Background & Justification

As more and more states make broadband investment a priority, it is important to develop metrics to help identify areas in dire need of investment, measure adoption of the technology and track progress over time. Pursuant to a request by the North Carolina Department of Information Technology's Broadband Infrastructure Office (BIO), this document provides a quick overview of the factors affecting broadband infrastructure deployment as well as broadband adoption. In addition, a series of indices are presented to measure both availability and adoption in North Carolina.

Broadband-related metrics typically fall under two categories: availability and adoption. For the availability category, some indicators utilized include access to types of technology, number of providers, access to specific speed thresholds and others. In addition to these metrics, it is important to also shed light on the quality of service such as slower speeds or large differences between download and upload speeds (also known as asymmetrical service). Lastly, barriers to infrastructure deployment are also important to include such as age of housing units and housing density.

On the adoption side, a variable is available that showcases the share of homes subscribing to DSL, cable or fiber or not subscribing at all (no internet access) [1]. However, research points to other variables that affect technology adoption including but not limited to age, income, presence of children and educational attainment among others. These variables also must be included to measure adoption *potential* in addition to simple adoption. Important to keep in mind is that one key variable that affects adoption is missing: cost of service. This variable was not included because it is not available from secondary data sources.

Lastly, and in addition to the two indices discussed already, a state-wide report is generated as well that sheds light on the quality of service (measured by median speeds, competition, and technology) and digital parity between urban and rural areas of the state. Digital parity refers to similar if not identical service available in urban and rural.

Data & Methods

Data for these indices were obtained from two sources. First, the Federal Communications Commission (FCC) Form 477 is a biannual form submitted by providers that includes advertised speeds and technologies available at the Census block level. While this dataset is known to have serious limitations, including overestimating the availability of broadband and relying on advertised versus actual speeds, it remains the only national dataset available and includes useful data, such as the technology types used and number of providers per census block. The dataset version utilized was December 2017 v2 and included only service advertised to consumers or homes (excluded service to businesses). All other variables were obtained from the American Community Survey (ACS) 5-Year 2013-2017 dataset. Data was aggregated to or downloaded at the Census tract level resulting in 2,162 tracts analyzed. Tracts with no population or households according to the Census were removed (34 in total) from the dataset.

[1] The FCC also publishes data on the share of homes with at least 10 megabits per second (Mbps) download and 1 Mbps upload, or 10/1 for short. This speed threshold is much lower than the minimum 25/3 Mbps also stipulated by the FCC resulting in potentially misleading adoption levels and thus was not used.

Regarding availability and quality, obvious indicators such as access to a provider as well as to the current FCC definition of 25 megabits per second (Mbps) download and 3 Mbps upload (25/3) were included. However, since some states (Minnesota) have pushed this threshold higher (100/20 by 2026), North Carolina will be at a competitive disadvantage if the indices show that the predominant speeds for a majority of the population is 25/3. Age of housing units and household density also affect broadband availability. Newer homes may be pre-wired for broadband connectivity reducing cost to providers while older homes may increase cost. Less homes per square mile makes broadband investment more expensive and means less customers. For these reasons, no access to a provider, 25/3, 100/20, age of housing units and households per square mile were included in the index.

Fiber networks have by far the largest data transmission capability of any existing technology. Susan Crawford, in her latest book, compares data transmission of fiber as a 15-mile wide river versus copper having a 2-inch pipe capacity. As more applications will likely require faster speeds, access to fiber needs to be included in any availability metric. On the other hand, having access to *only* DSL, which relies primarily on copper, places any community or homes at a disadvantage affecting availability.

Symmetrical connections refer to identical download and upload speeds. This is becoming increasingly important given that many homes not only consume (download) but also produce (upload), because of home businesses, children using cloud applications for homework assignments and research, and/or telehealth applications that require real-time interaction and 24/7 monitoring. Communities and homes with symmetrical speeds will be at a competitive advantage. Therefore, a ratio of symmetry (upload/download) needs to be included

Regarding adoption, two of the most important variables (cost and digital literacy/skills) are not available. However, there are other variables that can be used as proxies for adoption itself, as well as, potential to adopt. As discussed previously, the ACS publishes an indicator of the share of homes that do not have internet access (do not subscribe). Similarly, homes that do not have a computing device of any kind are also more likely to not subscribe to the internet as do those with lower incomes, speak limited English, and whose members have any type of disability. On the other hand, research points to younger age cohorts, more educated, children at home and teleworkers as significant drivers of broadband adoption. Based on these research findings and due to data availability, eight (8) variables were included in the availability and quality index and eleven (11) for the adoption potential index. Pearson correlations and ordinary least squares regression results indicate that in fact these indicators affect each other in the way outlined below. Refer to the technical appendix for more information.

Broadband availability and quality index (a higher score denotes better availability and quality)

Contribute

1. Pop253: Percent population with access to 25/3 (+)
2. Pop10020: Percent population with access to 100/20 (+)
3. Fiber: Percent population with access to fiber (+)
4. Symmetrical: Ratio of upload to download median advertised speeds (+)
5. Density: households per square mile (+)
6. HomeAge: percent housing units built in 2010 or later (+)

Undermine

7. No providers: Percent population with access to no providers (-)
8. DSLOnly: Percent population with access to DSL only (-)

Broadband adoption potential index (a higher score denotes a higher broadband adoption potential)

Increase

1. Sub: Percent households with a DSL, cable or fiber-optic subscription (+)
2. A1834: Percent population ages 18 to 34 (+)
3. Bach: Percent population age 25 or more with bachelor's or more (+)
4. Children: Percent households with children (+)
5. WFH: Percent workers age 16 and over working from home (+)

Decrease

6. A65: Percent population ages 65 or over (-)
7. NIA: Percent households with no internet access (-)
8. NCD: Percent households with no computing devices (-)
9. Poverty: Percent population in poverty (-)
10. Disability: Percent noninstitutionalized population with a disability (-)
11. LE: Percent households with limited English (-)

Table 1 summarizes the variables utilized, their sources, and year.

Variable	**Source**	**Year**
Percent pop. with access to 25/3	Federal Communication Commission	December 2017 v2
Percent pop. with access to 100/20	Federal Communication Commission	December 2017 v2
Percent pop. with access to fiber	Federal Communication Commission	December 2017 v2
Symmetrical (upload/download ratio)	Federal Communication Commission	December 2017 v2
Density (households/square miles)	U.S. Census Bureau ACS	2013-2017
Percent homes built in 2010 or later	U.S. Census Bureau ACS	2013-2017
Percent pop. with access to no providers	Federal Communication Commission	December 2017 v2
Percent pop. with access to DSL only	Federal Communication Commission	December 2017 v2
Percent homes with DSL, cable or fiber	U.S. Census Bureau ACS	2013-2017
Percent pop. ages 18-34	U.S. Census Bureau ACS	2013-2017
Percent pop. with a bachelor's or more	U.S. Census Bureau ACS	2013-2017
Percent households with children	U.S. Census Bureau ACS	2013-2017
Percent workers age 16+ working from home	U.S. Census Bureau ACS	2013-2017

Percent pop. ages 65 and over	U.S. Census Bureau ACS	2013-2017
Percent households with no internet access	U.S. Census Bureau ACS	2013-2017
Percent households with no computing devices	U.S. Census Bureau ACS	2013-2017
Percent pop. in poverty	U.S. Census Bureau ACS	2013-2017
Percent pop. with any disability	U.S. Census Bureau ACS	2013-2017
Percent homes speaking limited English	U.S. Census Bureau ACS	2013-2017

Given that each index utilizes variables with different normal distributions and units, z-scores were calculated for each variable and added up according to the signs identified. Z-scores indicate where a particular value falls compared to the average and standard deviation of the sample, which in this case included all 2,162 tracts and 100 counties in the state.

These z-score signs were assigned if that particular indicator contributed or undermined the overall index score since both indices were designed in such a way that a higher score denotes more broadband availability and quality and higher broadband adoption potential. For example, under broadband availability and quality, the higher the percent of population with access to no providers, the lower the broadband availability and quality, thus a negative sign.

Variables in the availability and quality index were weighted as shown in table 2. Unfortunately, there is no research that indicates what weight should be given to each variable. Weights assigned reflect internal priorities and goals of the state broadband office. The percent population with fiber as well as the percent without access to providers were assigned the highest weight (0.25 each), given that fiber deployment is a high priority for the office and to ensure areas with no access at all are identified and targeted for investment.

Next, percent population with access to 100/20 was assigned a weight of 0.15, in part to ensure North Carolina remains competitive compared to other states. Population with access to 25/3 and DSL only were assigned a weight of 0.1 each since the former achieves the minimum speed while the latter does offer connectivity, but its quality is not the best. Lastly, the symmetrical, density, and home age variables were assigned a weight of 0.05 each. Symmetrical speeds are important but given how the variable is calculated (upload to download ratio), it may inadvertently give more importance to low symmetrical speeds (say 10/10). Density and home age, while impacting broadband deployment, are hard to affect through strategic investments from the state broadband office.

Table 2. Availability Variable Weights

Variable	**Weight**
Pop 253	0.10
Pop 10020	0.15
Fiber	0.25
Symmetrical	0.05
Density	0.05
Home Age	0.05
No Providers	0.25
DSL Only	0.10
Total	1.00

Unlike the availability and quality index, the adoption and adoption potential variables were not assigned specific weights other than ensuring the weight of each variable was distributed equally since the number of variables impacting the index in a positive fashion were not the same number as those affecting the index in a negative way. For these reasons, variables were multiplied times 0.0909 (1/11).

Keep in mind that future versions of these indices can weight variables accordingly based on future research and/or documented and empirical feedback from stakeholders. The equations below show how each index was calculated:

Equation 1: Broadband Availability and Quality (z-scores)

Pop253*0.1 + Pop10020*0.15 + Fiber*0.25 + Symmetrical (ratio of upload to download median speeds)*0.1 + Density*0.05 + HomeAge*0.05 - No Providers*0.25 - DSLOnly*0.1

Equation 2: Broadband Adoption and Adoption Potential (z-scores)

Sub*0.0909 + A1834*0.0909 + Bach*0.0909 + Children*0.0909 + WFH*0.0909 - A65*0.0909 - NIA*0.0909 - NCD*0.0909 - Poverty*0.0909 - Disability*0.0909 - LE*0.0909

The resulting values for equations 1 & 2 were normalized to a range from 0 to 100 for easier comprehension and comparison. In other words, a number closer to 100 indicates better broadband availability and quality and less challenges as well as a higher broadband adoption potential. However, the fact that a geography scores 100 does not mean there are no improvements to be made. Likewise, a geography scoring zero does not mean all indicators are bad. Please note that the scores were calculated by using their respective geographic units and thus comparisons between geographies (Tracts versus counties) is not possible.

Results

Table 3 showcases the top and bottom five counties in the state based on their broadband availability and quality index score. Remember that scores were normalized to a range of 0 to 100, where a higher score denotes a higher broadband availability and quality. Indicators that contributed to this score are shaded in green while indicators that undermined this score are shaded in red. Mecklenburg County, which had the highest score in the state, had a favorable household density (770.4 households per square mile) and the second highest share (5.7 percent) of homes built in 2010 or later (% Age Home) among the top five counties. However, less than two-thirds of its population had access to fiber (61.7 percent) and its upload speed was only 20 percent or 0.2 of the advertised download speed (Up/Down Ratio). In other words, from a policy perspective, Mecklenburg County needs to invest in fiber infrastructure, update it housing stock, and improve its upload/download ratio.

On the other hand, Hyde County ranked last in the state (score of zero) when it came to broadband availability and quality. Its advertised upload speed was 20 percent of the advertised download speed. Little more than one-fifth of its population (20.9 percent) had access to 25/3 versus only 1.1 percent with access to 100/20 and a little more than three percent with access to fiber. None of its homes were built in 2010 or later potentially making it costlier for providers to deploy broadband, in addition to its very low household density (only 3 homes per square mile). Close to one-fifth of its population (17.4 percent) had access to no providers and a little more than 70 percent had access to DSL only.

Table 3. Top and Bottom Ten Counties with Broadband Availability and Quality

Rank	Name	% Pop. 25/3	% Pop. 100/20	% Pop. Fiber	Up/Down Ratio	Hhld. Density	% Age Home	% Pop. No Prov.	% Pop. DSL Only	Availability and Quality
1	**Mecklenburg**	100.0	100.0	61.7	0.200	770.4	5.7	0.0	0.0	**100.00**
2	**Wake**	99.8	99.7	61.7	0.200	466.0	8.1	0.1	0.2	**97.76**
3	**Davie**	99.4	99.4	85.9	0.200	60.2	1.7	0.2	0.4	**95.64**
4	**Guilford**	99.8	99.7	51.5	0.200	313.5	3.4	0.1	0.1	**90.28**
5	**Ashe**	92.5	90.7	90.5	0.100	28.1	2.5	1.1	1.1	**89.96**
96	**Duplin**	64.6	60.2	1.4	0.080	26.5	2.2	10.8	26.3	**32.22**
97	**Swain**	46.0	0.0	0.0	0.083	28.0	3.8	8.4	45.3	**25.15**
98	**Greene**	33.4	3.0	0.0	0.080	27.6	4.1	6.7	91.2	**20.12**
99	**Graham**	46.3	0.0	0.0	0.083	11.3	1.3	11.1	42.6	**18.15**
100	**Hyde**	20.9	1.1	3.4	0.200	3.0	0.0	17.4	70.8	**0.00**
---	**North Carolina**	94.8	88.5	30.6	0.200	81.0	4.5	0.9	4.5	**----**

Table 4 showcases the top and bottom five counties in the state based on their broadband adoption and adoption potential score. Remember that scores were normalized to a range of 0 to 100, where a higher score denotes a higher broadband adoption and adoption potential. Indicators that increase broadband adoption and adoption potential are shaded in green while those that present challenges are shaded in red. Wake County had the highest broadband adoption and adoption potential score in the state (100). Indicators that could present challenges were relatively low (barely exceeding ten percent), with the highest share (10.5 percent) among those ages 65 and over, while its share of homes subscribing to broadband was high (almost 82 percent). Close to one-quarter of its population was ages 18 to 34 and more than half had a bachelor's degree or more. One-third of homes had children and a little over eight percent of workers ages 16 and over worked from home.

On the other hand, Tyrrell County ranked last (score of zero). Less than half of its homes subscribed to broadband (46.3 percent) and less than ten percent of its population had a bachelor's degree or higher. On the indicators that can present challenges to adoption, a little more than one-quarter of its population was in poverty while a little more than one-fifth had a disability. Close to one-third of homes did not own any computing devices and a little more than one-fifth of its residents were 65 years or older. Lastly, a little more than 40 percent of homes did not subscribe to the internet. When looking at the broadband availability and quality indicators of Tyrell County (not shown), its overall score of 43.11 places it close to the middle of the rankings in the state. Therefore, it is clear that the county faces more of an adoption issue rather than availability since more than 80 percent of its population had access to 25/3 and less than five percent had access to no providers, for example.

Table 4. Top and Bottom Ten Counties with Broadband Adoption and Adoption Potential

Rank	Name	% Bbnd Sub	% Ages 18-34	% Bach	% Hhlds. Children	% Work from home	% Ages 65 and over	% No int. access	% No comp. devices	% Poverty	% Disability	% Lim. Eng.	Adoption Potential
1	**Wake**	81.7	24.0	51.0	36.6	8.2	10.5	8.0	5.4	10.1	8.4	2.9	**100.00**
2	**Orange**	77.9	29.5	57.6	29.2	8.4	12.5	8.7	6.9	14.0	9.0	3.3	**94.17**
3	**Onslow**	74.3	40.8	20.2	39.9	5.3	8.6	13.0	8.3	14.1	16.9	1.1	**89.22**
4	**Union**	76.0	18.3	34.0	44.4	7.2	11.7	10.4	7.8	9.4	9.6	2.8	**89.09**
5	**Mecklenburg**	74.3	25.8	44.1	32.8	6.7	10.4	12.8	8.1	13.4	8.7	4.8	**81.71**
96	**Graham**	35.8	17.9	14.2	23.9	3.7	22.8	45.0	38.3	19.0	19.4	0.7	**7.08**
97	**Washington**	43.1	18.2	9.1	25.8	1.8	22.0	39.2	30.7	24.1	22.7	0.2	**6.56**
98	**Duplin**	40.5	19.7	10.8	31.2	3.0	16.6	37.2	24.4	26.3	19.0	6.7	**5.95**
99	**Northampton**	37.2	17.8	12.8	24.9	2.7	23.7	42.4	32.0	25.4	22.4	0.6	**2.28**
100	**Tyrrell**	46.3	19.5	7.6	18.6	1.5	22.0	41.5	32.2	26.8	22.4	0.0	**0.00**
---	**North Carolina**	65.2	22.8	29.9	31.4	5.2	15.1	19.8	14.5	16.1	13.7	2.4	---

Notice how Wake County was the only county that ranked in the top five in both broadband availability and quality as well as broadband adoption and adoption potential. This means that Wake County is ripe to leverage the technology for community and economic development to improve its quality of life. Graham County, on the other hand, repeated in the bottom five in both indices. This means that this particular county faces challenges both on the infrastructure and availability as well as in the adoption side. Keep in mind that even if a county scores the maximum score, or the minimum score, this does not mean there are no areas for improvement or certain indicators that are favorable.

Wake County, for example, while ranking first in broadband adoption and adoption potential and second regarding broadband availability and quality, it still had an asymmetrical speed issue and more than one-third of its population without access to fiber. In addition, when looking at the tract-level data for Wake County, major differences are noticeable. In the adoption front, some tracts scored as low as 24 with more than one-third of homes in that particular tract with no internet access and no computing devices and almost half of its residents were in poverty. Multiple tracts had broadband subscription levels below 50 percent.

On the other hand, Tyrrell County that ranked last in broadband adoption and adoption potential ranked 71st when it came to broadband availability and quality (not shown). While 82 percent of its population had access to 25/3, efforts need to be made to improve conditions to increase adoption and adoption potential. Consider that less than half of its households subscribed to broadband, less than ten percent of its population 25 years or older had a bachelor's degree or higher, about one-third of its households did not have computing devices, and about one-quarter and one-fifth of its residents were in poverty and with any type of disability, respectively. Programs to subsidize internet, affordable and reliable devices, and/or trainings to improve skills and relevance are needed.

Technical Appendix

Pearson Correlations: Broadband Availability and Quality Variables (n=2,162)

	pPop253	pPop10020	pFib	Symmetrical	HhldDensity	pHomeAge	pPopNoProv	pPopDSLOnly
pPop253	1	.709**	.205**	.086**	.295**	.085**	-.672**	-.844**
pPop10020	.709**	1	.248**	.118**	.297**	.108**	-.444**	-.637**
pFib	.205**	.248**	1	.241**	.381**	.088**	-.161**	-.189**
Symmetrical	.086**	.118**	.241**	1	.062**	-.053*	-.056**	-.090**
HhldDensity	.295**	.297**	.381**	.062**	1	.050*	-.210**	-.269**
pHomeAge	-.085**	.108**	.088**	-.053*	.050*	1	-.061**	-.066**
pPopNoProv	-.672**	-.444**	-.161**	-.056**	-.210**	-.061**	1	.392**
pPopDSLOnly	-.844**	-.637**	-.189**	-.090**	-.269**	-.066**	.392**	1

Pearson Correlations: Broadband Adoption and Adoption Potential (n = 2,162)

	pSub	pA1834	pBach	pHhldsCh	pWFH	pA65	pNIA	pNCD	pPoverty	pDisability	pLimEng
pSub	1	.008	.753**	.141**	.486**	-.124**	-.927**	-.883**	-.664**	-.637**	-.164**
pA1834	.008	1	.062**	-.075**	-.077**	-.544**	-.073**	-.102**	.377**	-.242**	.186**
pBach	.753**	.062**	1	-.084**	.631**	-.038	-.731**	-.699**	-.490**	-.655**	-.121**
pHhldsCh	.141**	-.075**	-.084**	1	-.050*	-.529**	-.118**	-.127**	-.059**	-.267**	.159**
pWFH	.486**	-.077**	.631**	-.050*	1	.102**	-.469**	-.446**	-.349**	-.409**	-.139**
pA65	-.124**	-.544**	-.038	-.529**	.102**	1	.156**	.192**	-.197**	.433**	-.289**
pNIA	-.927**	-.073**	-.731**	-.118**	-.469**	.156**	1	.952**	.646**	.646**	.124**
pNCD	-.883**	-.102**	-.699**	-.127**	-.446**	.192**	.952**	1	.614**	.653**	.083**
pPoverty	-.664**	.377**	-.490**	-.059**	-.349**	-.197**	.646**	.614**	1	.344**	.300**
pDisability	-.637**	-.242**	-.655**	-.267**	-.409**	.433**	.646**	.653**	.344**	1	-.138**
pLimEng	-.164**	.186**	-.121**	.159**	-.139**	-.289**	.124**	.083**	.300**	-.138**	1

**. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed).

Ordinary Least Squares Regression Results for Availability and Quality Index

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.990[a]	.981	.981	1.77207

a. Predictors: (Constant), pPopDSLOnly, HomeAge, Symmetrical, HhldDensity, pPopNoProv, pFib, pPop10020, pPop253

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	32.544	.681		47.761	.000
	pPop253	.186	.007	.210	25.842	.000
	pPop10020	.102	.002	.214	49.547	.000
	pFib	.078	.001	.208	61.992	.000
	Symmetrical	15.412	.286	.166	53.912	.000
	HhldDensity	.005	.000	.218	65.322	.000
	HomeAge	.525	.008	.210	69.835	.000
	pPopNoProv	-.764	.016	-.218	-48.544	.000
	pPopDSLOnly	-.208	.006	-.221	-35.605	.000

a. Dependent Variable: Availability

Ordinary Least Squares Regression Results for Adoption and Adoption Potential Index

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.02877

a. Predictors: (Constant), pLimEng, pNCD, pHhldsCh, pA1834, pWFH, pDisability, pPoverty, pA65, pBach, pSub, pNIA

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	33.858	.012		2931.957	.000
	pSub	.132	.000	.154	1187.719	.000
	pA1834	.199	.000	.154	2294.874	.000
	pBach	.113	.000	.154	1783.370	.000
	pHhldsCh	.220	.000	.154	2417.632	.000
	pWFH	.550	.000	.154	2626.104	.000
	pA65	-.297	.000	-.154	-2002.769	.000
	pNIA	-.172	.000	-.154	-839.288	.000
	pNCD	-.216	.000	-.154	-1034.811	.000
	pPoverty	-.189	.000	-.154	-2088.823	.000
	pDisability	-.388	.000	-.154	-2024.146	.000
	pLimEng	-.596	.000	-.154	-3098.615	.000

a. Dependent Variable: Adoption