2016

South Carolina Mobile Broadband Performance Study:

A more precise view of mobile broadband availability and reliability in South Carolina

October 24, 2016

COSTQUEST ASSOCIATES | ECONOMIC RESEARCH & ANALYSIS

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EXECUTIVE SUMMARY

INTRODUCTION

CostQuest Associates has been asked by U.S. Cellular to independently assess the ground realities of availability and speeds of mobile broadband in South Carolina. CostQuest developed a plan and drive test scenarios for assessing mobile broadband and retained the services of RootMetrics® to conduct the drive tests and deliver data. The results of this mobile performance assessment project are presented herein. Given this was an independent study, U.S. Cellular was not involved in any aspect of the design or presentation of results.

Drive testing of mobile networks in the U.S. has generally been focused on metropolitan areas and primary roadways. If there have been significant efforts to test network reliability in rural areas, the results have not been made public. Given the lack of data on service availability and broadband speeds, this initiative presented a first-step opportunity to inform the discussion. The following paper presents a high-level overview of multiple efforts to gather and benchmark data that will hopefully support a better understanding of customer experience with mobile broadband across varied geographies.

OVERVIEW OF ASSESSMENT EFFORTS

RootMetrics®, an independent mobile analytics firm which offers scientific insights into how users experience networks under real-world conditions, was retained and asked to perform dedicated drive testing to assess availability and throughput of mobile broadband for two specific areas in South Carolina. RootMetrics® was asked to test network characteristics, including availability and throughput, for the four largest carriers serving South Carolina, AT&T, Sprint, T-Mobile, and Verizon. CostQuest also obtained South Carolina drive test data from a recent statewide project RootMetrics® had conducted.

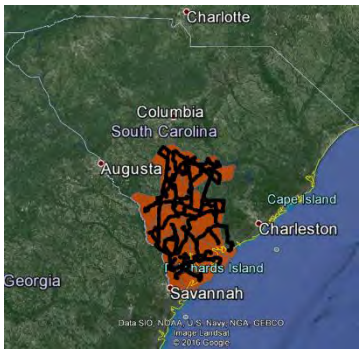
We have aggregated the test results for all four carriers specifically for this report. No carrier-specific tests will be shown - if for no other reason than to avoid having this data support another TV advertisement featuring giant maps or balls rolling down a ramp.

Three Separate Efforts

Three drive test studies were conducted. The first study was conducted independently by RootMetrics® as part of a greater project aimed at measuring mobile broadband speeds and availability in more populated centers and heavily-traveled roads across South Carolina. The second study was conducted under the direction of CostQuest and focused on regional coverage away from metropolitan centers. The third study, also directed by CostQuest, was a more thorough benchmarking project concentrated on rural roads in just one county within the same region in southeast South Carolina as the second effort. The following is a summary of the three studies.

Study 1 – South Carolina Statewide Non-Rural Benchmarking

Description: An assessment of mobile performance in major cities and towns across the entirety of South Carolina, and the roads connecting them.
Carriers Benchmarked: AT&T, Sprint, T-Mobile and Verizon
Dates: March 12, 2016 – March 17, 2016
Test Cycle: 7.5 minutes between tests
Total Test Points: 5,817



Study 2 – Regional Benchmarking in SE South Carolina

Description: An assessment of mobile performance along major roads in seven counties in the southeastern portion of South Carolina.
Carriers Benchmarked: AT&T, Sprint, T-Mobile and Verizon
Dates: May 2, 2016 – May 6, 2016
Test Cycle: 7.5 minutes between tests
Total Test Points: 4,086

Study 3 – Rural County Benchmarking in Orangeburg County

Description: An assessment of mobile performance on rural roads in a largely rural county in southeastern South Carolina.
Carriers Benchmarked: AT&T, Sprint, T-Mobile and Verizon
Dates: June 30, 2016 – July 2, 2016
Test Cycle: 1.5 minutes between tests
Total Test Points: 9,993

Overview of Drive Testing Methodology

RootMetrics® pairs engineering expertise with statistical methodologies to design network performance tests, collect data on mobile network performance that reflects a consumer's experience, and employ statistical techniques to determine results. This approach ensures that all networks are measured on a level playing field, without bias, allowing RootMetrics® to provide real-world data that confirms or challenges mobile performance metrics that are otherwise only theoretical or based on ideal conditions.

Testing Network Access and Data Throughput

The RootMetrics® testing methodology represents the consumer experience of downloading and uploading data, among other network activities. Employees of RootMetrics® called Scouters collect test samples. Mobile performance testing is conducted with a proprietary application that measures network performance across mobile network operators simultaneously. The application is installed and run on

advanced off-the-shelf smartphones available to the public at the time of testing. A different mobile network operator services each device, and each device runs the application to test data performance. Testing is conducted while driving, virtually no indoor testing was done in support of this effort.

The application focuses its testing around data (download & upload throughput testing). To evaluate download and upload throughput performance, the RootMetrics® testing application attempts to open and maintain 4 simultaneous HTTP connections to measure the total bytes transferred during the test period. Download and upload throughput reliability and speed are measured during testing.

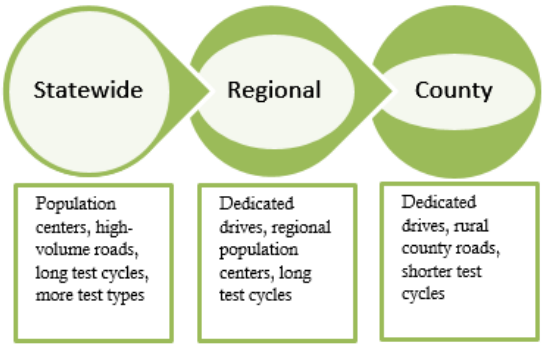
At the beginning of a shift, each Scouter is provided with a list of test locations, which have been randomly selected in advance using an algorithm, refined by RootMetrics® Field Operations Management. Performance is measured while driving. Before collecting samples, Scouters complete a pre-test checklist to ensure that all testing equipment is configured and operating correctly. All data is sent to secure servers at RootMetrics® to be processed, aggregated, and analyzed.

Typically, drive tests are conducted along freeways, major arterials, and residential streets where the population within a market generally lives and travels. However, for this effort, drive testing was done outside of metropolitan areas and on rural roads as well.

Timing of the data collection period is scheduled to measure performance during representative usage periods. Therefore, testing is not conducted during major holidays, extreme weather, or during periods of significant population migration effects.

Summary of Findings

It's important to understand how the study results differ given the varied geographic footprints, road types and a population density of the three separate drive test studies. Results of the studies are shown in aggregate (all three studies together), comparatively, and separately. Earlier drive testing results influenced the design of each subsequent study. As data was analyzed from earlier studies, identified findings allowed us to focus our next efforts on areas, roads and test types that could shed some light on ground realities.



Note on Road Classifications

As one reads the below summary on findings from these drive testing efforts, it's important to understand some basics about roads and road categories. We performed drive tests on various road classifications defined by the U.S. Census Bureau, using Feature Class Codes. These codes identify the types and uses of roads and paths of travel. Below is a table showing the types of roads driven for these drive test efforts. While there are 15 road classes, the test points for all of these drive test efforts predominantly fell into three main road categories. Other classifications, including private roads, vehicular trails (4WD), walkways, alleys and paths/trails were not the focus of these tests. Any tests falling into these other classifications will be shown as "other roads" in the reporting output.

S1100	Primary Road	Primary roads are generally divided, limited-access highways within the interstate highway system or under state management, and are distinguished by the presence of interchanges. These highways are accessible by ramps and may include some toll highways.
S1200	Secondary Road	Secondary roads are main arteries, usually in the U.S. Highway, State Highway or County Highway system. These roads have one or more lanes of traffic in each direction, may or may not be divided, and usually have at-grade intersections with many other roads and driveways. They often have both a local name and a route number.
S1400	Local Neighborhood Road, Rural Road, City Street	Generally a paved non-arterial street, road, or byway that usually has a single lane of traffic in each direction. Roads in this feature class may be privately or publicly maintained. Scenic park roads would be included in this feature class, as would (depending on the region of the country) some unpaved roads.

Figure 1: USCB Tiger Road Class Summary

NETWORK RELIABILITY BY STUDY

While availability and speeds appear good at the statewide level, results deteriorate as you move down in geography. The measurement of reliability is generally seen in the following results as successful connections to a mobile network at download speeds of greater than 4Mbps.

Connection Success

The degradation of reliability is notable as the drive tests moved from population centers (Study 1) and primary roads (Study 2) to more rural areas (Study 3). It is also clear that the rate of successful connections at speeds greater than 4Mbps down is lower on secondary roads outside of cities and towns (CDP's), as compared to major roads. The chart below shows the download and upload success rates by study. Study 1 (statewide) is broken out between population centers and roads. Note that throughput results are based on tests that were able to establish a connection (access success).

Connection Attempts by Study	STUDY 1 – SOUTH CAROLINA STATEWIDE NON-RURAL BENCHMARKING	STUDY 2 – REGIONAL BENCHMARKING IN SE SOUTH CAROLINA	STUDY 3 – RURAL COUNTY BENCHMARKING IN ORANGEBURG COUNTY	GRAND TOTAL
Total Number of Connection Attempts	26,321	24,341	76,000	126,662
Total Number of Successful Connections	23,194	16,286	39,349	78,829
Percent Successful Connections	88%	67%	52%	62%

Figure 2: Connection Attempts by Study

Connection Success by Road Classification

The table to the right shows the rate of success for network connections by road classification. The results show that once a user turns off a primary road, the likelihood of having a successful connection drops dramatically.

In addition to showing throughput for download tests it is also important to note where failed connections occurred. The below map show failed connections across the all areas tested.

Road Classification Code	**Percent Successful Connections**
S1100	90%
S1200	63%
S1400	56%
Other Roads (S1740, S1780, S1630, S1640)	82%

Figure 3 - Connection Success by Road Class

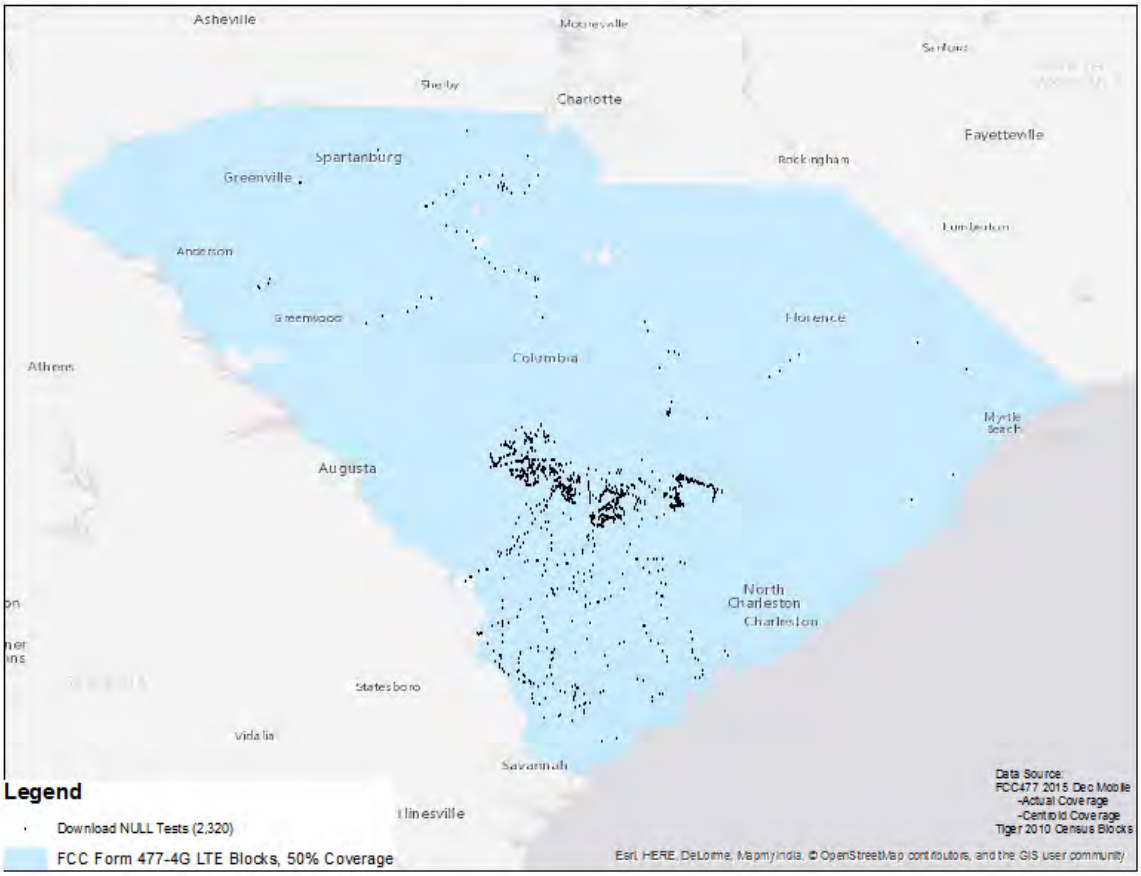


Figure 4 - Connection Failures - All Studies

Access Success

In addition to determining whether test equipment was able to connect to the network, additional testing was done on the throughput once connected. Throughput success can be measured by the ability for data to be transferred via upload or download. This "Access Success" was measured for all tests where connections were made.

Access to Network by Road Classification	STUDY 1 – SOUTH CAROLINA STATEWIDE NON-RURAL BENCHMARKING	STUDY 2 – REGIONAL BENCHMARKING IN SE SOUTH CAROLINA	STUDY 3 – RURAL COUNTY BENCHMARKING IN ORANGEBURG COUNTY	GRAND TOTAL
S1100	99%	95%	N/A*	97%
S1200	92%	84%	78%	83%
S1400	96%	74%	75%	79%

**No access tests were completed on S1100 roads in Study 3. Road miles driven in this study were immaterial.*

Figure 5 - Access Summary by Road Classification and Study

Results In and Out of CDP's

Throughput

For all three studies, drive testing was done inside and outside of city and town boundaries (CDPs). Results show that, across all three studies, there was a difference in throughput for tests in and out of CDPs. The table below shows the throughput differences between download tests inside and outside of CDPs.

City/Town or Between	Road Class	Total Download Tests	Total Tests w/ Speeds < 4Mbps (Down)	Percent Tests w/ Speeds < 4Mbps (Down)
Tests Inside City/Town Boundaries (CDP)	S1100	48	18	38%
	S1200	1,432	314	22%
	S1400	1,823	420	23%
	Other Roads	41	14	34%
	All Roads	3,344	766	23%
Tests Outside City/Town Boundaries (CDP)	S1100	255	54	21%
	S1200	2,652	948	36%
	S1400	3,612	1,551	43%
	Other Roads	67	24	36%
	All Roads	6,586	2,577	39%

Figure 6 - Download Speeds by CDP Location

Signal Strength

Across all studies the drive tests showed that 23% of tests failed to achieve 4Mbps down within CDP's, while nearly 40% of tests from roads outside were below that threshold. It's also notable that for the tests outside of CDP's, the more rural roads (S1400) fared the worst in terms of speeds.

Yet another way of measuring relative service quality from the perspective of access to the network is in signal strength. The drive tests gathered data on signal power received upon connection to a network. This is measured in the ratio of power in decibels per milliwatt (dBm). A dBm power level closer to zero (less negative) indicates a stronger signal. The table below shows that the signal strength outside of CDPs (cities and towns) averages lower than within CDPs. Recognizing that a mobile signal deteriorates as dBm goes lower on the negative scale, the results are notable.

Average Signal Strength in dBm	STUDY 1 – SOUTH CAROLINA STATEWIDE NON-RURAL BENCHMARKING	STUDY 2 – REGIONAL BENCHMARKING IN SE SOUTH CAROLINA	STUDY 3 – RURAL COUNTY BENCHMARKING IN ORANGEBURG COUNTY	GRAND TOTAL
Tests Within CDP Boundaries	-98.6	-101.5	-96.9	-98.4
Tests Outside of CDP Boundaries	-101.1	-105.1	-105.7	-104.6
Grand Total	-99.6	-104.2	-103.4	-102.4

Figure 7 - Signal Strength (dBm) by CDP Location and Study

Results by Pop Density

Based on the results shown above, one can surmise that areas with lower population density tend to have service with lower throughput (4Mbps or less). This is further supported by throughput by density. The table below shows the average population density for Census Blocks where the tests occurred.

Speed Test Results	Average Population Density			
	Test 1 - Statewide	Test 2 - Regional	Test 3 - County	Grand Total
Less than 4Mbps Down	556 per Sq Mi	124 per Sq Mi	181 per Sq Mi	235 per Sq Mi
Greater than 4Mbps Down	758 per Sq Mi	239 per Sq Mi	382 per Sq Mi	472 per Sq Mi
All Tests	**693 per Sq Mi**	**186 per Sq Mi**	**277 per Sq Mi**	**362 per Sq Mi**

Figure 8 - Pop Density by Download Speed Tier

BENCHMARKING RESULTS BY TEST EFFORT

CostQuest applied an iterative process to this assessment of mobile broadband service availability and throughput. The three separate studies have provided us with not only interesting and varying results but also a much better view on how one might conduct future efforts for the purposes of policy making. Study 1 was a statewide effort, Study 2 was regional and Study 3 was for just one county. As the geographic areas driven grew smaller, the test cycle shortened and yielded more test results. For example, the statewide effort (Test 1) resulted in just over 5,800 tests, while the drive testing in Orangeburg County resulted in nearly 10,000 tests. Conducting tests in this manner allowed the CostQuest and RootMetrics® teams to adjust test cycles (from 7.5 minutes in Study 1 and Study 2, to 1.5 minutes in Study 3) and drive plans as we learned more about the data. This approach also allowed us to narrow our focus on areas where service availability and speeds where intuitively going to be in question, that is, at the cell edge.

TEST 1 – SOUTH CAROLINA STATEWIDE NON-RURAL BENCHMARKING

The first drive test study can be characterized as an assessment of mobile performance in cities and towns across the entirety of South Carolina, and the major roadways between them. That is, there was a concerted effort to drive test areas where a large majority of South Carolina's population lives and works. This effort can actually be seen as two separate assessments, 1) drive testing within the boundaries of CDPs and, 2) drive testing the main roads between these population centers. The results yield a look at what mobile broadband consumers can expect in terms of availability and throughput in predominately non-rural areas.

Overall Results

As one might expect, the results of the drive tests in these more populated and well-traveled areas show that 4G/LTE service is generally available to support demand in population centers and the primary roads between those places. That being said, there are clear differences in service availability and speeds that are shown in the FCC's Form 477 data and the data gathered from drive tests.

The map below shows the plotted tests with colors indicating speed tiers. The background of this map shows FCC Form 477 service availability (based on the Actual Area approach) for all four carriers tested in this benchmarking effort. While the FCC does not publicly report actual speeds of carrier networks, the Form 477 availability seen in the below maps represents advertised coverage at 4G LTE speeds. Based on the drive testing results, there appears to be service of 10Mbps available to most population centers and major roads. However, there are a notable number of drive tests showing speeds less than 4Mbps. Many of these tests show up in areas that are shown to be served according to Form 477 data.

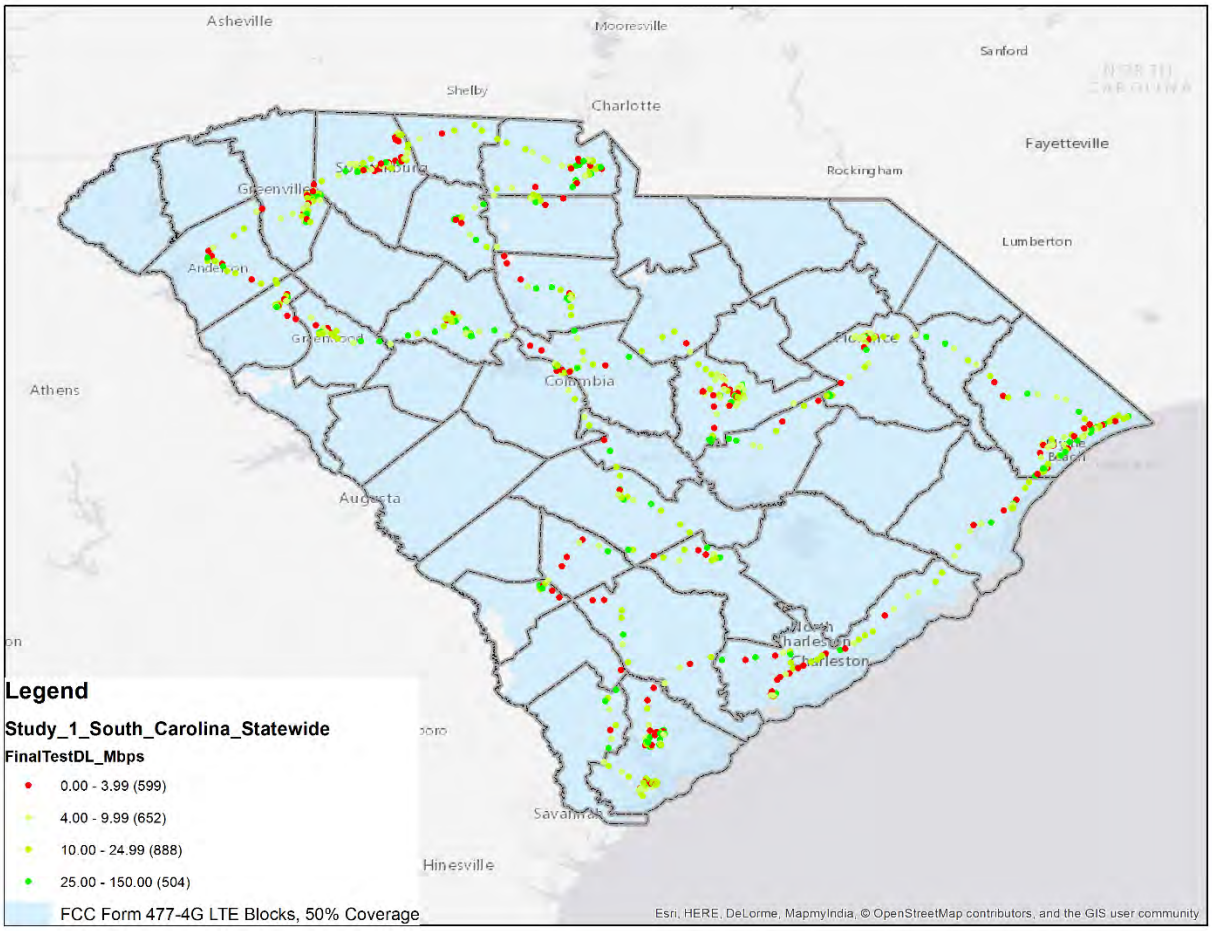


Figure 9 - Statewide Benchmarking Throughput Results w/ 477 Overlay (w/o Connection Failures)

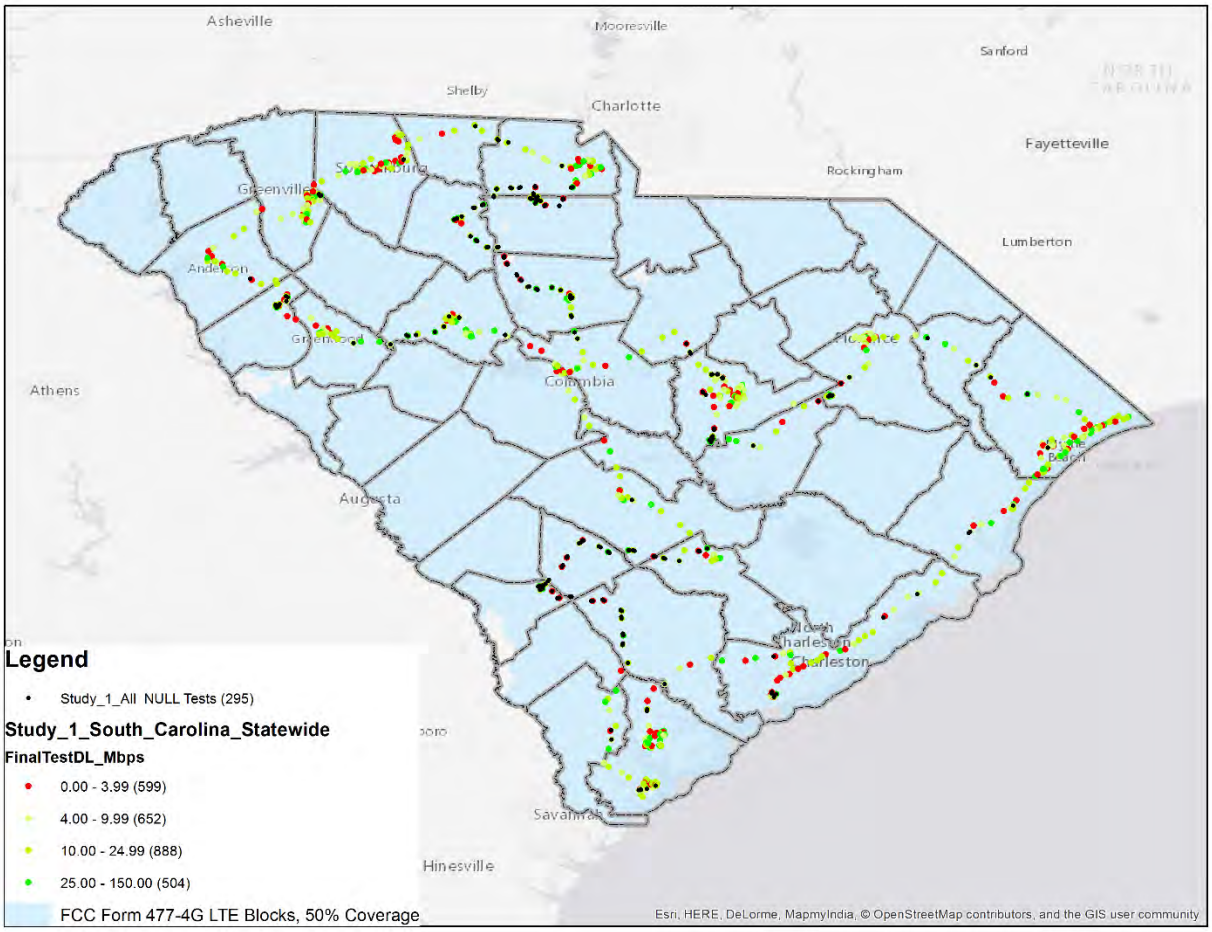


Figure 10 - Statewide Benchmarking Throughput Results w/ 477 Overlay (with Connection Failures)

Coverage Comparison the FCC Form 477 Data

Even with what can be described as generally good LTE service availability in these populations centers and well-traveled roads, there is a difference between what the Form 477 data shows as served and what the consumer experience is on the ground. This benchmarking effort took the drive testing team through over 1,100 unique Census Blocks on their 5-day drive. Of those 1,100 blocks, the team collected download speeds in 679. The Form 477 data, using the Actual Service Area approach, shows that there is coverage present in every one of those census blocks. However, the drive test results show that there was at least one test showing speeds below 4Mbps in over 500 of those blocks. This does not include tests that showed no connection or lack of availability.

Tested Speeds	Census Block Count
Presence of Tests <4Mbps	504
Total CB's w/ Download Tests	679

Figure 11 - CB Count by Download Speed Threshold for Study 1

TEST 2 – REGIONAL BENCHMARKING IN SE SOUTH CAROLINA

The second study applied the same drive testing approach as the first, but focused tests in one region within South Carolina. This region contains 7 counties in the southeastern corner of South Carolina. This effort was conducted to collect more data points (tests) and learn more about what the differences might yield when testing was done in an area where a person may typically travel during a typical week.

Overall Results

This regional study represented a wider range of roads and geography types than did the statewide study. With that, we see measurable differences in network reliability metrics. There are clear corridors of concern for accessing networks at broadband speeds across the 7 counties tested in Study 2. While there are many tests that resulted in low speeds or failure in those areas that show no advertised coverage in the FCC data, there are also many roads that show poor results in areas where the 477 data shows service availability for LTE. The results show a larger failure rate with network connections, more Census Blocks with connection failure within them, and lower download speeds outside of CDPs and on rural roads.

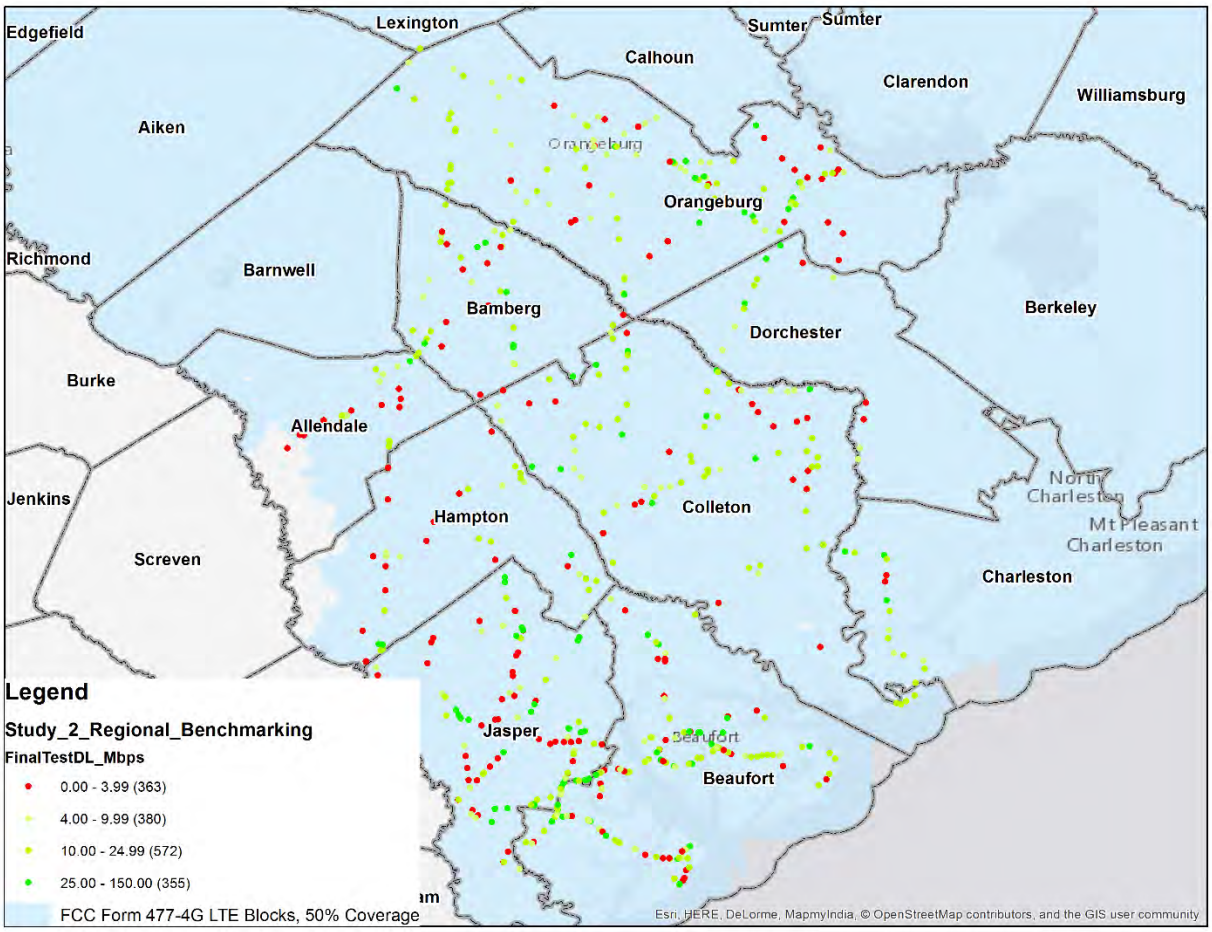


Figure 12 - Regional Benchmarking Throughput Results w/ 477 Overlay (w/o Connection Failures)

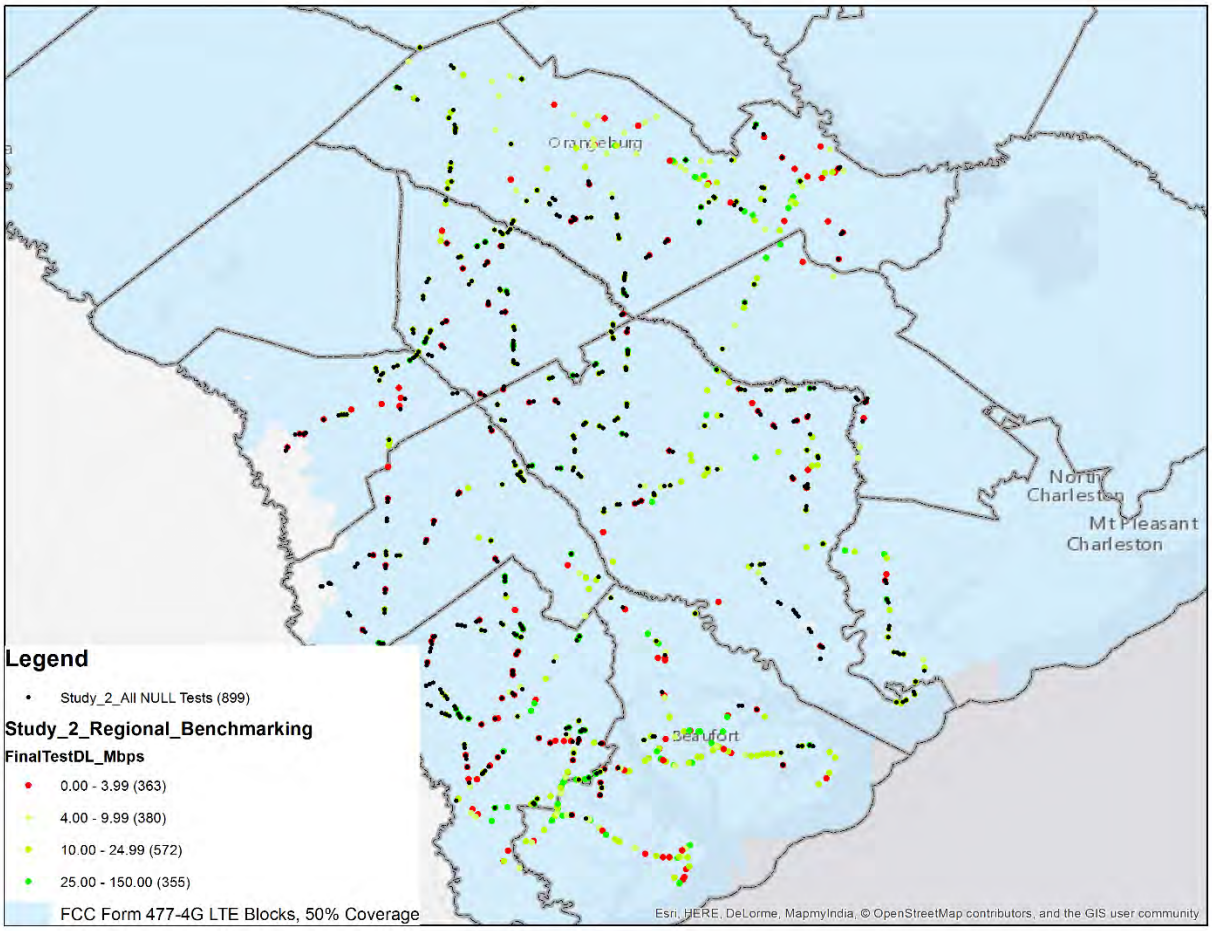


Figure 13 - Regional Benchmarking Throughput Results w/ 477 Overlay (with Connection Failures)

Coverage Comparison the FCC Form 477 Data

The difference between the Form 477 data and the benchmarking results are significant in the regional drive test effort. For this study, the drive testing team collected download speed tests in 650 Census Blocks in SE South Carolina. The Form 477 data, using the Actual Service Area approach, shows that there is coverage present in all but two of those Census Blocks. However, the drive test results show that there was at least one test showing speeds below 4Mbps in 515 of those blocks. This accounts for 79% of all blocks with download tests in this effort. This does not include tests that showed no connection or lack of availability.

Tested Speeds	Census Block Count
Presence of Tests <4Mbps	515
Total CB's w/ Download Tests	650

Figure 14 - CB Count by Download Speed Threshold for Study 2

TEST 3 – RURAL COUNTY BENCHMARKING IN ORANGEBURG COUNTY

The third study was an assessment of mobile performance on rural routes, in one predominantly rural county. The drive testing of Orangeburg County was conducted with the specific purpose of understanding what the customer experience would be for rural residents and workers. These tests were done primarily on Tiger Road Classification S1400 roads. These roads are described by the Census Bureau as "Local Neighborhood Road, Rural Road, City Streets." These are neither primary nor secondary roads, these are roads between homes, businesses, and farms.

Overall Results

The Form 477 data shows ubiquitous LTE service availability in Orangeburg County. However, in Figure 15 below, there a significant number of tests at speeds below 4Mbps. On rural roads (mostly S1400), there are nearly as many test failures and tests at low speeds as there are successful tests at or above broadband speeds. The first map below (fig. 15) shows download speed test by tier group. The second map (fig. 16) shows the same speed tests with connection failures added.

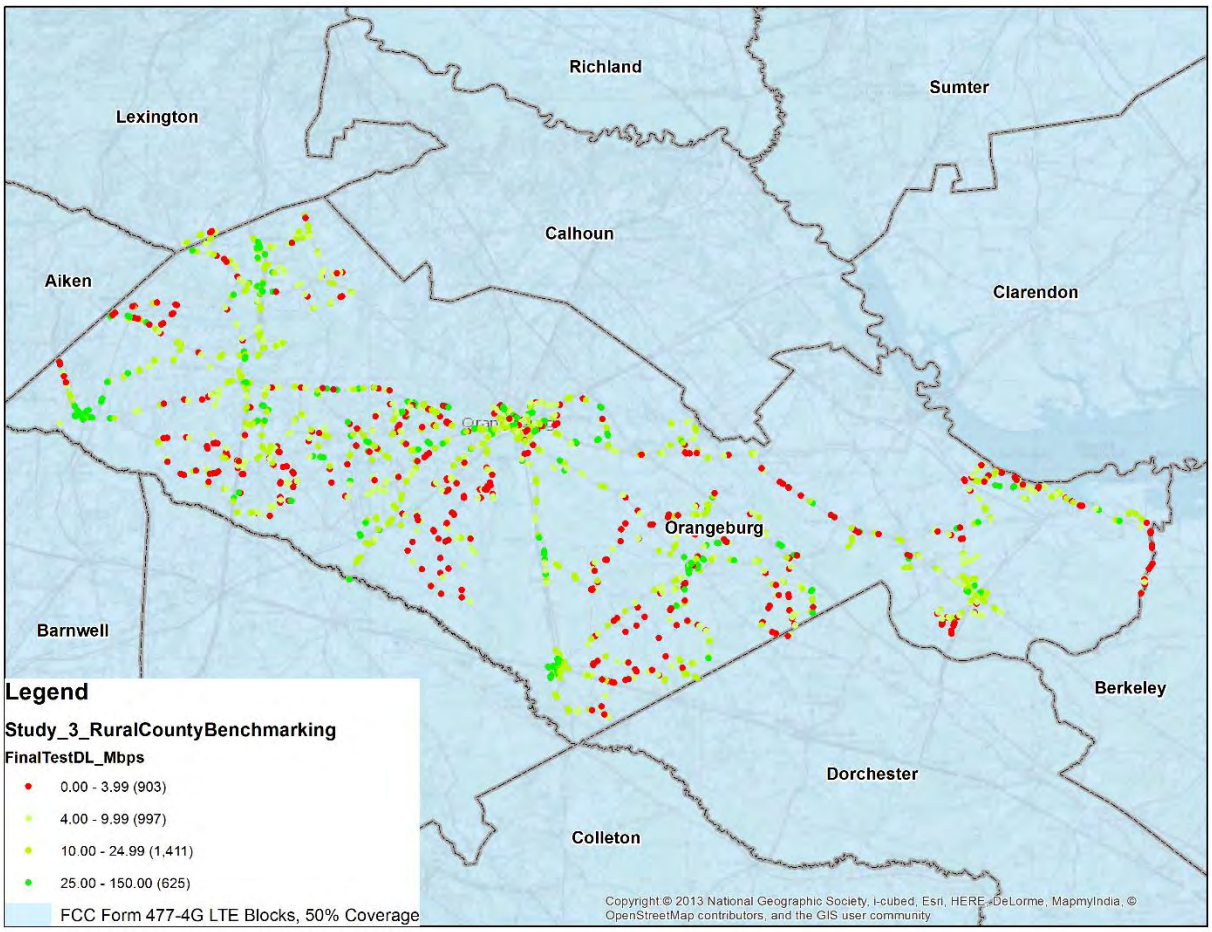


Figure 15 - Orangeburg Benchmarking Throughput Results w/ 477 Overlay (w/o Connection Failures)

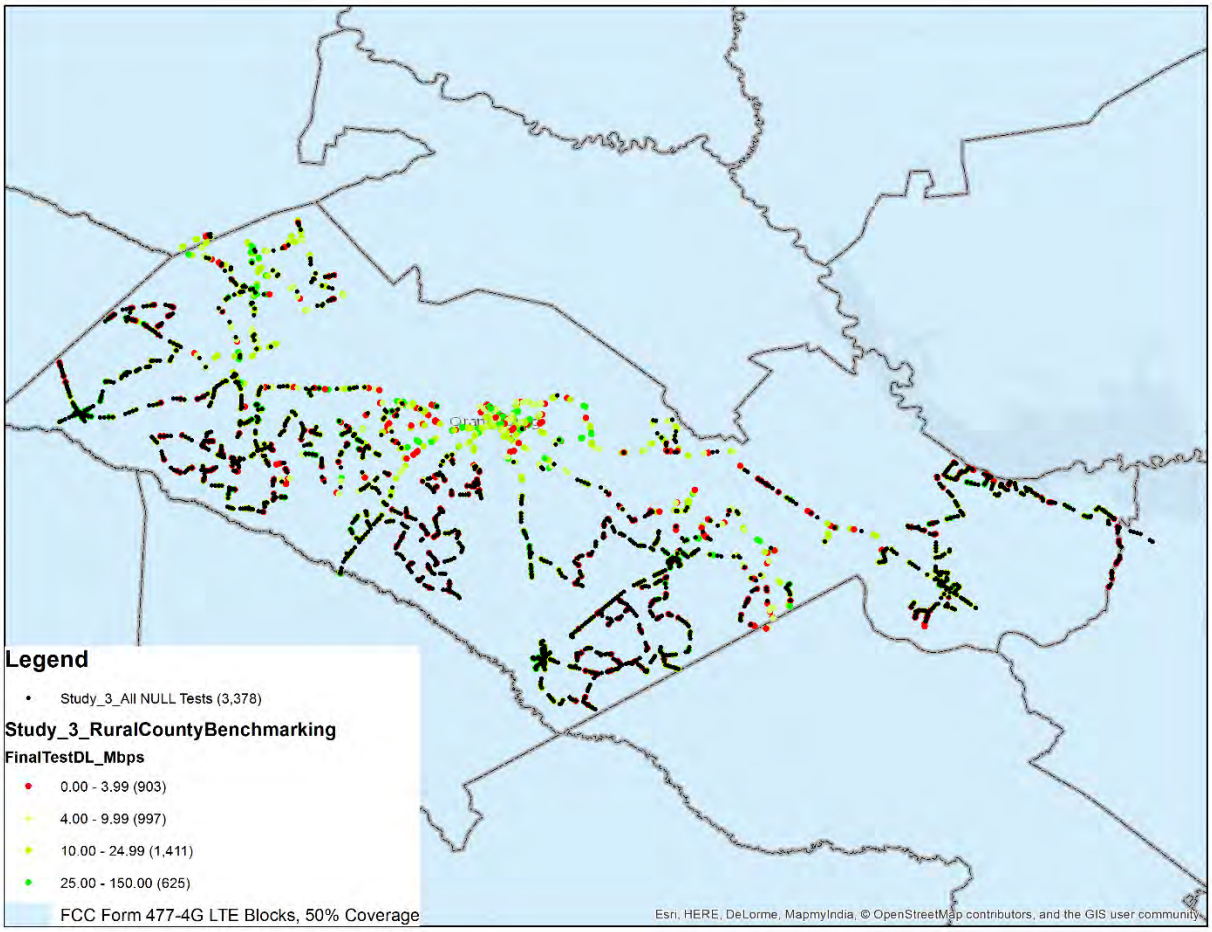


Figure 16 - Orangeburg Benchmarking Throughput Results w/ 477 Overlay (with Connection Failures)

Coverage and Throughput by Roads and Population

When plotting the same tests with an overlay of population density we see that most of the sub 4Mbps tests fall within Census Tracts with lower pop density. The map below (fig. 17) shows the tested speeds on road segments grouped into either greater than or less than 4Mbps.

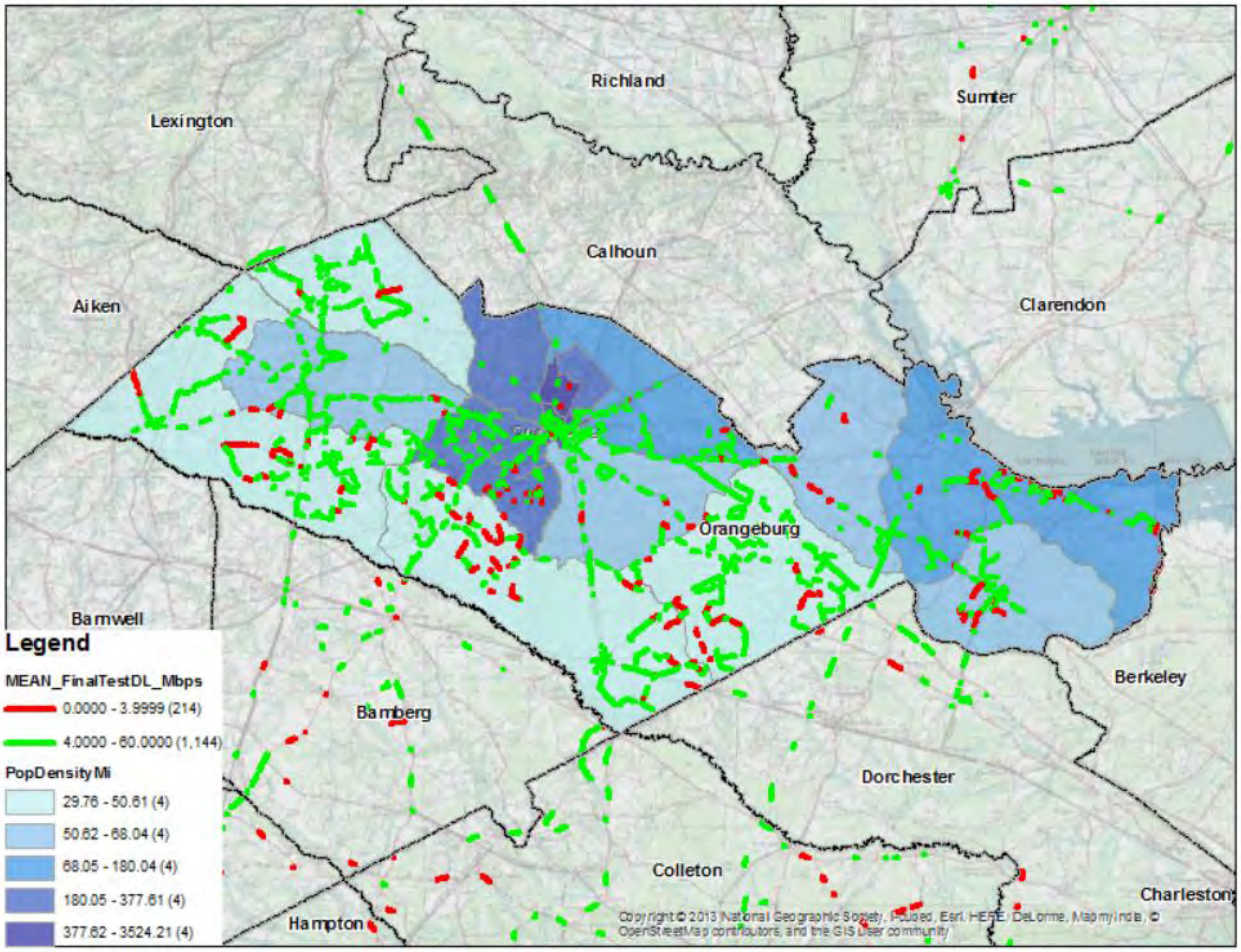


Figure 17 - Dowload test by speed tier w/ population density

Coverage Comparison the FCC Form 477 Data

The difference between the Form 477 data and the benchmarking results grow even greater with the largely rural drive test in Study 3. The drive testing team collected download speed tests in 816 Census Blocks in a five-day period in Orangeburg County. The Form 477 data, using the Actual Service Area approach, shows that there is coverage present in all of those Census Blocks. However, this benchmarking test measured speeds below 4Mbps in over 750 of those blocks. This accounts for 92% of all blocks with download tests for Study 3.

In terms of the ability for testing equipment to connect to a network, the failure rate was significant. Of the 816 blocks tested for connections and download throughput, 515 (63%) of them had tests that resulted in no connection. This almost always indicates a lack of service availability. Keep in mind that there are typically multiple tests per Census Block. Knowing that there may be one or more failed tests in a block does not necessarily indicate that service is generally poor in that block. However, challenges abound if one looks at the Census Block as a uniform area that may support policy-making decisions or lead to grand statements about service availability or speeds. Certain areas within most rural Census Blocks in

Orangeburg County, and likely many other rural areas across the U.S., have speeds below 4Mbps and/or a general lack of ability to connect to the network.

Tested Speeds	Census Block Count
Presence of Tests <4Mbps	753
Total CB's w/ Download Tests	816

Figure 18 - CB Count by Download Speed Threshold for Study 3

Connection Success	Census Block Count
Presence of Tests w/ No Connection Success	515
Total CB's w/ Download Tests	816

Figure 19 - CB Count by Connection Success for Study 3

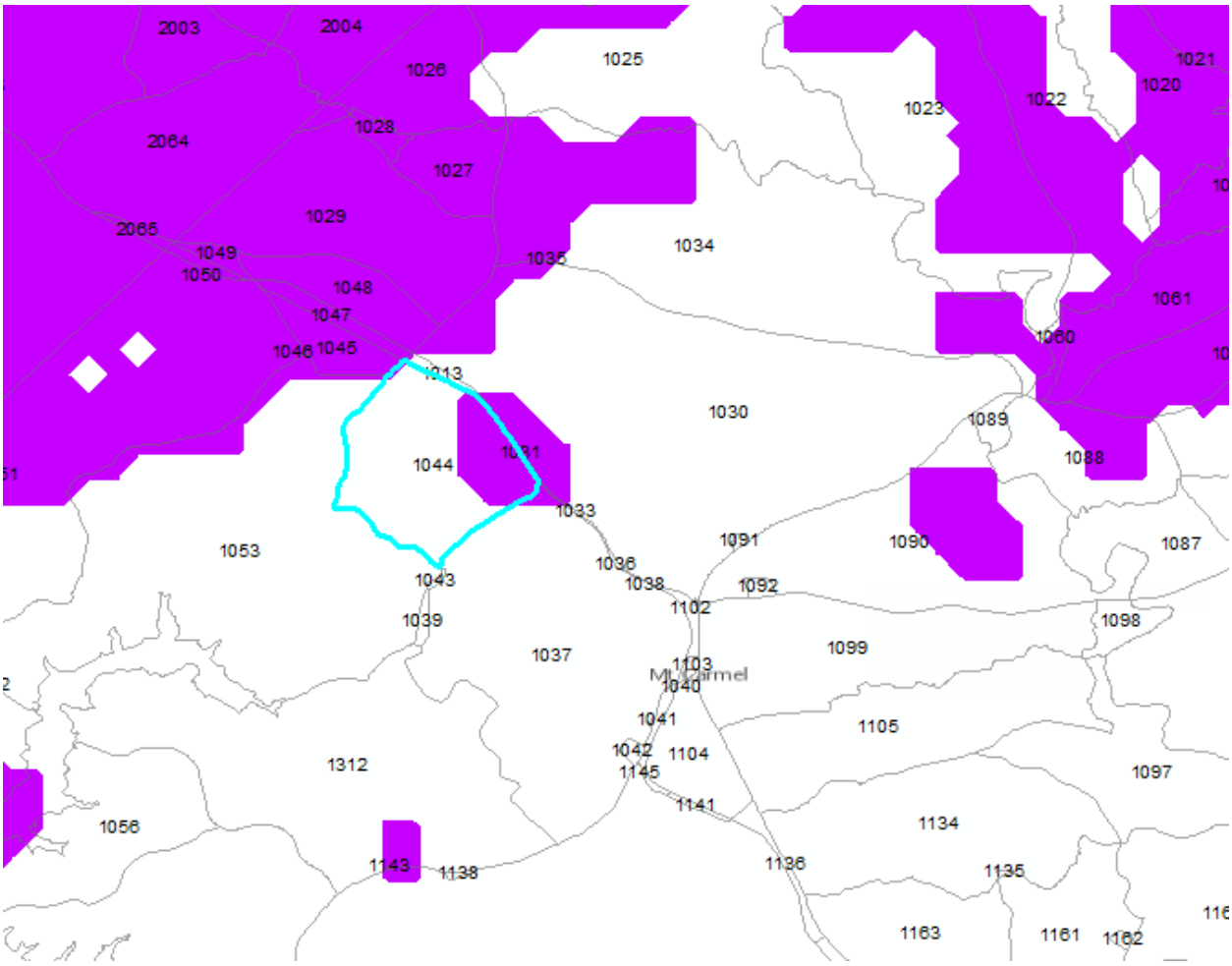
AN ASSESSMENT OF THE FCC'S FORM 477 MOBILE BROADBAND DATA

As readers contemplate the results of these drive testing efforts and the general comparison to the FCC 477 data, it's important to do so within the context of the available data. The various comparisons to the publicly released Form 477 data in this study are limited in usefulness to the extent that the released data comes with assumptions and geographic and throughput generalizations. While the FCC has worked to improve upon prior releases by employing new methodologies, there are still questions about the application of these approaches when it comes to policy making.

With the release of December 2015 Form 477 mobility deployment data, the FCC provided a shapefile (SHP file) as well as two forms of derivative data in text (CSV) format. A shapefile is a geospatial file that represents the actual coverage polygon submitted by Form 477 filers. The two tabular files are derivatives of the shapefile. While we would recommend use of the SHP file for most analysis, parties may choose or need to limit their analysis and subsequent decisions based on the CSV format data. If the CSV files are used, issues with their use must be understood. The following reviews the CSV files and the issues with their use.

The two text files reconstitute the shapefile into a Census block[1] based representation. The difference between the two text files is mainly the geospatial method used to move from a coverage polygon to a Census Block representation. For example, in the map below, the coverage polygon (purple) needs to be associated with the Census Blocks (gray borders). The specific question answered by the two text based derivative files is how does one associate partially covered Census Block 1044 (in turquoise highlight) with the purple coverage fragment. Another issue illustrated in the map below shows block 1099 looks to be covered at the centroid, but not throughout. This highlights how one method can lead to showing coverage in a block, where the other method may not.

[1] A Census Block is the smallest unit of geography for which the decennial Census provides demographic information-such as population and housing units.



The Centroid Method CSV file uses the geographic centroid of a Census Block to designate if the Block was covered within a provider's broadband deployment submission. The file demonstrates a relationship between the deployment information and the Census Blocks when the centroid of the Block is contained within a provider's deployment polygon.

The Actual Area CSV shows a calculation of the area in common (overlapping) between the provider's deployment feature and a Census Block to develop a percent coverage of the Census Block.

This section of the paper contains our impressions of these two release formats. As our impressions are formed based upon the intended use, it is important to note that the continued, frequent release of the actual SHP files is critical. With the actual SHP files, either CSV format can be developed. Also, as the impressions we form are based upon our current intended use—the review of Form 477 deployment information—our impressions of the suitability of either CSV format for a given case may shift if the intended use changes.

A Geographic Centroid

The Public Notice mentions prior FCC analysis used the centroid method while starting with this Form 477 data release, their analysis will use the actual area coverage methodology.[2]

As Census Blocks describe relatively small amounts of area, a geographic centroid is a single point used to represent the area of the block. Centroid points are described as the geographic center of mass or simply as an average location.[3]

In simplest terms, the Block's centroid is the average location of all points that form the boundary of the Block. If the Block were square, the centroid would be a point directly at the center of the block. If the Block were circular, the centroid would be the center of the circle. Since Census Blocks tend to be irregular in shape, the centroids can be found inside[4] or outside of the Census Block boundary but they always represent an average location for the boundary points.

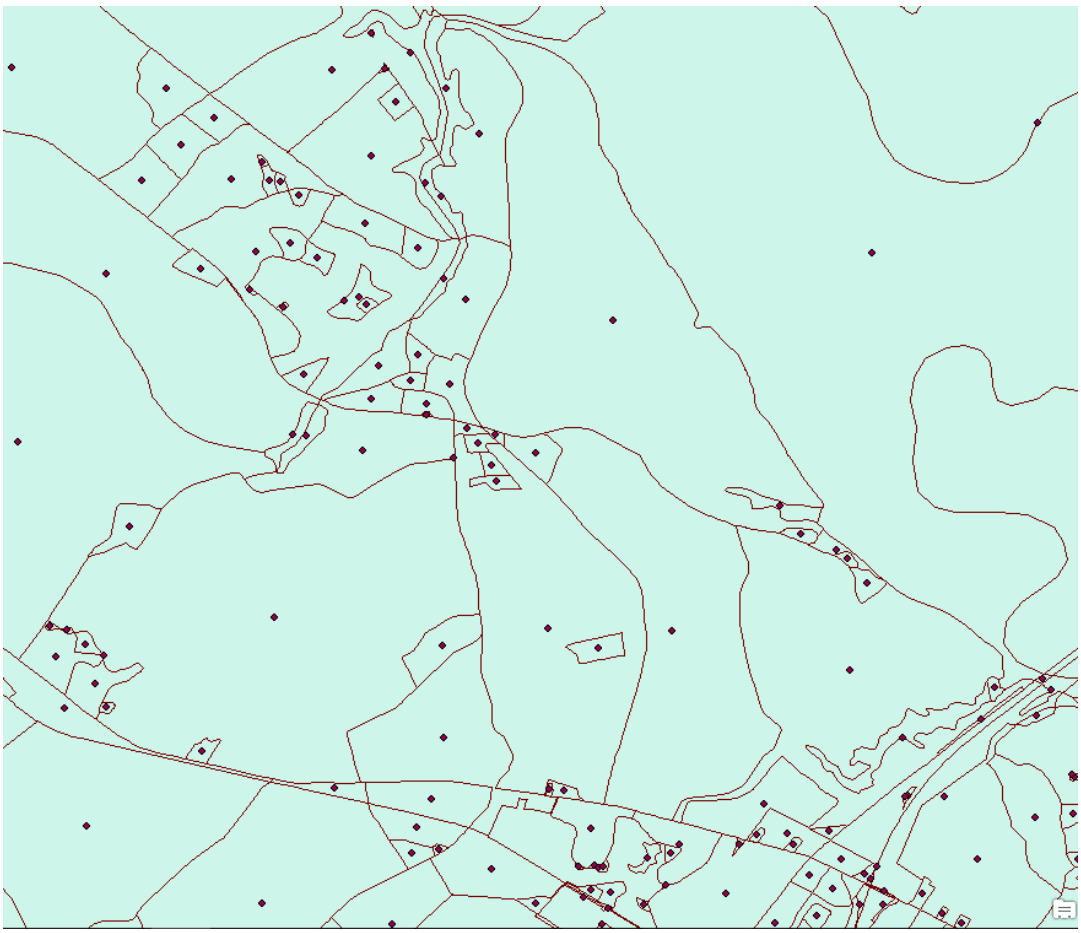


Figure 20: Example of centroid points and Census Blocks

[2] See FCC RELEASES DATA ON MOBILE BROADBAND DEPLOYMENT AS OF DECEMBER 31, 2015 COLLECTED THROUGH FCC FORM 477 WC Docket No. 11-10, para 12

[3] ESRI provides additional information in their definition, see http://support.esri.com/other-resources/gis-dictionary/term/centroid

[4] The Attachment to the Public Notice does not clarify if centroid methodology uses the centroid or the interior centroid. An interior centroid is constrained to be within the polygon, while a centroid may be outside of the polygon.

Centroids are frequently used in geospatial operations because they tend to produce a faster result and they tend to produce a binary result--the centroid point is either in or out of another polygon's boundary.

The question of suitability of the Census Block Centroid approach versus the Actual Area approach largely depends on the intended purpose of the analysis and on how large of a geographic area are you looking at.

Our experience has been that there is nothing wrong with using a Census Block Centroid approach or Actual Service Area approach to develop derivatives of shapefiles, but care must be taken in considering how the method influences the end result of the analysis.

The Decision

If you build a map of centroid derived block associations versus actual area block associations, you may see a pattern of coverage differences as shown below.

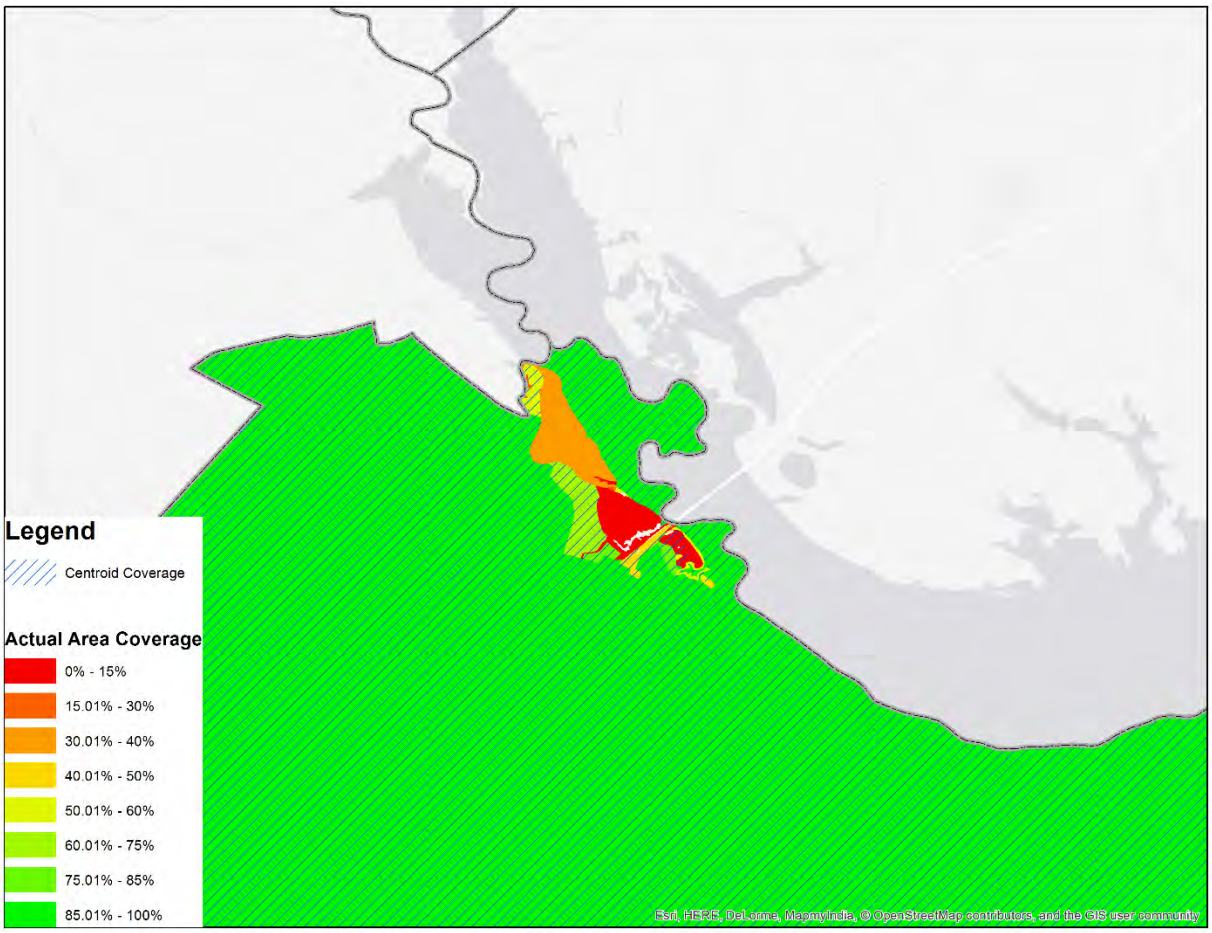


Figure 21: Centroid covered blocks (in line fill) compared to actual area coverage (in color shading)

In this map, blocks 'covered' by centroid are shown as diagonal line fill. Beneath the centroid fill layer, blocks are colored based upon the FCC determined the percent of the actual area covered. In the map, we see that there are a number of blocks that would be covered by the Census Block Centroid approach, but are less than 100% covered in the Actual Service Area approach.

In effect, each approach measures something about the area of area of a Census block. With the Actual Area approach, the question will turn on what percent of a block's area is necessary to be covered to say the entire block is covered. That may be an important question, but it won't be the only question.

When the shapefile is analyzed and decomposed to an area or centroid measure of Census Block coverage, you eliminate the 'where' component of the 477 deployment information. By looking only at derived text files based upon Census Blocks, you may know what Block is covered or how much area is covered, but the analysis loses the richness of the carrier supplied geographic information. You don't know if that 50% coverage is coverage of a water body, a highway, a side-street or a farm.

Implications for Policy Analysis

In the map below, Census Block boundaries are shown in white, roads in thin black and percent coverage in the same color scale as above. As a general rule, larger Census Blocks are formed based upon roads. Analysis of this map immediately begs the question: is the objective of the coverage analysis to cover the area, to cover the paths of travel (roads) or some combination of both?

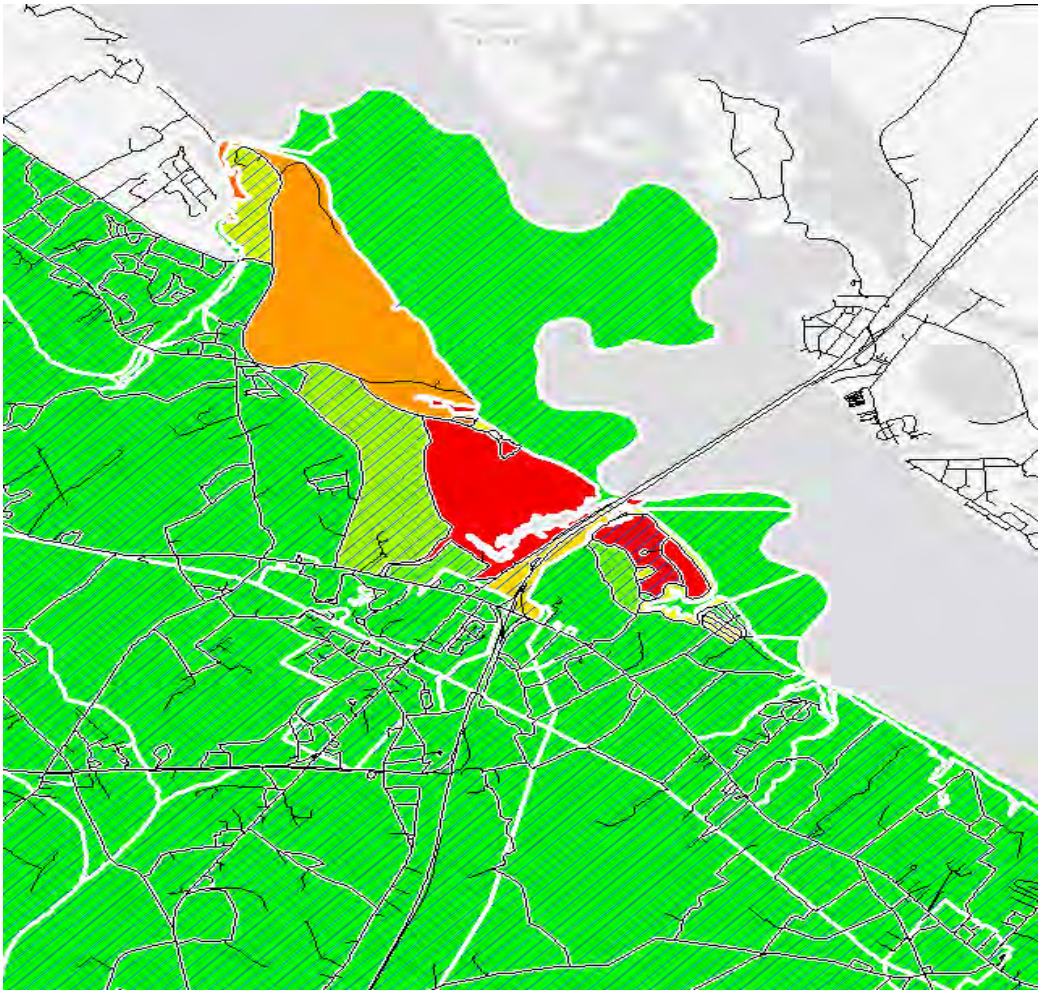


Figure 22: Coverage map with roads and Census Blocks

In that roads tend to be the perimeter of blocks, both the Actual Area and Centroid approach are disconnected from directly considering the impact on roads. Neither approach directly measures coverage against the likely paths of travel.

As demonstrated earlier in this paper, there appears to be variation in mobile broadband experience (download speeds, lost connections) within a Census Block. If the patterns seen in our sample of performance tests remains consistent in larger areas, it may be prudent to examine if only an area based measure of broadband presence-such as percent block covered by 477 submissions is sufficient for determining if broadband coverage is present.

Finally, in that the released 477 coverage files only represent a minimum of speed without any information regarding what that speed is[5] or how the carrier developed the deployment information the impact of a disparity in the Centroid approach versus the Actual Area approach is diminished by the fact that released data lacks important information about the quality of the offered service—what speed or bandwidth the consumer should experience.

The current 477 release is helpful to describe the presence of coverage. If speed is assumed to be based upon technology it is also possible to measure against assumed speed ranges. But without making broad assumptions about speed and deployment technology, none of the released deployment data provides speed information. A disparity based upon Actual Area versus Centroid approaches is overshadowed because the public data are silent as to the claimed speed. We could be comparing an LTE speed of 1 Mbps downstream versus 25 Mbps and 'seeing' both as the same thing. As consumers of the information, the utility of the deployment information is reduced by the lack of speed information.

CONCLUSION

This study, and the results of this collection of benchmarking data across much of South Carolina, can be seen as a first step in a larger process of measuring mobile customer experience across varied geographies. The study answers a number of questions about the differences in access and use of mobile networks on various roads and census areas in South Carolina. However, these areas represent neither the best, nor likely the worst, of a collective customer experience when it comes to mobile networks in the U.S. In summary, the data collected are generally indicating the following:

- Network reliability, when viewed as the ability to connect to a network and transmit or receive mobile data, differs a great deal inside and outside of Census Designated Places (cities and towns). Successful connection rates and throughput speeds are generally lower outside of city and town boundary limits.
- Network reliability across road classifications differs a great deal as well. Connection rates, signal strength and throughput are all lower on roads that are not within primary travel corridors between population centers.
- Throughput speeds are generally much lower in areas with lower population density.

[5] See FCC RELEASES DATA ON MOBILE BROADBAND DEPLOYMENT AS OF DECEMBER 31, 2015 COLLECTED THROUGH FCC FORM 477 WC Docket No. 11-10, para 10, "For mobile users, this is the more relevant figure as the minimum advertised speed is the speed they are more likely to consistently experience".

- The FCC's Form 477 data on mobile network availability, while helpful when trying to understand general presence of mobile providers, does not accurately represent customer experience with respect to access and use of networks. Many areas that are shown as served by mobile providers in the 477 data are either completely unserved or served at speeds below what would be reasonably considered as broadband (4Mbps down).
- Neither of the FCC's methods for displaying mobile broadband service areas, the Centroid approach or Actual Area approach, allow users to accurately measure coverage against likely paths of travel.

While the effort yielded important data on network reliability across different demand points, it still begs a number of questions, including:

- While there is a better understanding of network metrics from inside a car, on roads, we did not measure indoor (in buildings and homes) coverage. How would the results differ inside metropolitan, suburban, and rural structures?
- Only network connection and data throughput were measured for all three studies. Texts, voice, email and web/application use tasks were not measured. Given the number of road miles and areas to cover, the test cycles did not allow for all these tests. What would the results show us if the various tasks consumers regularly perform were measured?
- If speed tiers were made available by the FCC, how would those advertised speeds compare with the drive tested results?
- While the areas of South Carolina were selected as a representative sample of population centers, roads and rural areas, what would a larger, more diverse sample area show us? Could assumptions be made regarding nationwide service availability and reliability be made if a larger study were conducted?

CostQuest and RootMetrics® stand ready to assist in the further investigation of these and other issues.