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OPPORTUNITIES AND CHALLENGES FOR RURAL BROADBAND INFRASTRUCTURE INVESTMENT

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Abstract
Insufficient internet access is holding back local economies, reducing educational outcomes, and creating health disparities in rural areas of the U.S. At present, federal and state funding is available for rural broadband infrastructure deployment, but existing efforts have not invested in analytical work to maximize efficiency and minimize cost. In this study, we use a state-of-the-art matrix (SAM) to identify key challenges and opportunities facing rural broadband infrastructure from previous research and government reports. We focus on six themes: (1) technology, (2) hardware costs, (3) financing, (4) adoption, (5) regulatory/legal, and (6) management. We highlight key issues to be addressed by both private and public decision-makers to effectively manage broadband investment as well as engage stakeholders to improve access and adoption. Much of the challenge for rural broadband infrastructure is related to a low return on investment due to high capital costs and low population densities. However, there are many innovative approaches to overcoming this barrier from technical, policy, and social perspectives. Unfortunately, adoption and management are understudied and would benefit from additional research to design effective decision-making tools and programs. From a systems perspective, solutions that leverage tools from a diverse set of perspectives, rather than purely focusing on technology deployment, are more likely to be sustainable in the long-term. We outline an agenda for future work based on the needs of rural communities as well as local and state governments.

Keywords
Rural Broadband, State-of-the-Art Matrix, Strategic Planning, Infrastructure

Introduction
High-speed rural internet access is associated with increased incomes and reduced unemployment via increased opportunities for remote work and the ability to expand brick and mortar enterprises online (Whitacre et al., 2014). In fact, econometrics analysis suggests that a 10% increase in fixed broadband access increases GDP in developed countries by approximately 1.2% (Qiang et al., 2009). Consequently, governments around the world have invested funds to deploy broadband infrastructure in underserved areas.

In addition to increasing access, rural broadband efforts aim to improve the quality of service by providing advanced capabilities. The U.S. Congress defines "advanced telecommunications capability" as that which allows users to "originate and receive high-quality voice, data, graphics, and video" services (47 U.S.C. 1302, 1996). The U.S. Federal Communications Commission (FCC) has established download/upload speed benchmarks of 25 Mbps/3 Mbps for fixed services and 10 Mbps/3 Mbps (median) for mobile services (FCC, 2018). Beyond economic benefits, improved broadband services can improve health outcomes by increasing access to telemedicine in rural areas that are far from a doctor or hospital as well as education outcomes by allowing students to access online learning resources at school.

However, a recent study by the FCC shows that rural and tribal communities still lag behind in broadband deployment. In rural areas, only 68.6% of Americans have access to both fixed and mobile LTE broadband services (at any speed), compared to 97.9% in urban areas (FCC, 2018). Mobile internet access has expanded more rapidly than fixed internet access due to the reduced cost of mobile infrastructure. However, as of 2018, the FCC has determined that "mobile services are not currently full substitutes for fixed services" (FCC, 2018). Beyond the issues associated with a reduced speed standard, mobile services may have data caps (depending on the plan), limit the number of devices that can be tethered, and tend to have more reliability problems than a fixed connection.

Montana, Mississippi, and Arkansas, which represent parts of the country with large rural areas, have the lowest broadband access statistics (BroadbandNow, 2018). Census data suggests that lower-income counties tend to have lower subscription rates and these trends are amplified in rural areas. Although the American Community Survey does not ask why people do or do not subscribe to internet services, rural areas may have lower subscription rates due to poor service and reduced competition, which increase perceived cost (Census, 2018). Poor internet access is especially egregious on Tribal lands. In fact, in 2018, the U.S. Government Accountability Office found that FCC data overstated tribal access to broadband, which may have negative implications for availability of federal funding for infrastructure investment (GAO, 2018).

At present, federal and state rural broadband investment is focused on deployment with limited support for research activities to increase cost-effectiveness and leverage system efficiencies. There is a need for analytical research to guide decision-making and strategic planning. In order to identify opportunities for this type of research, this paper uses a state-of-the-art matrix (SAM) to identify gaps in the literature and determine key areas for future research.

Methods

An integrated literature review is complemented by a SAM analysis to illustrate the topics covered by a given research article. Integrated literature reviews are valuable for synthesizing large bodies of literature to identify new theories and framework for further research. SAM analyses have been effectively used to supplement integrated literature reviews by identifying research gaps for both electric vehicles (Egbue et al., 2012) and microgrid energy systems (Hale & Long, 2018). SAM analyses are particularly effective for evaluating the coverage of a body of literature related to complex systems that can be addressed from multiple perspectives (i.e. technical, economic, social, organizational).

In a bottom-up approach, each article was reviewed for key barrier types and then these barriers were summarized into six categories, including: (1) technology, (2) hardware costs, (3) financing, (4) adoption, (5) regulatory/legal, and (6) management as summarized in Exhibit 1. If an article addressed one of the barrier types presented in Exhibit 1, then an "x" was recorded in the SAM analysis (see Exhibit 2). The SAM analysis indicates the presence of discussion, but does not judge the quality or completeness in a particular article. We elaborate on the themes that emerged from the SAM analysis in the next section. Countries were included in the SAM analysis to demonstrate that the rural-urban digital divide is a challenge for both developed and developing countries.

Exhibit 1. State-of-the-Art Matrix Definitions

Theme	Definition
Technology	Limitations with present technologies or novel technological approaches
Hardware Costs	Challenges related to costs associated with materials and technology
Financial Mechanisms	Limitations with current funding mechanisms or novel financial models
Adoption	Models for predicting and approaches for influencing technology adoption
Regulatory/Legal	Challenges related to the regulatory or legal environment
Management	Strategies for distributing resources and engaging stakeholders

An initial search for "rural broadband" in the SCOPUS database retrieved 132 articles. We then limited the search to peer-reviewed articles and conference proceedings published between 2006-2018 reducing the total articles to 103. An initial review of abstracts and keywords was used to identify a representative set of 30 articles (29% of total) to be included in the SAM analysis.

Results and Discussion

Exhibit 2 summarizes the results of the SAM. Each barrier type is discussed in more detail in the following sections. The SAM is comprised of articles from North America (Canada, United States, Haiti), Europe (United Kingdom, Germany, Croatia, and the Netherlands), Asia (India and Malaysia), South America (Peru), and Australia (New Zealand). No articles from Africa were included. The United States represented the largest share of the articles with nine (30%), followed by the UK with six (20%), and Canada with four (13%). Countries may approach rural broadband infrastructure investment differently to overcome varying challenges associated with achieving economies of scale, complex geological terrains, and organizational efforts. Cross-country comparisons are left for future research.

Exhibit 3 reports the number and percentage of articles that discussed each barrier type. Technology, hardware costs, regulatory, and financing barriers were similarly represented in the selected articles, with coverage ranging from 53% for financing to 63% for technology. In contrast, adoption and management were much less of a focus in the literature, suggesting that these areas may be worth further investigation.

Technology

Scientists and engineers have developed innovative technologies to reduce infrastructure costs and address topographical challenges (e.g. mountains, long distances) in rural communities. Relevant technologies include a rural extension for wifi (Paul et al., 2007), a point-to-multipoint wireless distribution system that integrates renewable energy technologies for off-grid siting (Darbari et al., 2010), and a method to leverage underutilized TV white space frequencies (Kumar et al., 2015). The goal of this work is to evaluate the factors that influence broadband infrastructure investment in rural communities, so we defer to the corresponding references for a more in-depth discussion of the functionality. However, it is important to note that rural areas may be particularly well suited to innovative technologies that are designed around their needs, rather than deploying technology that is optimized for an urban environment. There may be opportunities for universities to partner with rural communities to deploy testbeds that serve to (a) validate technology options and (b) provide a service to rural businesses and homeowners. However, provisions should be in place to ensure that this is not a temporary fix that is removed or degraded when research funding ends. In addition, there may be value in developing communications to help rural communities navigate the pros and cons of different types of broadband technologies in order to better advocate for themselves.

Hardware Costs

Capital expenditures associated with hardware costs are often identified as a primary barrier for deploying broadband in rural communities, which is why federal and state agencies (e.g. USDA, FCC) have focused on providing funds to address this barrier. Galloway (2007) surveyed fiber, fixed wire, wireless, and satellite costs to conclude that commercial provisioning is unfeasible in markets where profitability is low. Rural areas tend to have a lower population density, which provides fewer customers to absorb the fixed costs of broadband infrastructure. Yau et al. (2011) found that weather patterns (e.g. increased storms) and topographical conditions (e.g. mountains) also increased deployment costs in rural areas in Malaysia. Taylor (2017) examined the use of analog television waves in specified ranges to provide wireless broadband service to rural communities in Canada. One of the primary challenges was the high cost of equipment, $600-700 per household, because the specific frequency band was only available in Canada and economies of scale could not be used to reduce hardware costs. The other articles included in the SAM discuss similar challenges related to the large initial costs and the inability to provide sufficient return on investment to providers. There are opportunities to develop non-traditional business models, such as coops or public-private partnerships, that are better suited to ensuring affordability by reducing the need for high profit margins. In addition, there may be opportunities to leverage existing infrastructure (e.g. electrical poles) or coordinate deployment activities (e.g. bury cable when constructing a new road) to reduce the required investment.

Financial Mechanisms

Low population densities in rural areas limit the potential of market-driven approaches to drive rural broadband expansion. As a result, government subsidies and innovative financing schemes are required. Across the world, governments have set aside significant funds for rural broadband. The U.S. invested $7.2B as part of the American Recovery and Reinvestment Act (ARRA) of 2009 in the form of grants and loans to facilitate broadband deployment in un-served and underserved areas and continues to make further investments today. Meanwhile, the European Union has invested 1B euros for new projects and upgrading existing infrastructure and Australia allocated $258M to subsidize the setup costs for new service providers (Nayan et al., 2012).

Exhibit 2. State-of-the-Art Matrix (SAM)

	Author	Year	Country	Technology	Hardware Costs	Financial	Adoption	Regulatory	Management
1	Sawada et al.	2006	Canada	x	x	x		x	
2	Galloway	2007	UK	x	x	x		x	x
3	Ramirez	2007	Canada, US				x	x	
4	LaRose et al.	2007	US				x		
5	Paul et al.	2007	India	x	x				
6	Wood	2008	US	x	x	x		x	x
7	Omar et al.	2010	Malaysia	x					
8	Darbari et al.	2010	UK	x	x				
9	Briggeman and Whitacre	2010	US					x	
10	LaRose et al.	2011	US	x		x			
11	Alvin et al.	2011	Malaysia	x	x	x			
12	Blantz and Summer	2011	Haiti	x	x			x	x
13	Nayan et al.	2012	Germany	x	x	x		x	x
14	Kawade and Nekovee	2012	UK	x	x	x		x	
15	Prasad	2013	India	x	x	x		x	x
16	Prieger	2013	US	x		x		x	
17	Krizanovic et al.	2013	Croatia				x		
18	Zaidi	2013	None	x	x				
19	Whitacre et al.	2014	US					x	
20	Kumar et al.	2015	India	x	x			x	
21	Simo-Reigadas et al.	2015	Peru	x	x	x			
22	Conley	2015	US				x		
23	Villapol et al.	2017	New Zealand	x	x			x	x
24	Ashmore et al.	2017a	UK	x					x
25	Ashmore et al.	2017b	UK		x	x	x	x	
26	Plant and Odame	2017	Canada			x			x
27	Ali and Duemmel	2018	US			x		x	x
28	Salemink and Strijker	2018	Netherlands			x	x	x	
29	Taylor	2018	Canada	x	x	x		x	x
30	Price et al.	2018	UK		x	x	x		

Exhibit 3. Absolute and Relative Coverage of Topics in SAM

Theme	Number	% of Total
Technology	19	63%
Hardware Costs	17	57%
Regulatory/Legal	17	57%
Financing/Funding	16	53%
Management	10	33%
Adoption	7	23%

However, it's unclear if grants and loans for infrastructure deployment are effective. In an evaluation of the USDA Community Connect program, LaRose et al. (2011) found that grants alone did not expand broadband adoption and were most effective when they stimulated private sector competition or were coupled with community-level education efforts. Similarly, Price et al. (2018) studied two phases of policy intervention in the UK. Phase one, delivered from 2003-2006, included one-time subsidies to encourage small and medium sized enterprises to use a basic broadband service, monthly recurring subsidies for delivery of symmetrical broadband service using wireless technologies, and partial funding for individual projects. Phase two, delivered from 2011-2015, included training events related to the applications of superfast broadband, tailored support, and technology hubs for small and medium sized enterprises to experiment with emerging technologies. This approach was very successful at spurring adoption in addition to access. Some work is also being done on innovative financing schemes. For example, an organization in Haiti has experimented with identifying strategic "anchor tenants" that possess sufficient resources to pay for broadband services in order to make that service accessible to the greater population (Blantz and Summer, 2011). There are opportunities to develop new financial mechanisms for both infrastructure deployment as well as adoption. For example,tax incentives, rebates, and bonds should all be explored as potential tools for expanding rural broadband.

Adoption

Rural broadband projects sometimes suffer from low adoption rates, even when high-speed internet is available, due to challenges associated with the digital divide and high poverty rates. Minimizing cost is a critical first step for increasing adoption, but affordability is not the only factor at play. Analysis of the Agricultural Resource Management Survey Data, a biannual survey deployed by the U.S. Department of Agriculture, suggests that farmers do not incorporate internet services in their business models because they do not own a computer (27%), have inadequate internet service (3%), have internet security concerns (2%), and other reasons (38%). It may be necessary to invest in digital literacy training and raise awareness about the potential applications for farming operations to increase internet technology adoption (Briggeman and Whitacre, 2010). LaRose et al. (2007) incorporate socio-cognitive and demographic variables into a model to explain broadband utilization in rural communities in the U.S. Their model suggests that connecting experienced internet users with potential users within a community might be a successful strategy for increasing adoption rates. A broadband initiative in Haiti empowers aspiring online entrepreneurs through a training program and shared computing infrastructure (Blantz and Summer, 2011).

However, increased broadband adoption also introduces risks for rural communities. Conley and Whitacre (2016) found that high levels of rural broadband adoption are associated with lower levels of creative-class employees and entrepreneurs in those locations. It is possible that improved internet access leads to individuals discovering job opportunities in other places. More research is needed to better understand the causal relationship between access and adoption as well as the ripple effects of improving internet access in rural communities. In order to build effective and sustainable programs, we need to understand short and long-term adoption drivers.

Legal/Regulatory Environment

Deployment of new technologies requires a favorable legal and regulatory environment for issues such as right-of-way and spectrum access. These types of barriers can make it difficult to identify and implement solutions. For example, in Canada, the Telecommunications Act of 1993 does not allow funds collected from urban areas to be used for rural communications projects. Given that 80% of the population is located in 4% of the landmass, this inability to employ cross-subsidies poses a challenge. Sawada et al. (2006) used geospatial analysis to show that a large portion of Canada's rural communities could gain access to broadband with existing technologies while following this law. In other cases, it is necessary to change the law. Efforts to bring 3G services to rural communities in Peru via low-cost sharing of wireless infrastructure prompted legislative changes that forced mobile operators to use existing rural telecommunication infrastructure. In addition, a role was established to oversee leasing conditions and arbitrage mechanisms (Simo-Reigadas et al., 2015).

In addition, companies may have different regulatory burdens depending on their size. For example, in Pennsylvania, small phone companies operate under the National Electrical Contractors Association rate of return regulation scheme which guarantees an 11.25% rate of return on investment. This approach partially eliminates risks associated with infrastructure upgrades such as upgrading to a fiber optic network. Conversely, large phone companies operate under a price cap regulation that sees them focus on areas where the greatest investment returns are located (i.e. urban areas) (Wood, 2008). Analytical work is needed to assess whether these regulatory regimes are effectively meeting the needs of rural communities.

Management

A robust and successful broadband infrastructure investment strategy must engage the local community, rather than simply delivering technology. Ramirez (2007) suggests that a centralized (i.e. state-level) policy is unlikely to effectively address the needs of a given community. He uses the theory of change to recognize that innovation occurs at the nexus of people and technology. He recommends adaptive management, a methodology based on different stakeholders adapting management approaches based on a common understanding of system response, as a strategy to jointly manage resources in rural areas. In two community-led broadband efforts in the United Kingdom, Ashmore et al. (2017) investigated the effectiveness of the social resilience analytical framework posited by Scott (2013) in evaluating the effectiveness of community-led broadband initiatives in the United Kingdom. The framework used capitals, agency, and sense of place as dimensions of social resilience with the intersection of the three serving as a state of strong resilience. Their study explored two initiatives, one that successfully delivered a broadband network and one that did not. The successful initiative possessed leaders with strong technological and human capital, a volunteer structure that demonstrated high levels of individual agency capable of effectively engaging with resources, and a community that was able to propel the building process due to a strong sense of place. On the other hand, the unsuccessful initiative lacked technological knowledge and capital and required external consultation, which hindered progress. In the Netherlands, the national government shifted responsibility of broadband provisioning to provincial councils due to the local nature of the problem. Salemink and Strijker (2018) describe this as a 'participation society', where local and regional governments interact directly with citizen-led initiatives comprised of well-educated and well-connected citizens. While this approach encourages community resilience and responsibility, it may also lead to discrimination if some populations are not engaged in the process. Ultimately, the national government intervened with generic policies and little infrastructure was installed due to inadequate government support. More research is needed to understand which types of management approaches are effective under different conditions and develop tools to help governments employ the most effective strategies.

Conclusions and Recommendations

This study uses a SAM analysis to characterize the broadband literature and highlight the challenges and opportunities facing broadband access and adoption. The study identified six interrelated themes including (1) technology, (2) hardware costs, (3) financial mechanisms, (4) adoption, (5) regulatory environment, and (6) management strategy. For technology, the analysis suggests that new technologies may be more effective and efficient for rural deployment, rather than limiting deployment to existing technology that is optimized for urban areas. For hardware costs, low population density, complex terrains, and poor economies of scale drive high costs, which are not easily addressed with market-based approaches. For financial mechanisms, it is unclear that the current approach - government loans and grants for deployment - will be effective for creating new markets, which require high adoption rates. For adoption, survey data suggests that rural areas may not perceive internet access as being worth the cost, which suggests that digital literacy training is critical for increasing adoption rates. For the regulatory environment, existing laws and regulations can impede innovative solutions. For management strategy, broadband initiatives tend to be more successful when managed locally. Much of the challenge for rural broadband infrastructure boils down to a low return on investment due to high capital costs and low population densities.

Of the six barriers to rural broadband identified in this study, it is evident that there are gaps in the literature related to broadband adoption and management. For adoption, more research is needed to understand the drivers for short (e.g. government subsidies) and long-term (e.g. new industries) adoption. For management, more research is needed to understand how to bridge local and state or federal control to ensure that broadband initiatives are successful. These two areas in combination with innovative and cost-effective technology, effective funding mechanisms, and flexible policies are critical to developing effective broadband investment strategies. From a systems perspective, policy interventions or financial mechanisms that focus narrowly on deployment have a lower likelihood of success compared to interventions that directly address adoption and management challenges. In other words, even if broadband technology is available (i.e. there is access), there is no guarantee that rural customers will adopt it. Managing the initiative locally and investing in strategies to increase adoption (e.g. digital literacy training, subsidized adoption) are likely to increase the chances of sustaining a market to support broadband access in the long-term.

A successful broadband strategy must also develop metrics that address how the technological aspects of the system interact with the social, economic and cultural aspects. Thus, robust decision-making tools should focus on adoption in addition to access. It is important to employ systems-level approaches that view broadband access and adoption as a complex system where stakeholder engagement is critical for success. Analytical research is needed to evaluate broadband access, use, and adoption to better understand opportunities and barriers.

Future Work

The SAM analysis identifies the key issues to address for community decision-makers, such as local government officials, telecom companies, rural coops, utilities, small business owners, farmers, and rural homeowners. Given the scope of the problem, there is an urgent need for public-private coordination and to address the gaps identified in the areas of broadband adoption and management. Future work will involve semi-structured interviews and surveys to identify the range and quality of perspectives on rural broadband investment processes. Some questions to be addressed include the following:

1. What investments in broadband infrastructure have been made in your community to date?
2. What was the decision-making process? What risks were the community worried about? What benefits did the community expect to get? How did your community pay for the infrastructure?
3. How did this process compare to other infrastructure investments in your community?

This work is needed to identify the specific challenges for public-private coordination and design interventions to improve system performance. These interventions may range from data collection tools (e.g. app to crowdsource broadband service quality) to aggregated data repositories (e.g. database of existing infrastructure that can be leveraged) to decision aids (e.g. standardized benefit-cost-risk template). Once developed, it is critical to evaluate the impact and effectiveness of these resources.

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