budgets, reliability, propagation, and loading, T-Mobile also will use a database of accurate site configurations, including antenna models, antenna heights, antennas azimuths, etc. that match the OSS. T-Mobile will also use high resolution geodata and building vector databases that represent current land usage information for each morphology that enhance the accuracy of the propagation predictions. Lastly, T-Mobile will use population-based traffic maps that improve loading assumptions and statistical analysis capability.

Calibration. T-Mobile will validate the accuracy of propagation models (market by market) using calibrated scan drive test data to ensure that the proper propagation model is assigned for each site in a market. Continuous Wave (CW) data will be used to tune models in advance before assigning to a site. User equipment (UE) data trace will be used to audit the accuracy of the models and assignments. Detailed propagation calibration audit reports will be submitted to the FCC.

Coverage Datasets. Coverage maps will be provided showing coverage at the 3-year and 6-year marks, consistent with the FCC commitments. Coverage maps will be generated for individual frequency bands and commonly aggregated into low-band and mid-band maps.

V. COVERED POPULATION CALCULATION

Verification of RF Propagation Models Using Drive Tests. RF propagation models compute expected receive signal across various geographies, incorporating path loss, clutter absorption, diffraction, and 3D variables like terrain and clutter height. Investments in the underlying geodata, such as clutter data, clutter heights, and vector data, improve the accuracy of propagation modeling. [redacted] Low-band and mid-band models behave differently, and T-Mobile will employ specific models for each frequency band. Field measurements from drive tests will be used to validate model accuracy.



VI. SPEED TEST POPULATION CALCULATION

Methodology Overview.

The U.S. geography will be divided into 500-meter grids. The grids containing Census block address-weighted centroids will be tested unless the Census block has a population of fewer than five people or the grid cell lacks accessible roads.

Census block is the smallest statistical unit of the U.S. Census and cover the entire territory of the United States, Puerto Rico, and the Island Areas. Census block address-weighted (or population-weighted) centroids intend to represent the location of the highest concentration of households within a Census block. T-Mobile has chosen to work with address/population weighted block centroids licensed through Pitney Bowes as the most accurate method for tracking where people are.

The total population of a grid cell is defined as the sum of the population of each Census block address-weighted centroid located within the grid.

Each grid cell containing at least one drivable road and at least five people will have a stationary and a mobile speed measurement. For cell grids without a drivable road, T-Mobile will perform speed measurements in a proxy grid, defined as the grid nearest to the population-weighted centroid that has accessible roads. About 2.3 million grids across the nation will have an associated speed test from actual field measurements. T-Mobile will create a reference matrix based on the millions of grids with measured speed and signal strength, associated network load, and bandwidth.

Approximately 0.6 million grid cells with fewer than five people won't be tested and will instead leverage the reference matrix. Their predicted signal strength, dominant sector bandwidth, and busy hour network load will be looked up against the measured data to get a speed value for the grid (*see* Section X). Over five million speed measurements will be taken at different locations and under diverse network conditions. These will quantify the delivered speeds for each tested grid, as a weighted average of stationary and mobile speed.

The population of each grid cell will be associated with the calculated grid(s)' speed. The nation's population will be summed up against delivered grid speeds meeting the commitment targets and categorized as urban or rural following each Census block population classification split.

VII. ROADWAY AND STATIONARY MEASUREMENT LOCATION SELECTION

Roadway Selection. T-Mobile will utilize Pitney Bowes' latest roadway vectors available, among other supporting roadway geospatial databases, to define optimum drive test routes in between stationary test locations. Whenever possible, T-Mobile will utilize a route towards an edge of the grid cell that is not the nearest edge to the tested centroid. Measurements will be conducted along the drive routes where the drive test team will stop to run stationary speed measurements.

Stationary Measurement Location Selection. One stationary speed measurement will occur within the 500-meter grid in which the population-weighted centroid (as determined by Pitney Bowes data) is located for the Census block. The stationary measurement will occur as close to the centroid as possible, taking into account drivable roads and safety precautions. If a grid cell contains more than one pop-weighted centroid, then the measurement shall be performed as close as possible to the centroid with the greatest population. Certain large rural Census blocks may have measurements taken within one or two additional grids (discussed in Section IX below).

For each measured proxy grid cell that does not contain a population-weighted centroid, the stationary measurement shall be conducted as close as possible to the grid cells' geometric centroid, taking into account drivable roads and safety precautions.

Each grid containing at least one drivable road and at least 5 people will have a stationary and mobile speed measurement. For grids without a drivable road, T-Mobile will perform a stationary speed measurement in the grid nearest to the population-weighted centroid that has accessible roads.

Measured vs. Cell Sites. Each grid area has a dominant serving cell site associated with it, so T-Mobile can estimate which site is likely to be measured for every grid and make sure all serving macro cell sites are measured. The dominant cell is defined as the cell sector that best covers the grid.

VIII. MOBILE SPEED MEASUREMENT

Methodology. T-Mobile will also perform a mobile speed measurement in each grid in which it performs a stationary speed measurement (mobile measurements will begin in the same grid as the stationary measurement but may finish in an adjacent grid). As a rule of thumb, the mobile measurement will begin once the vehicle has reached the speed of traffic on the road, driving away from the stationary speed measurement location and on a route towards an edge of the grid cell that is not the nearest edge to the tested centroid. This is applicable to both grids that have population-weighted centroids and proxy grids.

As T-Mobile has consistently noted, mobile speed measurements are inherently complex and difficult to replicate. A mobile speed measurement generally can take between 30 to 60 seconds to complete. Within the very small 500-meter grids used, the mobile speed measurement will start in the targeted testing grid but may end in a neighboring grid. The mobile speed measurement start location will be used to associate it with a grid cell and subsequent calculations of combined grid speeds.

IX. LARGE RURAL CENSUS BLOCK METHODOLOGY

In rural Census blocks with areas greater than or equal to 1.5 square miles, T-Mobile will conduct testing in one or two grids in addition to the centroid grid. For Census blocks greater than 10 square miles, T-Mobile will conduct tests in two additional grids. For Census blocks between 1.5 and 10 square miles, T-Mobile will conduct tests in one additional grid.

Identifying Developed Grids

T-Mobile will utilize the National Land Cover Database (NLCD 2016 or the latest version of this database available six months prior to the start of the drive test) land use dataset that has nationwide data on land cover at a 30-meter resolution (web site: https://www.mrlc.gov/data) to find "developed" bins (areas with development) and rank them by the amount of development, with the most developed grids to be selected for additional testing. NLCB-defined low, medium, and high intensity development areas will be used to define "developed" bins.

- **Developed, High Intensity** - Includes highly developed areas where people reside or work in high numbers. Impervious surfaces account for 80 to 100 percent of the total cover.
- **Developed, Medium Intensity** - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 to 79 percent of the total cover.
- **Developed, Low Intensity** - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 to 49 percent of the total cover.

A "developed score," which is the weighted sum of developed 30-meter land use bins in a 500-meter grid, will be used to rank and identify the most developed grids. The weights for each developed class follow their class definitions for relative percent of impervious surface cover.

- **High Intensity Weight = 4 | Medium Intensity Weight = 2.5 | Low Intensity Weight = 1**

"Developed, Open Space" class will be used as a backup if there are no low, medium or high developed classes in the Census block. If there are no developed grids in the large Census block, the speed measurement would be restricted to the original centroid grid.

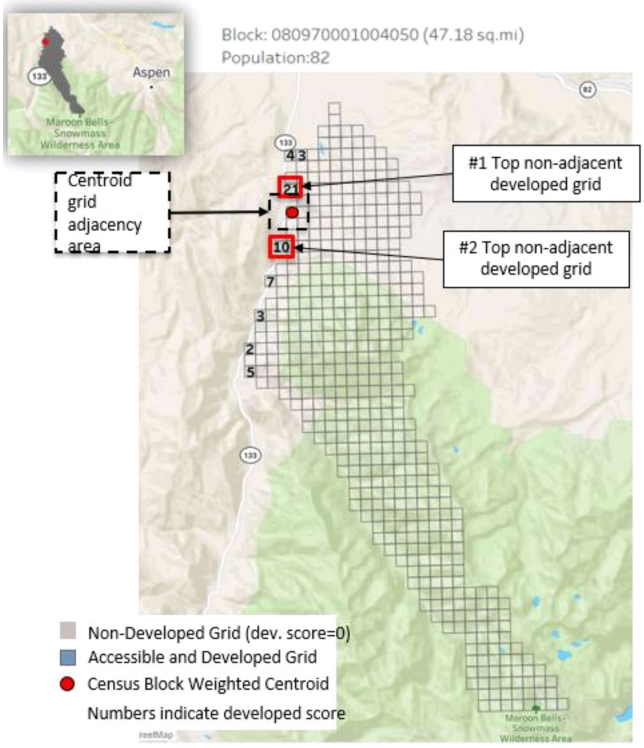
Selection of Additional Testing Grids in Large Rural Census Blocks

Data Sets. Pitney Bowes Street Pro roadway vectors will determine the accessibility of the grid cell. Land use dataset will be used to identify population concentrations and to measure the "developed score."

The Land Use dataset will be overlaid with 500-meter grid cells. 500-meter grids cells will be classified as "eligible" if they meet both of the following conditions: 1) the grid is accessible; 2) the grid has "developed land-use" in the open, low, medium, or high intensity classes.

Selecting Additional Testing Grids. T-Mobile will sort eligible grids in descending order by developed score**,** high, medium and low intensity counts. For Census blocks greater than 10 square miles, T-Mobile will select the two most developed grids non-adjacent to the centroid grid and non-adjacent to themselves. Adjacent grids would only be selected if there are no non-adjacent grids. For Census blocks between 1.5 and 10 square miles, T-Mobile will select the most developed grid non-adjacent to the centroid grid. Adjacent grids would only be selected if there are no non-adjacent grids. Grids must be at least 50% contained in the large rural Census block to be subject to additional testing, and not contain a *pop-weighted centroid of a different Census block*.

An example of the process for selecting additional testing grids is set forth below.



a) Identify eligible grids:

- Accessible and developed grids identified in blue.

b) Sort eligible grids descending by developed score, along with adjacency status relative to centroid grid.

Grid_ID	Developed Score	Adjacency Status
08367695	21	Not Adjacent
08366702	10	Not Adjacent
08365707	7	Not Adjacent

c) Select the most developed grid non-adjacent to the centroid grid. In this example, since area larger than 10 square miles two additional grids will be selected.

Grid_ID	Developed Score	Adjacency Status
08367695	21	Not Adjacent
08366702	10	Not Adjacent
08365707	7	Not Adjacent

X. GRID AND CENSUS BLOCK SPEED

Tested Grids. The speed attributed to a tested grid will be calculated as a weighted average across stationary and mobile test measurements – 75% of the grid stationary speed measurement plus 25% of the grid mobile speed measurement – reflecting ordinary T-Mobile customer usage. For example, a grid with stationary speed measured at 200 Mbps and mobile speed at 185 Mbps will have a combined grid speed of (0.75 x 200 Mbps) + (0.25 x 185 Mbps) = 196 Mbps. If there are multiple grids tested in a Census block (refer to Section IX), the Census block speed will be the average of the calculated speed in each tested 500-meter grid. If the Census block speed meets or exceeds the commitment, all the population in the Census block would be counted towards the commitment; if it does not exceed the commitment, none of the population in the Census block would be counted.

Non-tested Grids. Very few grids with population will not be tested; untested grids will be solely those that have fewer than five people. To derive a speed for those, non-tested grids will be checked against the coverage prediction tool and network load report. A coverage prediction tool will provide predicted dominant cell and predicted signal conditions. Once the dominant cell is identified, the Cell Sector Network Load Report will provide bandwidth and busiest hour network load. The speed for non-tested grids will be derived from the reference matrix, with T-Mobile selecting the lowest download speed from grids that match in terms of signal strength to the nearest whole integer, associated network load to nearest whole integer percent, and bandwidth.

XI. THIRD PARTY OVERSIGHT

Prior to commencement of drive testing, T-Mobile will provide the Bureau with a slate of candidates to provide independent third party oversight. The Bureau will have 30 days to object to any of the listed candidates after which time T-Mobile will select the independent third party from the list of accepted candidates. The independent third party that will provide oversight to ensure that the nationwide drive test is conducted in accordance with the methodology agreed to with the Bureau, including:

- Review of drive test equipment to be used.
- Review of instructions provided to drive test teams.
- Review of randomly selected drive test data to ensure accurate post-processing of data.
- Review of randomly selected post-processed results to ensure accuracy of information provided to the Bureau.

T-Mobile will notify the Bureau of the identity of the third party before commencing the start of the drive test.

XII. DELIVERABLES

Within 9 months following each of the third and sixth annual anniversaries of the closing date of the T-Mobile/Sprint merger, T-Mobile will submit to the Bureau a report that will include the following:

- Drive Test Results:
  - Scanner data export: measured RSRP per band along with its location coordinates.
  - Speed measurements export: type of test (stationary or mobile), download speed values, test start and end location coordinates, RSRP of serving cell, network load for serving cell within hour of test (see Appendix A for sample deliverable dataset).
  - Drive test routes.
- Polygon shapefiles showing T-Mobile Low-band 5G Coverage Area and Mid-band 5G Coverage Area as of the 3-year or 6-year date (whichever is applicable).
  - The associated link budget and RSRP value used to create coverage polygons.
- A statement quantifying the U.S. Population and Rural Population covered by each of the Low-band 5G Coverage Area and Mid-band 5G Coverage Area as of the 3- year or 6-year date (whichever is applicable) along with national and rural population with download speeds greater than 50 and 100 Mbps.
- A list of 5G Sites (including information identifying individual sites; *see* Appendix A for sample deliverable dataset) and spectrum deployed, broken into rural and non-rural categories.
- Non-conforming results will be provided to the Bureau with the exception of tests that fail due to equipment failure or human error.
- A certification from the T-Mobile Chief Technology Officer that the representations in the shapefiles, population coverage numbers, site and spectrum deployment numbers, and speeds are true and correct.

With the exception of the certification, the above deliverables (and any supporting or related network and/or test data) will be afforded confidential treatment pursuant to the relevant provisions of Part 0 of the Commission's Rules.

APPENDIX A: Sample Deliverable Datasets

Stationary speed measurement data will include:

- Test_ID
- Date_Time
- Grid_ID
- ServingCell_ID
- Latitude, Longitude
- Technology
- ServingCell_Band1
- ServingCell_Bandwidth1
- ServingCell_RSRP1
- ServingCell_Load1
- All other secondary cells being used as supported during the stationary measurement:
    - ServingCell_Band2, ServingCell_Bandwidth2, ServingCell_RSRP2, ServingCell_Load2
- DL_Speed

Mobile speed measurement data will include:

- Test_ID1
- Date_Time_Start
- Date_Time_Stop
- Grid_ID_Start
- Grid_ID_Stop
- ServingCell_ID_Start
- ServingCell_ID_StopLatitude_Start
- Longitude_Start
- Latitude_Stop
- Longitute_Stop
- Technology1
- ServingCell_Band1
- ServingCell_Bandwidth1
- ServingCell_RSRP1
- ServingCell_Load1
- All other secondary cells being used as supported during the mobile speed measurement:
    - Technology2, ServingCell_Band2, ServingCell_Bandwidth2, ServingCell_RSRP2, ServingCell_Load2
- DL_Speed

5G site data will include:

- Site ID
- Latitude
- Longitude

- Number of Sectors
- Sector Azimuths
- Site Type
- Urban-Rural Classification
- Site Height
- Antenna Height
- Backhaul Medium
- Backhaul Capacity
- Deployed 5G 600 MHz
- Deployed 5G 700 MHz
- Deployed 5G 800 MHz
- Deployed 5G PCS
- Deployed 5G AWS
- Deployed 5G BRS
- Deployed 5G EBS
- Deployed 5G C-Band
- Deployed 5G CBRS
- Deployed 5G mmW