ANL/DIS-21/9

Internet Access Index

Measuring the Availability and Household Adoption of High-speed Internet

National Preparedness Analytics Center
Decision and Infrastructure Sciences Division

ANL/DIS-21/9

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Measuring the Availability and Household Adoption of High-speed Internet

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What is the Internet Access Index (IAI)?

The internet is a central driver in how households access information and services, learn, connect with family and friends, shop, and work. However, almost 14 percent of households in the United States[1] do not have the ability to access high-speed internet. Access to broadband or high-speed internet has taken on increased importance during the COVID-19 pandemic as many workplaces and schools shifted to a virtual environment. Argonne National Laboratory (Argonne) developed the IAI to better understand the challenges many households face in connecting to high-speed internet, whether due to lack of broadband availability from internet service providers or difficulties in subscribing to a broadband service.

What Does the IAI Measure?

The IAI is calculated as the product of 3 factors using publicly available data from the Federal Communications Commission, the National Telecommunications and Information Administration, and the U.S. Census Bureau. The first two factors gauge the quality and availability of high-speed internet and the third factor represents the public's ability to subscribe to high-speed internet services. The IAI scores United States' census tracts on a [0,1] scale, where values near 0 represent areas with less internet access and values approaching 1 represent more internet access. The maximum score (1.0) of the IAI would mean that all census blocks within a census tract have high speed internet available at the highest national speed, and that all households within the tract have a fixed broadband subscription of some type. To better visualize the results, Argonne binned the data into 5 relative bins (darker colored bins means better internet access) and created maps available at https://www.anl.gov/dis/covid19-impact-analyses.

Why is the IAI Important?

The COVID-19 pandemic surfaced deep digital divides across America. A lack of access to highspeed internet has made it more difficult for households to work from home or access basic services, including education and healthcare. Understanding where high-speed internet is accessible and accessed (where households subscribe to broadband services) will continue to play a critical role in the well-being of individuals, the economy, and communities well into the future. The IAI index and accompanying map identifies areas that could be considered broadband deserts where communities do not have quality access to the internet and therefore will find it more difficult to participate in an increasingly digital world. For example, it highlights locations where it is harder for students to participate in virtual learning, where individuals cannot access telemedicine services, or work remotely.

How to Use the IAI?

The goal of the IAI is to provide an easy-to-understand metric that can be flexibly applied to a wide variety of research and decision-making purposes that relate to internet access. Researchers and

[1] American Community Survey Table S2801, 2019 1-Year Estimates.

policymakers can use this index to better understand the current high-speed internet accessibility landscape and to assess potential impacts of variable internet accessibility on education, healthcare, economic development, and other critical services through the lens of high-speed internet access. For example, governments, industry, and non-for-profit organizations could consider how to take advantage of areas with high levels of internet access as well as make accommodations for those without internet access. In these communities, individuals may not have an email address or the ability to easily complete digital forms. Go to the IAI story map located here to view the results and interact with IAI data. You can also download the IAI data here.

Index Update 2022

In August 2022, Argonne updated its initial Internet Access Index (IAI; published May 2021) with updated data from both the Federal Communication Commission's (FCC) and the U.S. Census Bureau's (Census) American Community Survey (ACS). During this update process, Argonne also reviewed the National Telecommunications and Information Administration's (NTIA's) Indicators of Broadband Need mapping tool.[2] This tool brings together public data from the Census Bureau's American Community Survey (ACS) and the FCC Form 477 data and combines these products with user speed test data from Measurement Lab (M-Lab) and Ookla. The original Argonne IAI combined data from the FCC Form 477 maximum download speed data with broadband adoption data from the ACS. The goal was to provide an index value that represented both the availability of high-speed internet and household subscription rates to provide a more nuanced view of internet access. FCC Form 477 data is currently self-reported by internet service providers and therefore may not fully capture what internet speeds households are accessing. Now that user speed test data are available at the census tract level via Ookla, Argonne has modified the IAI to include the user speed test data, thereby improving the accuracy of the tool.

Changes to this latest version of the IAI include:

- Use of Ookla median user download speed data as the numerator in the download speed ratio
  - Inclusion of the Ookla user speed test data resulted in overall IAI scores that are markedly lower than those reported in the previous version of the index. These lower scores are primarily the result of the user speed test data being lower than the median maximum download speeds used in the initial version of the index. Argonne believes that inclusion of the user speed test data produces a more accurate representation of the state of internet access nationally.
- Use of the national median of the maximum download speed as the denominator in the download speed ratio
  - Note: although this is a modest theoretical change, practically this has no effect on the overall calculation as the national maximum download speed in the previous version of the IAI was 1000 mbps and the median value used in the updated index calculation is also 1000 mbps.

Census began releasing the decennial census results and updated five-year ACS estimates at the end of 2021. As a part of every decennial census, Census updates the census tract boundaries. For example, the 2010 Census resulted in approximately 73,000 census tracts, while there are approximately 85,000 tracts as of the 2020 Census, indicating that many tract boundaries have changed. Other data products used in the IAI including FCC and Ookla use the 2010-2019 census tract boundaries. As a result, Argonne continued to use ACS 2015-2019 5-year estimates to supply the percent of broadband subscription data within a census tract to ensure spatial parity. A preliminary review of 2020 Census data indicates that the percent of households with a broadband subscription increased by 1.8% nationally, indicating some improvement in household access. While it was not feasible to incorporate this data at this time, future updates of this index will incorporate this data, as feasible.

[2] National Telecommunications and Information Administration Indicators of Broadband Need Public Map. https://broadbandusa.ntia.doc.gov/resources/data-and-mapping

Introduction

The internet is a central driver in how households access information and services, learn, connect with family and friends, shop, and work. However, almost 14 percent of households in the United States[3] do not have the ability to access high-speed internet for a variety of reasons including:

- The availability of internet service or broadband infrastructure in their community,
- The willingness or financial ability to subscribe to an internet service provider, or
- The capacity of the individual to buy the equipment (i.e., computer, tablet, cell phone).

Definition of Broadband

The Federal Communication Commission (FCC) indicates that the term 'broadband' commonly refers to high-speed internet access that is always on and faster than dial-up access. The current definition of high-speed internet is 25 mbps down/3 mbps up. This is the minimum download speed recommended for activities such as education and telecommuting.

Federal Communications Commission. *Broadband Speed Guide.* https://www.fcc.gov/consumers/guides/broadband-speed-guide

The Internet Access Index (IAI) described in this paper focuses on the first two factors, as these are frequently the product of large collective investments.

Access to broadband or high-speed internet has taken on increased importance during the COVID-19 pandemic. In the first quarter of 2020, broadband usage increased by 47% over the first quarter of 2019.[4] The pandemic caused the spike in demand as:

- Many workplaces shifted to a virtual environment. According to the Federal Reserve Bank of Dallas, 35.2 percent of workers who participated in the Real Time Population Survey (RPS) reported working from home in May 2020, as compared to 8.2 percent in February 2020.[5] This number remained high a year into the pandemic with 28.5 percent of workdays reported as work from home, about double the pre-pandemic amount.[6]
- Primary and secondary schools and institutions of higher learning across the United States deployed distance-learning programs to protect the wellbeing of students and teachers.
- Non-emergency healthcare services significantly shifted to telemedicine visits as compared to in office visits.[7]

COVID-19 surfaced deep digital divides across America. A lack of access to high-speed internet has made it more difficult for households to access basic services, including education and healthcare.

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[3] American Community Survey Table S2801, 2019 1-Year Estimates.

[4] Weinschenk, C. (2020). Open Vault: Pandemic Drives Almost a Year's Worth of Broadband Traffic Growth in the Span of a Couple of Weeks. https://www.telecompetitor.com/openvault-pandemic-drives-almost-a-years-worth-of-broadband-traffic-growth-in-the-span-of-a-couple-of-weeks/

[5] Bick, A., Blandin, A. and Mertens, K. (2020) Work from Home After the COVID-19 Outbreak. Federal Reserve Bank of Dallas. https://www.dallasfed.org/-/media/documents/research/papers/2020/wp2017r1.pdf

[6] Bick, A., Blandin, A. and Mertens, K. (2022) Work from Home After the COVID-19 Outbreak. Federal Reserve Bank of St. Louis. https://doi.org/10.20955/wp.2022.008

[7] Koonin LM, Hoots B, Tsang CA, et al. Trends in the Use of Telehealth During the Emergence of the COVID-19 Pandemic — United States, January–March 2020. Morbidity and Mortality Weekly Report 2020; 69:1595–1599. DOI: http://dx.doi.org/10.15585/mmwr.mm6943a3

Prior to the pandemic, Common Sense Media estimated that six-in-ten students (58%) said they used the internet at their home to do homework every day or almost every day. The same study also found that approximately 15-16 million K-12 public school students lived in homes without either an internet connection or a device adequate for distance learning at home resulting in a homework gap.[8] This "homework gap" became a "learning gap" as the pandemic led to an increased reliance on virtual learning in K-12 schools and institutions of higher education across America.

Goals

As the pandemic has served to highlight, understanding where high-speed internet is accessible *and* accessed (where households subscribe to broadband services) will continue to play a critical role in the well-being of individuals, the economy, and communities. Recognizing this need, Argonne National Laboratory (Argonne) developed the IAI to focus on the connectivity challenge: broadband availability and broadband adoption or subscription. Later iterations or enhancements may look at challenges related to device availability, digital skills, and applications, such as for health screenings, workforce training, and education.

The goal of the IAI is to provide an easy-to-understand metric that can be flexibly applied to a wide variety of research and decision-making purposes. The IAI uses nationwide, publicly available data from the National Telecommunications and Information Administration (NTIA), Federal Communications Commission (FCC), and the U.S. Census Bureau (Census) American Community Survey (ACS) to measure both availability (internet infrastructure and speed) and household adoption by combining advertised internet availability and speed data as reported by internet service providers (ISPs) with household subscription data.

Researchers and policymakers can use this index to better understand the potential impacts of variable internet accessibility or as one factor in more complex models looking at broader impacts of disparity and inequality nationwide. For example, policymakers can assess the implications of COVID-19's impact on education, healthcare, economic development, and other critical services through the lens of high-speed internet access.

This publicly available resource will assist government and non-government stakeholders with analysis related to infrastructure deployment in current broadband deserts, as well as programs to increase the number of lower income individuals that can afford internet subscription services. Additionally, this index can identify locations where government and not-for-profit programs and services should not rely on a household's internet access to provide services, for example individuals in households that do not have internet access may not have email addresses or be able to complete on-line forms.

During the IAI development process, Argonne consulted with staff from the NTIA, FCC, Department of Education, and the Federal Emergency Management Agency (FEMA) to solicit technical input.

8 Chandra, S., Chang, A., Day, L., Fazlullah, A., Liu, J., McBride, L., Mudalige, T., Weiss, D., (2020). Closing the K–12 Digital Divide in the Age of Distance Learning. San Francisco, CA: Common Sense Media. Boston, Massachusetts, Boston Consulting Group.

Data Sources

Table 1: Data sources used to compute the ANL Internet Accessibility Index.

Index Data	Data Source	Reference Period
Median Download Speed within a tract; Maximum Download speed within a block	FCC Fixed Broadband Deployment Data Form 477	Dec 31, 2020 data
Percent of blocks within a tract with download speeds ≥ 25 mbps	FCC Form Fixed Broadband Deployment Data Form 477	Dec 31, 2020 data
Percent of households with a broadband subscription (excluding cellular-only subs)	Census Bureau American Community Survey (ACS) Table S2801 5-year estimates	2015 – 2019
User median download speed	National Telecommunications and Information Administration Indicators of Broadband Need: Ookla Median download speed	July – Dec. 2020

To compose the IAI, Argonne relied upon three nation-wide datasets.

FCC Fixed Broadband Deployment Data (Form 477)

The most extensive publicly available data set detailing available service and internet speeds is collected by the FCC in their Fixed Broadband Deployment Data Form 477 (FCC Broadband; Table 1).[9] These data are self-reported by the ISPs and list information for both business and consumer/residential services such as maximum advertised upload and download speeds (megabits • second^{-1}; mbps) and the technology deployed to achieve those speeds. Because these data are self-reported there is the potential for broadband coverage to be overstated.

For the IAI, Argonne used all the available FCC speed information for the consumer/mass market/residential data regardless of technology.[10] Argonne derived two variables from the maximum advertised download speeds reported in the FCC Broadband data.

- *The national median of the maximum advertised download speed.* These data are reported at the census block-level. Argonne scaled the data up to the census tract-level to match the spatial scale of other data products used in the analysis. Argonne first calculated the maximum advertised download speed for a census tract from block-level information and then calculated the national median from these data. This median was then used as the basis

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9 Federal Communications Commission. Fixed Broadband Deployment Data from FCC Form 477 https://www.fcc.gov/general/broadband-deployment-data-fcc-form-477

10 Federal Communications Commission. *Technology Codes used in Fixed Broadband Deployment Data*. https://www.fcc.gov/general/technology-codes-used-fixed-broadband-deployment-data

for comparison in the speed ratio detailed below. Using the median as a reference point resulted in comparing speeds observed within a given census tract with those advertised as available at the typical tract, nationally. The FCC's Broadband Speed Guide indicates that the minimum download speed recommended for activities such as education and telecommuting is between 5 and 25mbps[11].

- *Percentage of census blocks within a census tract where ISPs advertise speeds greater than 25mbps.* The FCC Broadband Speed Guide defines the minimum threshold for "Advanced" broadband service as 25mbps. As such, Argonne also calculated the percentage of blocks within each tract that reported maximum advertised download speeds ≥ 25mbps.

ACS 5-year-estimate broadband subscription data (Table S2801)
To capture on-the-ground household accessibility to broadband infrastructure, Argonne used the American Community Survey (ACS) Table S2801 5-year estimate (2015-2019) internet subscription data (ACS Subscription; Table 1).[12] The primary advantage of using multiyear estimates is the increased statistical reliability of the data compared with that of single-year estimates, particularly for small geographic areas and small population subgroups. The inclusion of these survey data with detailed household adoption metrics helps to reduce potential overstating of maximum download speeds reported by the ISPs to the FCC. The ACS details broadband internet subscriptions based on households who said 'yes' to at least one of the following types of internet subscription: broadband such as cable, fiber optic, or DSL; a cellular data plan; satellite; or a fixed wireless subscription. As the FCC Broadband data refers to in-home broadband speeds only, the cellular-only respondents were removed from this broadband subscription metric. A map of cellular-only subscription levels can be found in Appendix A.

Indicators of Broadband Need Ookla speed test data[13]
For the 2nd quarter of 2022 update, Argonne prioritized the inclusion of user speed test data. This provides the opportunity to compare actual recorded user experiences with the potential download speeds reported by ISP's. The Ookla[14] data set presented in the Indicators of Broadband Need covers a period of July to December 2020.

Method

The IAI is calculated as the product of 3 factors. The first two factors gauge the quality and availability of high-speed internet; 1) the ratio of median user download speeds for a census tract to the median maximum advertised national download speed (the Download Speed Ratio) and 2) the percent of census blocks within a census tract with available Advanced Broadband Speeds (≥ 25 mbps) (Percent Advanced Broadband Speed). The third factor represents the public's ability to access the available

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11 Federal Communications Commission. *Broadband Speed Guide.* https://www.fcc.gov/consumers/guides/broadband-speed-guide

12 ACS Table S2801 5-year averages (2015-2019) https://data.census.gov/cedsci/table?q=Computer&t=Telephone,%20Computer,%20and%20Internet%20Access&tid=ACSST5Y2018.S2801

13 National Telecommunications and Information Administration Indicators of Broadband Need. https://broadbandusa.maps.arcgis.com/apps/webappviewer/index.html?id=e2b4907376b548f892672ef6afbc0da5

14 How Ookla Ensures accurate, reliable data: A guide to our metrics and methodology. May 12, 2021. https://www.ookla.com/articles/how-ookla-ensures-accurate-reliable-data-2021

high-speed internet by calculating the percent of households with broadband subscriptions per census tract (Percent Broadband Subscriptions).

Download Speed Ratio

To match the spatial scale among data sources, Argonne scaled the FCC data from the census block-level to the tract level by calculating the median of the maximum advertised download speeds for all services in all blocks within a census tract. To create a scale between zero and one that can then be combined with the percent values of the other two factors, Argonne divided this census tract median user download speed value with the median maximum advertised download speed for blocks at the national level (currently 1000 mbps or 1 gigabit). Scaling download speeds by the national median also provides the ability to easily compare individual census tracts regardless of location (i.e., it is possible to compare a census tract from California to one in Puerto Rico).

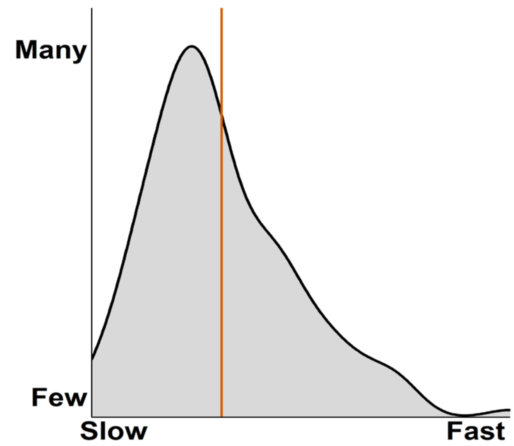

Figure 1: Example of a distribution with a distinct right tail. Notice how the mean (orange vertical line) is pulled to the right of the apex of the distribution curve. This occurs because a few 'Fast' values skew the mean towards the upper end.

The median user download speed data has a distinct right tail to the distribution because there are many more instances of middling to poor internet speeds across the country compared to the very few instances of census tracts with median user download speeds near the maximum observed (373 mbps; Ookla Indicators of Broadband Need data; Figure 1).

To reduce the influence of this long right tail, we applied a Box-Cox transformation[15] on both the median user download speeds and the national median download speeds. This transformation makes it easier to integrate the ratio with the ACS data and serves to make the data more-normally distributed, which allows the index to be used with a wider array of analytical methods such as regression analysis which assumes a normal distribution to the data. For a full description of the Box-Cox transformation method, please see Appendix B.

Index Calculation

All three census-tract scale factors are combined to create the IAI equation:

- Download Speed Ratio,
- Percent Advanced Speed, and
- Percent Broadband Subscriptions.

Argonne transformed the Percent Advanced Speed and Percent Broadband Subscriptions

Index Factor Definitions

Download Speed Ratio: ratio of median user download speeds to the median maximum advertised national download speed (1000 mbps).

Percent Advanced Speed: Percent of census blocks within a census tract with available Advanced Broadband Speeds (≥ 25 mbps).

Percent Broadband Subscriptions: percent of households with broadband subscriptions per census tract.

[15] Box, G.E.P. and D.R. Cox. 1964. An Analysis of Transformations. Journal of the Royal Society. Series B (Methodological). 26(2) pp. 211-252.

into proportions (0.0-1.0) to match that of the Download Speed Ratio.

$$IAI = Download\ Speed\ Ratio\ \times Percent\ Advanced\ Speed\ \times Percent\ Broadband\ Subscription \qquad [eq1]$$

The calculated index value scores a census tract on a numeric scale, where values near 0 represent areas with less internet access and greater values represent more internet access. As a result of scaling the download speed ratio to the national median, it is possible for the download speed ratio, and therefore the overall index score to be greater than 1. Download speed ratio greater than 1 would indicate that the census tract of interest has a user-experienced download speed that is greater than the typical maximum advertised download speed, nationally. In the index, a tract that scores closer to 1.0 on this index indicates: 1) that the user experience in that tract is comparable to the 'typical' tract nationally, 2) most of the blocks within the tract have advertised download speeds that are at or above the broadband threshold of 25 mbps, and 3) most households within the tract have a broadband internet subscription of some type. An example of how the index is calculated is detailed in eq2, below.

Example:

- Median user download speed for the tract: 25 mbps
- Median download speed, nationally: 1000 mbps
- Percent of blocks within the census tract with broadband speeds: 75% (0.75)
- Percent of households in the census tract with a broadband subscription: 65% (0.65)

$$\left(\frac{\text{BoxCox}(25)}{Box\ Cox\ (1000)}\right) \times 0.75\ \ \times 0.65\ = 0.03 \qquad [eq2]$$

To better analyze the results and to map the three individual factors and the IAI, Argonne sorted each of the data sets into seven bins. Argonne mapped the median of the user download speed data rather the Download Speed Ratio to make the actual reported download speeds more accessible for readers (Figure 2). To identify the best binning methodology for the data sets the research team used the Python Spatial Analysis Library, PySAL, and its Exploratory Spatial Data Analysis sub-package. Python is an open-source, high-level programming language that is used in social science research. The package includes nine potential binning methods.[16,17,18] Argonne found the best fits for the data sets were either the Natural Breaks method or the Jenks-Caspall classification method. The Jenks-Caspall method reduces the potential for outliers within each data class and maximizes variation between data classes. Binning methods used for each variable are presented in Table 4.

After binning the datasets into seven bins, the research team created choropleth maps using color to illustrate each of the seven bins.

16 The Python Exploratory Spatial Data Analysis Package includes the following nine binning methods: Equal Interval, Fisher Jenks, Head Tail Breaks, Jenks Caspall, Maximum Breaks, Natural Breaks (kmeans, stochastic), Quantiles, Percentiles, and Standard Mean.

17 Sergio Rey, Wei Kang, Levi John Wolf, mhwang4, Jay Laura, Philip Stephens, James Gaboardi, Charles Schmidt, Martin Fleischmann, and David C. Folch. "Pysal/Mapclassify: Mapclassify 2.3.0." Zenodo, 2020. https://pypi.org/project/mapclassify/

18 Mapclassify source code for classification schemes: https://pysal.org/mapclassify/

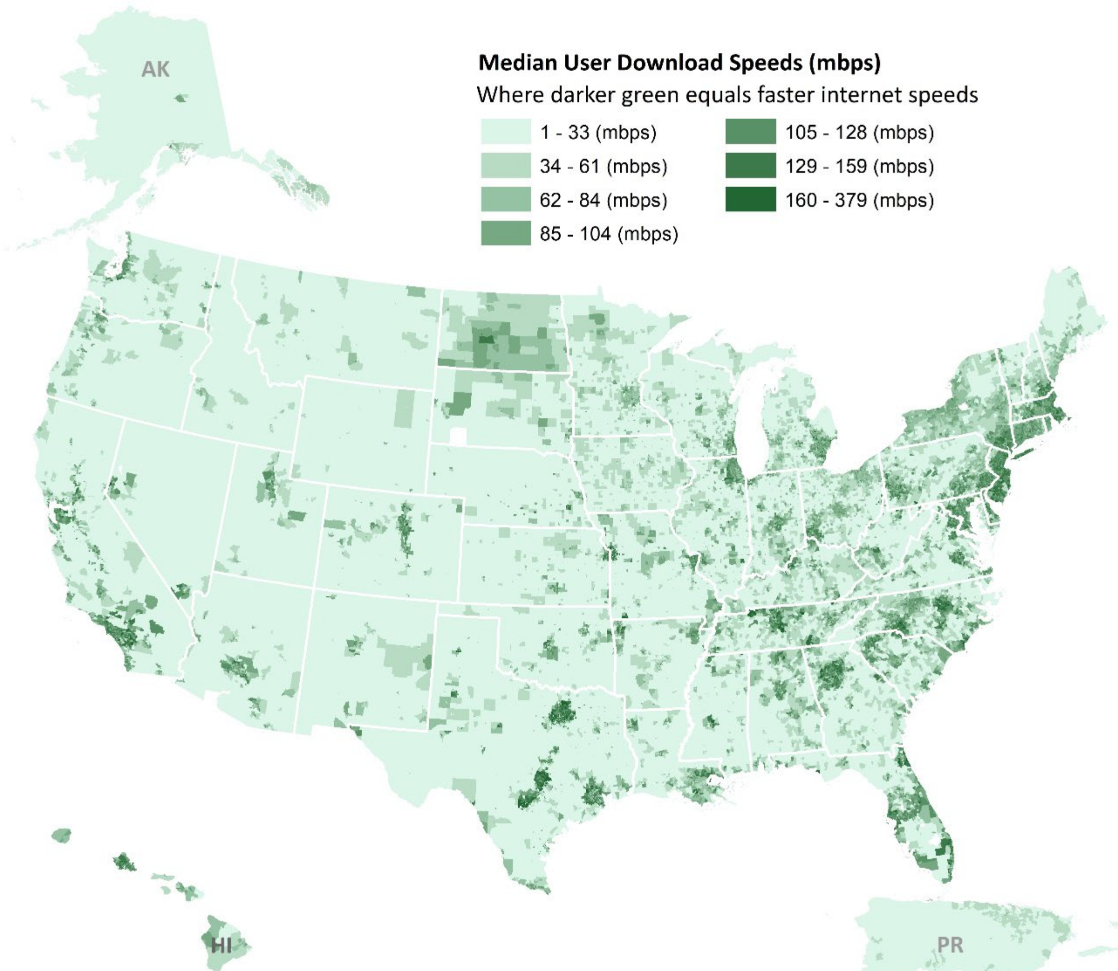

Figure 2: Census tract median user download speeds. Median user download speed is used in the calculation of the Download Speed Ratio described in the methods section. Darker green regions indicate faster median user download speeds (mbps). Data from Ookla NTIA Indicators of Broadband Need mapping tool (2022).

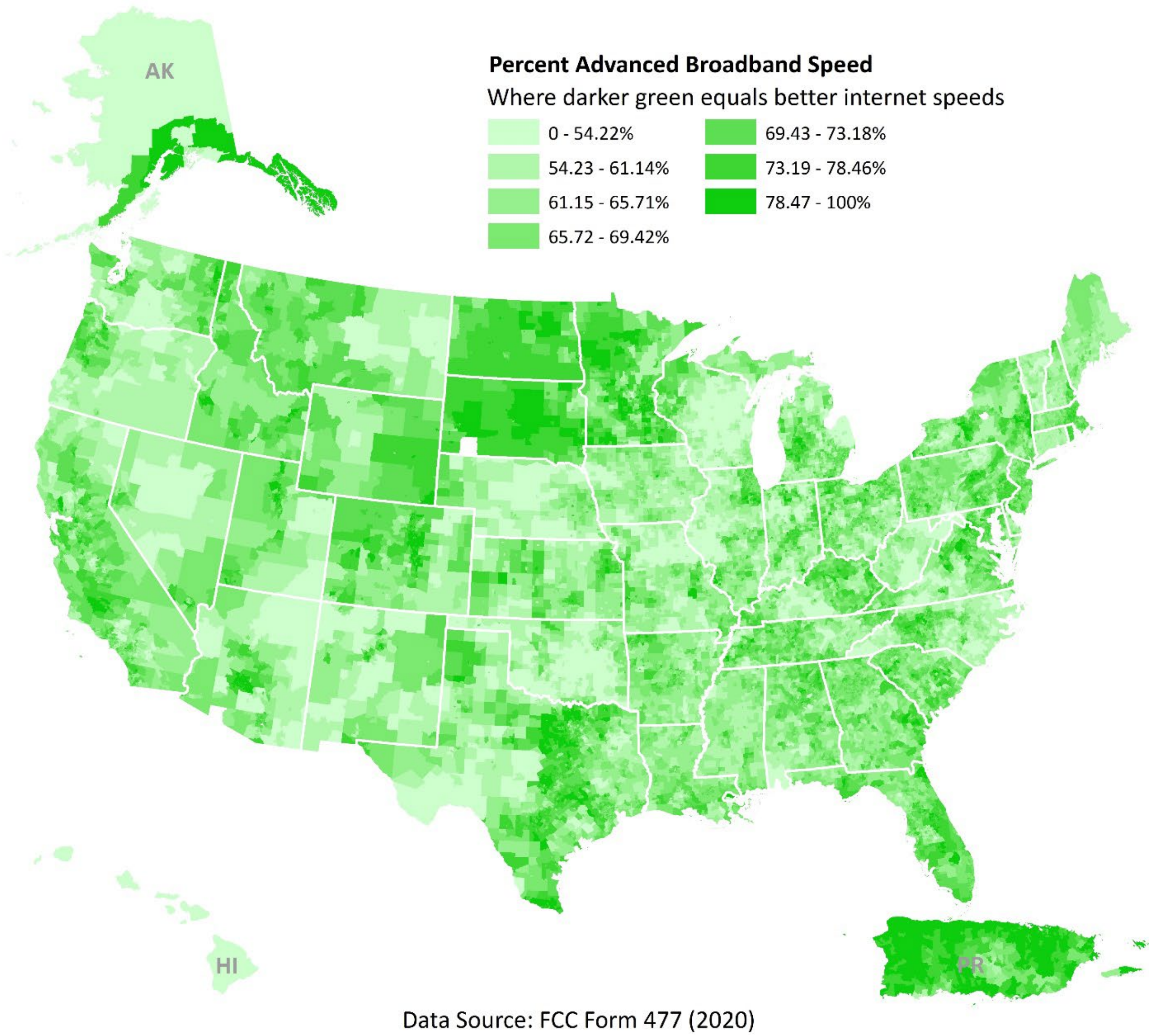

Figure 3: Advanced Broadband Speed for census tracts across the U.S. Darker green regions indicate more blocks within the tract have access to advertised download speeds greater than or equal to 25 mbps. Data from FCC Form 477 Data.

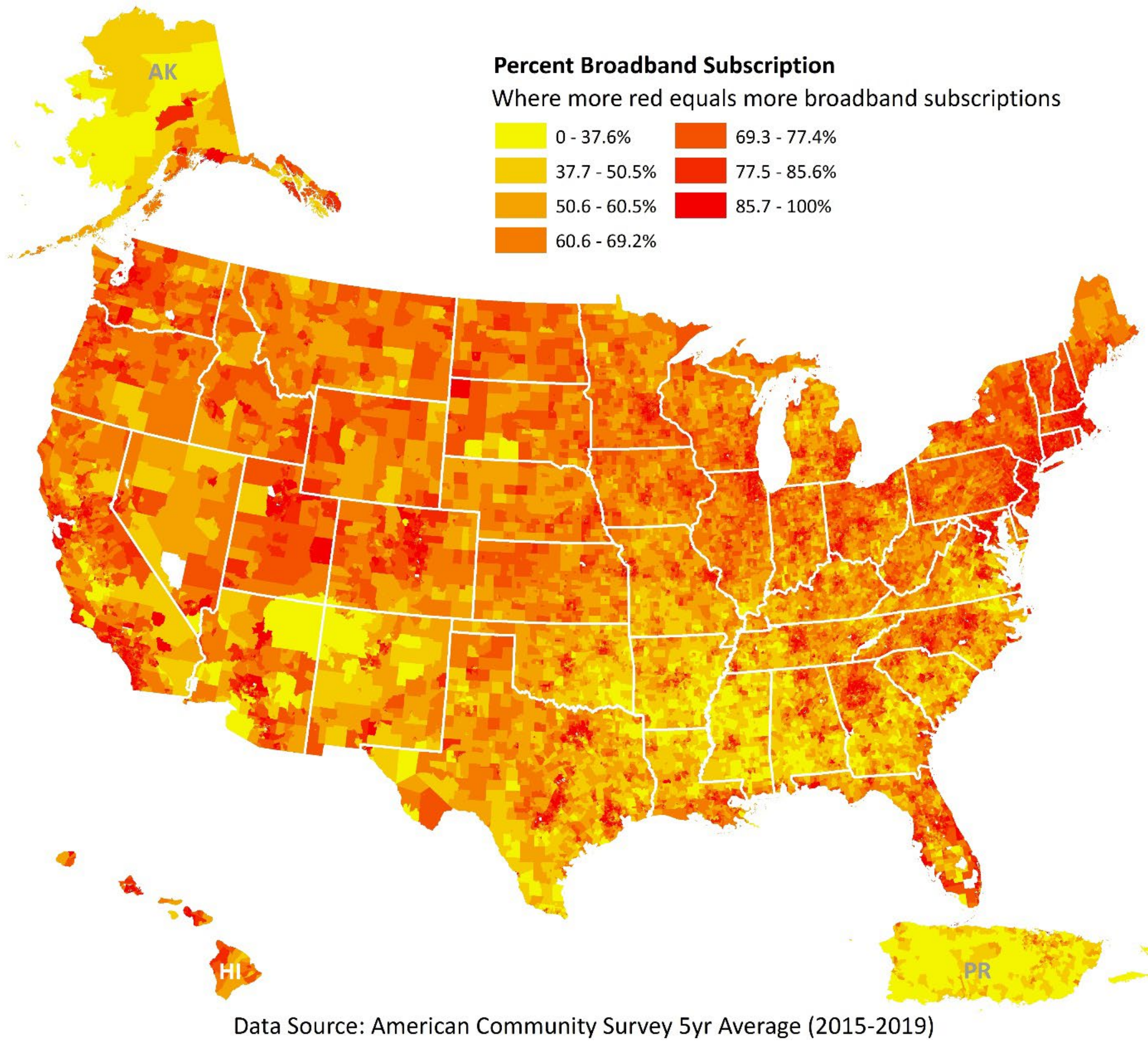

Figure 3: Percent Broadband Subscription for census tracts across the United States. Regions with darker color have more households that subscribe to a fixed internet service. Note: cell-only subscriptions are not included.

Internet Access Index

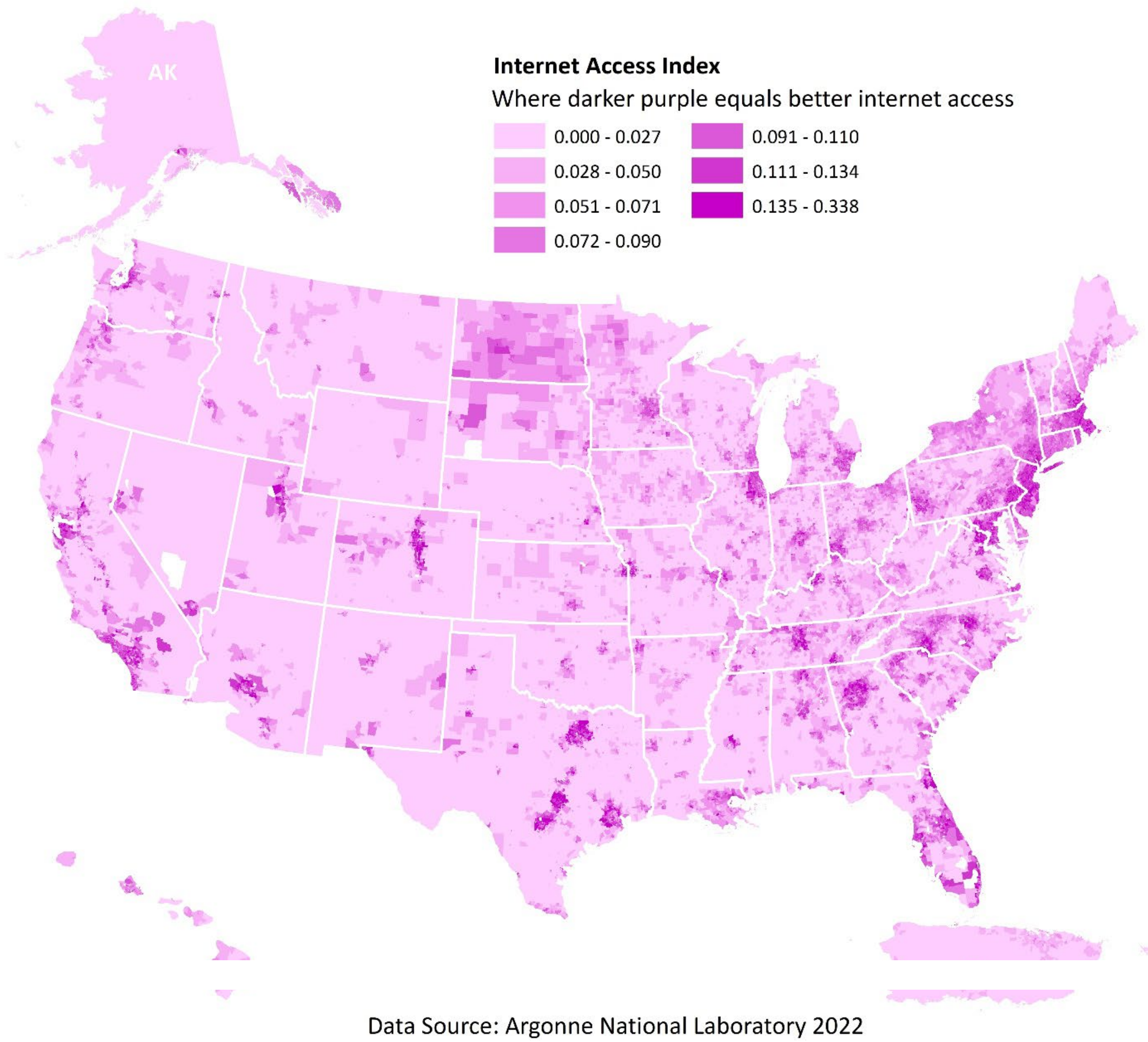

Figure 4: Resulting Internet Access Index (IAI) scores for the United States. The IAI is the product of the Download Speed Ratio, Percent Advanced Speed, and Percent Broadband Subscriptions. The index is scaled between 0 (poor access) and 1 (more access). Darker purple regions indicate higher IAI scores and therefore more internet access.

Limitations

Following are discussions of limitations concerning this approach:

Data quality. As with any index, the quality of the index is determined in large part by the quality and completeness of the inputs. Data collected by the FCC are self-reported by the ISPs, leading to the potential for broadband coverage to be overstated. There has been bipartisan agreement in Congress to improve data collection on broadband service availability, however funding has yet to follow. In April 2021, the FCC issued a rule, *Establishing the Digital Opportunity Data Collection Modernizing the FCC Form 477 Data Program*. This rule recognizes the need for more granularity and more accuracy in the data collection and requests additional public comment on the data collection process.[19] To improve the accuracy of the index, Argonne used NTIA's median user speed data for the 2nd quarter of 2022 update to this index. Argonne will continue to update the index to incorporate more granular and accurate data as it becomes available.

Missing Data. There are some instances of missing values in the data sets used. Because the ACS data are based on household survey data, there is always a chance of having tracts that are not sufficiently populated to be represented (e.g., national parks) or are reported by other means such as Tribal land. Calculations are available for 98.7% of the census tracts analyzed.

Lack of validation. There is no current dataset available to check the accuracy of the IAI. Argonne did compare the IAI to an index that has been used to better understand the potential digital divide that exists in the U.S. The Digital Divide Index (DDI) measures physical access/adoption of internet in technology across the country at the county level. The DDI uses similar data from the ACS and FCC, but layers in additional social measures such as: percent of homes without a computing device, percent of the population over 65, and the individual poverty rate among others[20]. To facilitate the comparison of IAI with the DDI, we aggregated the IAI from the census tract level to the county level. Overall, there exists a strong relationship (Pearson's $r = -0.40$; $p < 0.05$) between the IAI and the DDI for systematically selected states. Higher DDI values indicate greater distress (greater digital divide) and is inversely scaled to the IAI with the negative relationship expected.

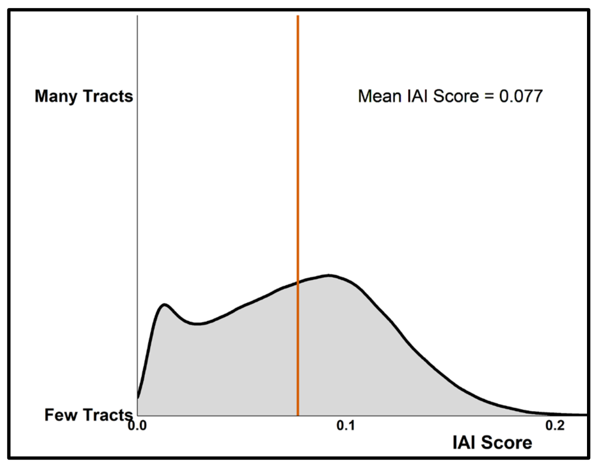

Figure 5: Density distribution curve for the resulting IAI scores.

19 FCC, "Establishing the Digital Opportunity Data Collection; Modernizing the FCC Form 477"Data Program," FCC-21-20, July 17, 2020, https://www.federalregister.gov/documents/2021/04/07/2021-04998/establishing-the-digital-opportunity-data-collection-modernizing-the-fcc-form-477-data-program

20 Gallardo, R. (2020). Digital Divide Index. Purdue Center for Regional Development. Retrieved from Digital Divide Index (DDI): http://pcrd.purdue.edu/ddi

Key Results

The IAI serves as a general measure of internet accessibility across the United States. Interesting highlights from the data include:

At the national scale, the mean IAI score is 0.077 (median = 0.078) with a minimum of 0 and a maximum of 0.338. A score of 1.0 of the IAI would mean that all blocks within the tract have access to the Advanced Broadband Speed, that users within the census tract experience download speeds equal to a ‘typical’ tract, nationally (currently 1000 mbps), and that all households within the tract have a fixed broadband subscription of some type. The IAI’s tract-level results are summarized at the state level and represent a ‘typical’ tract within each state (Table 2).

It is important to note that state-level summary does not show the variability of the census tract data. Argonne recommends using the IAI at the tract-level for the most accurate representation of the results as is shown in this example of Cook County, Illinois (Figure 7).

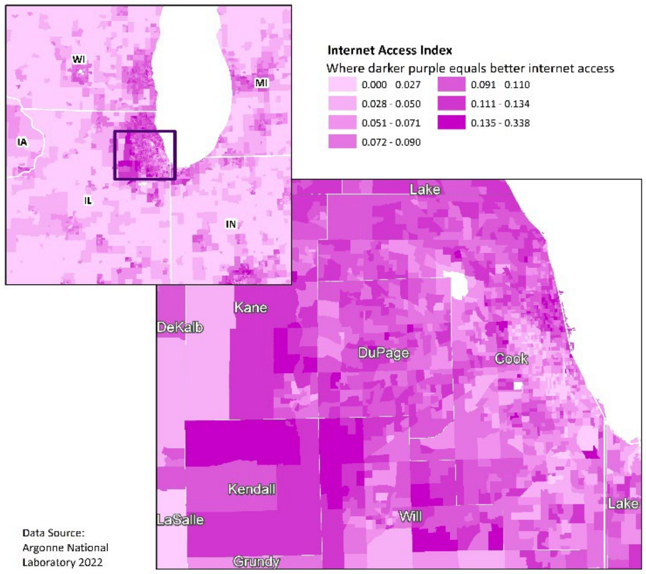

Figure 6: This view of the seven county region surrounding Chicago illustrates the variability of internet access at the census tract level.

Additional findings include:

- The District of Columbia showed the greatest average state-level score (0.12) and Puerto Rico the lowest (0.02) using the IAI.
- Michigan showed the greatest difference (0.34) between the minimum (0) and maximum (0.34) state IAI Scores, whereas Puerto Rico showed the smallest range (0.08) with a minimum IAI score of 0 and a maximum score of 0.08.
- The highest scoring census tract can be found in Washtenaw County, Michigan (0.338). 48% of the top 25 tracts are in Texas.
- The lowest scoring tracts using this index are generally located in more rural areas. Almost 32% of the 25 lowest scoring tracts are in Alaska.

Table 2. National-scale summary statistics for the Internet Index and variables used in its calculation.

Statistic	Median User Download Speeds (mbps)	Perc. Adv. Speeds	Perc. Broadband Sub.	Internet Index Score
Min	0.1	0.00 %	0.0 %	0.000
Q1	54.5	63.3 %	60.7 %	0.044
Median	89.8	68.5 %	72.7 %	0.078
Mean	87.6	67.8 %	70.4 %	0.077
Q3	116.214	73.0 %	82.5 %	0.107
Max	373.362	100.0 %	100.0 %	0.338
NA's	504	25	888	935

Median User Download Speeds

- Nationally, median user download speed is about 87.6 mbps and ranges from 0.1 mbps to 373.4 mbps (Table 2). The lowest median user download speeds come from Virginia and Pennsylvania and the fastest two tracts are in Michigan and Alabama.
- New Jersey has, on average, the highest user tract level internet speeds (131.4 mbps median user download speed), whereas Puerto Rico has, on average, the lowest speeds (26.5 mbps median user download speed).
- Michigan showed the greatest difference in median download speeds (difference = 371 mbps) from a high of 373 mbps to a low of 2 mbps.

Percent Broadband Subscriptions

- Nationally, approximately 70% of households subscribe to some form of fixed broadband services in a typical tract (Table 2). Percent Broadband Subscriptions range from census tracts with 0% (zero) to 100%. There are 26 census tracts that have zero Percent Broadband Subscriptions, with eight of those located in New York and 3 each in Texas and Puerto Rico.
- A total of 109 census tracts have estimates of 100 Percent Broadband Subscriptions, with New York and California accounting for 23 and 13 of those, respectively.
- New Hampshire had the highest mean subscription rate (80.62), and Puerto Rico recorded the lowest mean subscription rate (36.57%; Table 3).
- Variability in broadband subscriptions was greatest in New York, Oklahoma, Tennessee, Michigan, North Carolina, Texas, California, Florida, South Carolina, and Connecticut, where the range of Precent Broadband Subscriptions were 100. This means that there are tracts where all households have a broadband subscription of some type and tracts were zero households have a fixed broadband subscription of some type.
- Vermont saw the smallest difference (41.1%) between minimum (53.6%) and maximum (94.7%) Percent Broadband Subscriptions across tracts (Table 3).

Percent Advanced Speed

Having access to advanced broadband speeds will be necessary in an ever increasing remote-access society.

- Nationally, the average Percent Advanced Speed value ranged from 0% (zero) to 100% within a tract. Approximately 68% of the blocks within a ‘typical’ tract met or exceeded the threshold for advanced broadband speeds.

  - Nationally, 15 census tracts do not have access to advanced broadband speeds, with 11 tracts in Alaska and 4 tracts in Hawaii.
  - In 278 tracts, every block has access to advanced internet speeds, with Florida, Puerto Rico, and Michigan composing 46, 41 and 30 of those tracts, respectively.
- The District of Columbia, Puerto Rico, and Colorado show the greatest access to advanced broadband speed with averages of 86.26%, 79.19% and 78.06%, respectively (Table 3).
- Hawaii, West Virginia, and Oklahoma showed the lowest levels of access to advanced broadband speeds (41.43%, 55.47%, 55.55%, respectively).
- Alaska showed the greatest range between minimum and maximum Percent Advanced Speed (0% and 100%, respectively) and Rhode Island showed the smallest range (61.74% and 77.89%, respectively) with a difference of 16.15% (Table 3).

Summary

The IAI and accompanying map identify regions of the country that score very well where households have adequate access to broadband infrastructure. However, there are also many areas of that could be called broadband deserts where communities do not have quality access and therefore may find it difficult to participate in an increasingly virtual environment. These areas of inequity are not only realized at broad spatial scales, but can exist within the same city, or even from census tract to census tract as seen in northeastern Illinois (Figure 7). Presenting the IAI with census-tract granularity provides the means to target needed investments. The straight-forward nature of the index also allows for a rapid diagnosis of whether the challenges for an area are the result of a lack of infrastructure (low Download Speed Ratio/ Percent Advanced Speed) or are a lack of access (low Percent Broadband Subscriptions).

Future Research and Methodological Enhancements

This initial IAI is intended to serve as a foundational resource that can help to analyze broadband access related to critical services, such as education and healthcare. Argonne will continue to update and refine the IAI as new data becomes available and new analytic use cases are identified. Specific next steps could include:

- Additional analytic opportunities:
  - Exploration of household access to distance learning, and the identification with locations with a potential 'homework gap' where students required to attend school remotely do not have adequate access to the requisite infrastructure.
  - Analysis of areas where telework may be inhibited due to lack of adequate broadband access.
  - Identification of areas where improved internet access may facilitate greater access to expansive healthcare services.
  - Identification of areas where programs that rely on email addresses or digital forms need to provide accommodations for those without easy internet access.
- Methodology enhancements:
  - Scaling the index to multiple geographic extents (i.e., census block, school district, county) to allow for further analytic flexibility.
  - Further analysis of regions that do not meet the 25mbps threshold of broadband internet.
  - Implementation of machine learning approaches to identifying additional characteristics that either support or result in higher index values.

- Analysis of equitability of internet access by demographic and economic characteristics.
- Qualitative analysis of missing data from US territories beyond Puerto Rico.
- Continued and further collection of user download and upload speed data.

Table 3. State-level summaries showing mean values [minimum value, maximum value] calculated from tract-level data. Mean values can be interpreted as a typical or average tract within each state or territory.

FIPS	State/Territory Name	State/Territory Abb	Perc. Broadband Sub.	Median User Download Speed (mbps)	Perc. Adv. Speeds	IAI Value
01	Alabama	AL	58.42 [20.2, 96.6]	65.51 [5, 202]	65.01 [30.45, 80.77]	0.05 [0, 0.17]
02	Alaska	AK	69.37 [21.1, 92.8]	45.05 [1, 142]	66.13 [0, 100]	0.05 [0, 0.16]
04	Arizona	AZ	71.69 [6.4, 100]	77.61 [2, 176]	75.15 [34.92, 87.92]	0.08 [0, 0.21]
05	Arkansas	AR	54.91 [21.4, 91.9]	45.71 [2, 197]	66.36 [49.35, 82.6]	0.04 [0, 0.15]
06	California	CA	76.19 [0, 100]	105.42 [3, 248]	67.32 [40.41, 84.98]	0.09 [0, 0.23]
08	Colorado	CO	78.08 [17.6, 100]	88.6 [5, 202]	78.06 [35.91, 89.73]	0.1 [0, 0.21]
09	Connecticut	CT	77.47 [0, 100]	97.13 [17, 197]	59.9 [48.95, 73.12]	0.08 [0, 0.17]
10	Delaware	DE	75.86 [35.4, 99.1]	102.9 [14, 238]	67.11 [50, 81.08]	0.09 [0.01, 0.22]
11	District of Columbia	DC	73.42 [37.3, 100]	109.61 [37, 250]	86.26 [77.55, 94.65]	0.12 [0.03, 0.19]
12	Florida	FL	72.29 [0, 100]	92.21 [5, 241]	69.08 [50.86, 86.96]	0.08 [0, 0.22]
13	Georgia	GA	67.55 [9.5, 98.9]	80.99 [5, 218]	68.4 [51.39, 84.52]	0.07 [0, 0.18]
15	Hawaii	HI	76.68 [34.1, 100]	102.06 [12, 223]	41.43 [34.05, 52.79]	0.06 [0.01, 0.15]
16	Idaho	ID	70.25 [34.4, 91.9]	43.42 [7, 125]	74.14 [56.23, 86.21]	0.05 [0.01, 0.13]
17	Illinois	IL	70.15 [17.6, 100]	82.48 [4, 224]	66.95 [38.5, 84.78]	0.07 [0, 0.17]
18	Indiana	IN	66.12 [15.7, 100]	72.57 [6, 222]	64.03 [32.94, 84.34]	0.06 [0, 0.17]
19	Iowa	IA	67.54 [21, 100]	51.03 [7, 141]	62.05 [32.63, 80.28]	0.04 [0.01, 0.14]
20	Kansas	KS	68.89 [24.1, 97.2]	71.43 [5, 231]	67.53 [40.78, 83.95]	0.06 [0, 0.19]
21	Kentucky	KY	65.34 [23, 100]	74.22 [1, 234]	67.24 [37.99, 83.53]	0.06 [0, 0.18]
22	Louisiana	LA	60.35 [7, 100]	63.57 [2, 211]	61.34 [32.44, 78.21]	0.05 [0, 0.15]
23	Maine	ME	73.65 [41.1, 93.1]	54.11 [6, 148]	62.41 [51.44, 72.17]	0.05 [0, 0.12]
24	Maryland	MD	76.24 [17.1, 98.6]	103.4 [9, 262]	69.1 [44.44, 82.15]	0.1 [0.01, 0.19]
25	Massachusetts	MA	78.66 [33, 100]	112.48 [3, 302]	69.44 [50.78, 82.15]	0.1 [0, 0.19]
26	Michigan	MI	68.56 [0, 100]	74.7 [2, 373]	66.71 [36.56, 84.67]	0.07 [0, 0.34]
27	Minnesota	MN	73.76 [31.2, 97.4]	63.09 [8, 152]	75.7 [50, 87.21]	0.07 [0.01, 0.16]
28	Mississippi	MS	51.87 [17.5, 95.6]	42.81 [3, 236]	64.75 [50.16, 77.92]	0.03 [0, 0.18]
29	Missouri	MO	66.18 [22.8, 100]	84.24 [4, 277]	63.65 [36.83, 81.27]	0.07 [0, 0.19]

30	Montana	MT	68.86 [24.4, 94.9]	42.02 [4, 113]	67.02 [43.38, 82.86]	0.04 [0, 0.13]
31	Nebraska	NE	71.75 [37.1, 95.6]	73.81 [5, 236]	63.1 [33.75, 76.64]	0.06 [0, 0.18]
32	Nevada	NV	72.07 [19.8, 97.9]	81.08 [4, 156]	67.91 [45.5, 85.29]	0.07 [0, 0.17]
33	New Hampshire	NH	80.62 [46.5, 96.2]	91.13 [7, 192]	63.66 [50.9, 82.74]	0.08 [0.01, 0.16]
34	New Jersey	NJ	77.58 [18.8, 100]	131.41 [17, 310]	69.15 [52.65, 80]	0.11 [0.01, 0.24]
35	New Mexico	NM	60.75 [2, 100]	54.09 [5, 156]	66.96 [39.89, 86.17]	0.05 [0, 0.17]
36	New York	NY	73.65 [0, 100]	123.12 [2, 292]	69.56 [50, 86.31]	0.1 [0, 0.24]
37	North Carolina	NC	69.78 [0, 100]	92.68 [4, 234]	65.17 [43.86, 81.96]	0.08 [0, 0.2]
38	North Dakota	ND	70.08 [39.8, 95.2]	68.39 [12, 157]	73.13 [51.07, 83.15]	0.07 [0.01, 0.17]
39	Ohio	OH	69.94 [8.9, 100]	76.31 [5, 229]	66.54 [44.77, 83.71]	0.07 [0, 0.16]
40	Oklahoma	OK	61.38 [0, 100]	62.62 [3, 197]	55.55 [29.15, 76.48]	0.04 [0, 0.15]
41	Oregon	OR	76.01 [39.1, 97.4]	73.01 [4, 163]	67.22 [33.64, 86.1]	0.07 [0, 0.17]
42	Pennsylvania	PA	72.15 [25.1, 100]	90.9 [0, 244]	69.79 [47.82, 85.1]	0.08 [0, 0.23]
44	Rhode Island	RI	75.27 [29.9, 93.1]	105.52 [10, 206]	70.43 [61.74, 77.89]	0.1 [0.01, 0.17]
45	South Carolina	SC	64.6 [0, 100]	77.97 [6, 216]	68.76 [41.62, 84.18]	0.07 [0, 0.18]
46	South Dakota	SD	69.35 [22.4, 93.5]	54.34 [7, 147]	75.26 [48.32, 85.69]	0.06 [0.01, 0.15]
47	Tennessee	TN	64.11 [0, 100]	79.07 [4, 238]	66.61 [42.7, 82.05]	0.06 [0, 0.19]
48	Texas	TX	65.58 [0, 100]	100.97 [4, 279]	70.27 [36.02, 86.8]	0.08 [0, 0.31]
49	Utah	UT	78.12 [9.6, 97.4]	84.91 [3, 190]	75.78 [43.38, 87.65]	0.09 [0, 0.2]
50	Vermont	VT	74.53 [53.6, 94.7]	52.27 [5, 164]	56.86 [42.56, 74.39]	0.04 [0, 0.11]
51	Virginia	VA	73.13 [24.5, 100]	88.45 [5, 237]	68.27 [47.51, 86.13]	0.08 [0, 0.23]
53	Washington	WA	79.2 [21.2, 100]	84.86 [2, 188]	66.34 [33.68, 85.48]	0.08 [0, 0.18]
54	West Virginia	WV	66.25 [34.8, 89.2]	65.03 [5, 212]	55.47 [36.99, 72.71]	0.04 [0, 0.13]
55	Wisconsin	WI	70.52 [22, 95.6]	77.52 [5, 243]	58.37 [33.06, 78.34]	0.06 [0, 0.19]
56	Wyoming	WY	72.08 [40.9, 89.4]	44.21 [5, 110]	67.69 [42.65, 83.9]	0.04 [0, 0.13]
72	Puerto Rico	PR	36.57 [0, 77.9]	26.59 [2, 64]	79.19 [56.56, 91.43]	0.02 [0, 0.08]

Table 4: Binning Methods of specific variables

Variable	Binning Method
Percent with Broadband Subscription	Natural Breaks
Median User Download Speed	Jenks-Caspall
Maximum Download Speed	Natural Breaks
Percent Advanced Speeds	Jenks-Caspall
Internet Access Index Value	Jenks-Caspall
Number of Providers	Natural Breaks
Percent with cellular-only BB access	Natural Breaks

Appendix A: Select Index Tables and Figures

Table A-1: List of the 25 highest scoring tracts on the Internet Index.

Rank	Census Tract	County	State	IAI Value	Median User Download Speed (mbps)	Max. Download Speed (mbps)	Perc. Adv. Speeds	Max Download Speed (State)	Perc. Broadband Sub.
1	Census Tract 4219	Washtenaw County	Michigan	0.338	373	1000	70.97	2000	100.00
2	Census Tract 121	Taylor County	Texas	0.308	279	1000	80.57	10000	100.00
3	Census Tract 1316.12	Bexar County	Texas	0.255	233	1000	86.80	10000	88.10
4	Census Tract 1719.22	Bexar County	Texas	0.245	234	1000	85.52	10000	85.80
5	Census Tract 222.02	Salem County	New Jersey	0.242	310	1000	75.29	10000	77.60
6	Census Tract 305.10	Collin County	Texas	0.241	229	1000	76.63	10000	95.80
7	Census Tract 6100	Dutchess County	New York	0.240	292	1000	60.87	1000	100.00
8	Census Tract 86.01	New York County	New York	0.237	221	1000	81.82	1000	90.70
9	Census Tract 1720.02	Bexar County	Texas	0.237	224	1000	80.40	10000	91.20
10	Census Tract 1817.29	Bexar County	Texas	0.235	220	1000	80.89	10000	91.30
11	Census Tract 1058.12	Bucks County	Pennsylvania	0.234	244	1000	75.47	10000	89.90
12	Census Tract 1720.07	Bexar County	Texas	0.234	219	1000	79.90	10000	92.10
13	Census Tract 77	Queens County	New York	0.233	234	1000	78.08	1000	89.50

14	Census Tract 4913.02	Fairfax County	Virginia	0.232	233	1000	73.91	10000	94.30
15	Census Tract 70	New York County	New York	0.232	211	1000	83.33	1000	90.10
16	Census Tract 129	Taylor County	Texas	0.231	222	1000	74.89	10000	96.20
17	Census Tract 4015.01	Delaware County	Pennsylvania	0.231	243	1000	81.63	10000	82.60
18	Census Tract 6080.13	San Mateo County	California	0.230	203	1000	80.39	10000	95.70
19	Census Tract 1821.05	Bexar County	Texas	0.230	227	1000	78.69	10000	89.60
20	Census Tract 81	Queens County	New York	0.229	230	1000	78.21	1000	89.00
21	Census Tract 19	Queens County	New York	0.227	212	1000	76.90	1000	95.20
22	Census Tract 1316.10	Bexar County	Texas	0.225	225	1000	79.64	10000	87.30
23	Census Tract 1719.21	Bexar County	Texas	0.225	233	1000	78.90	10000	85.40
24	Census Tract 1720.06	Bexar County	Texas	0.223	212	1000	80.08	10000	90.00
25	Census Tract 6077.02	San Mateo County	California	0.223	212	1000	84.13	10000	85.50

Table A-2: List of the 25 lowest, non-zero, scoring tracts on the internet index. Index values of 0.000 in this table are the result of rounding. Results are presented in ascending order.

Rank	Census Tract	County	State	IAI Value	Median User Download Speed (mbps)	Max. Download Speed (mbps)	Perc. Adv. Speed	Max Download Speed (State)	Perc. Broadband Sub.
1	Census Tract 2	Yukon-Koyukuk Census Area	Alaska	0.000	7	40	0.305	1000	32.50
2	Census Tract 1	Kodiak Island Borough	Alaska	0.000	6	50	0.363	1000	65.70
3	Census Tract 3	Bethel Census Area	Alaska	0.000	6	35	1.461	1000	28.70
4	Census Tract 17	Fairbanks North Star Borough	Alaska	0.000	7	50	1.214	1000	35.60
5	Census Tract 1	Nome Census Area	Alaska	0.000	4	35	2.681	1000	32.00
6	Census Tract 9400	Socorro County	New Mexico	0.000	8	35	49.711	5000	2.00
7	Census Tract 9421	San Juan County	Utah	0.000	3	35	48.015	10000	9.60
8	Census Tract 9450	Coconino County	Arizona	0.000	5	115	51.042	5000	6.40
9	Census Tract 9400.12	Navajo County	Arizona	0.000	3	35	50.710	5000	15.70
10	Census Tract 9305	Butler County	Kentucky	0.000	1	1000	48.214	1024	50.40
11	Census Tract 3	East Carroll Parish	Louisiana	0.000	2	1000	59.152	10000	24.40
12	Census Tract 9409	Sandoval County	New Mexico	0.001	5	100	50.674	5000	8.20
13	Census Tract 4	Yukon-Koyukuk Census Area	Alaska	0.001	2	35	29.324	1000	35.10

14	Census Tract 305.01	Crittenden County	Arkansas	0.001	2	1000	60.819	10000	40.60
15	Census Tract 9443	Apache County	Arizona	0.001	7	115	47.987	5000	7.30
16	Census Tract 19	Fairbanks North Star Borough	Alaska	0.001	6	1000	7.330	1000	53.30
17	Census Tract 20	Coconino County	Arizona	0.001	2	1000	57.666	5000	61.40
18	Census Tract 48	San Juan Municipio	Puerto Rico	0.001	5	500	81.328	1000	6.90
19	Census Tract 9400	Cattaraugus County	New York	0.001	2	100	50.000	1000	45.00
20	Census Tract 9584	Lares Municipio	Puerto Rico	0.001	8	100	71.429	1000	5.60
21	Census Tract 9426	Apache County	Arizona	0.001	6	115	48.932	5000	11.00
22	Census Tract 9422.02	Coconino County	Arizona	0.001	4	35	48.613	5000	20.80
23	Census Tract 9437	McKinley County	New Mexico	0.001	6	115	53.705	5000	12.60
24	Census Tract 9449.02	Apache County	Arizona	0.001	7	115	49.964	5000	10.90
25	Census Tract 4	Southeast Fairbanks Census Area	Alaska	0.001	8	1000	12.519	1000	42.80

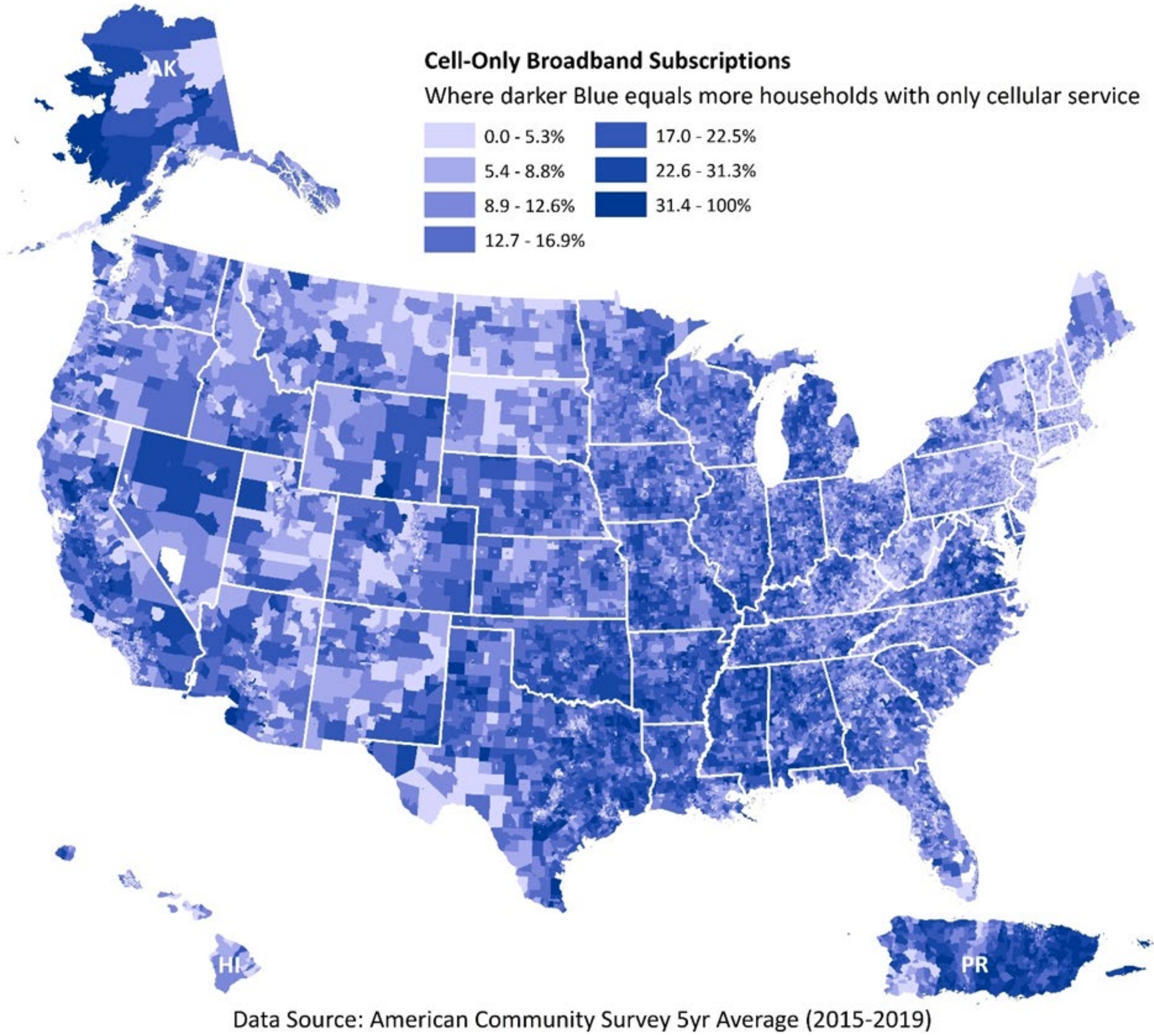

Figure A-1: National map of households with cellular-only broadband subscriptions presented at the census tract level (ACS 5-yr average 2015-2019). Darker blue hues represent areas where more households have cell-only subscriptions.

Appendix B: Data Transformation Methodology

To match the spatial scale among data sources, Argonne scaled the FCC Form 477 data up from the census block level to the tract level. To do this, the median maximum advertised download speed for blocks at the national level is used in the ratio calculation. Tract-level user download speed data (Ookla data) were downloaded from the National Broadband Access Map and used in the following processes.

A Box-Cox transformation[21] (λ= 0.75) was performed on the entire distribution of median user download speeds (n = 74,001). After optimizing for λ, the median national download speed (1000 mbps) was transformed using the same equation prior to the calculation of the ratio (eq2). The transformed numbers are then used to calculate the Download Speed Ratio that is then used in the greater IAI calculation.

A Box-Cox transformation was performed on these data as the original data have a distinct long right tail. Without the transformation this tail would persist through the index calculation, leading to less actionable results for end users. Performing the transformation on these data prior to the ratio calculation results in a final index distribution scaled between 0 and 1 that approximates a normal distribution and allows for quantitative differences to be more easily described at lower index values.

[21] Box, G.E.P. and D.R. Cox. 1964. An Analysis of Transformations. Journal of the Royal Society. Series B (Methodological). 26(2) pp. 211-252.

Appendix C. Record of Changes

Release	**Date**	**Notes**
Version 1	May 2021	Original release
Version 2	August 2022	Added the NTIA's Indicators of Broadband Need, Ookla speed test data as a data source. Changed denominator in the download speed ratio.