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Evaluating barriers to and impacts of rural broadband access

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EVALUATING BARRIERS TO AND IMPACTS OF RURAL BROADBAND ACCESS

by

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ABSTRACT

The lack of adequate broadband infrastructure persists in many rural communities. Beyond funding, additional barriers persist, such as digital literacy and community-level self-efficacy. As a result, the first contribution articulates barriers at the organizational level. This work proposes a framework based on the Theory of Planned Behavior to highlight stakeholder dynamics that have constrained Regional Planning Commissions from advancing broadband infrastructure in rural areas. One approach to address these barriers is to provide stakeholders with analytical tools to evaluate the benefits and costs of various broadband options for their community since there is not a one-size-fits-all solution. To this end, there are three contributions that provide guidance for evaluating improved broadband access. The first solution proposes a benefit-cost analysis at the county-level where changes in tax revenue are used to monetize the impact of rural broadband for a hypothetical Midwest county. The second solution demonstrates a method for evaluating the benefit of broadband in terms of social impact on education, employment, and healthcare in a small under-served community in northwest Missouri. Pre- and post-survey data were used to conduct comparisons between the targeted community, which received faster internet, and control communities. The third solution describes a socio-technical reference architecture to support the development of community-driven wireless broadband projects. By providing analytical tools for evaluating the impact of broadband solutions for rural communities, this research increases the capability of local communities to identify and advocate for broadband solutions that fit their needs.

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1. INTRODUCTION

1.1. BACKGROUND AND MOTIVATION

Broadband internet is an essential tool for economic activity, and this is no different in rural communities. The Federal Communications Commission (FCC) states that “broadband is a foundation for economic growth, job creation, global competitiveness and a better way of life” (FCC, 2011). The agency defined closing the digital divide as their #1 strategic goal and estimates that up to 6 million rural businesses and homes could benefit from the Rural Digital Opportunity Fund (RDOF) (FCC, 2020; Pai, 2018). The United States Department of Agriculture (USDA) estimates that rural broadband and the adoption of next generation precision agriculture could lead to a potential $47-65 billion in annual gross benefit for the USA (USDA, 2019). The contribution of the federal government to infrastructure investments can take the form of “direct spending, grants to state and local governments, loan guarantees, and preferential tax treatment” (Stupak, 2018).

Since 2002, the U.S. federal government has been funding rural broadband across multiple agencies using various mechanisms, accelerated as part of the COVID recovery (United States Government Accountability Office, 2017). The FCC runs the Connect America Fund (Connected Nation, 2018) as well as the Rural Digital Opportunities Fund (FCC, 2020), which both provide funding for deployment projects over 10 years. Similarly, the United States Department of Agriculture (USDA) ReConnect Program anticipates awarding another $1.15 billion in 2021 for underserved rural areas (USDA, 2021a, 2021b). As part of the American Recovery and Reinvestment Act, the National

Telecommunications and Information Administration (NTIA) managed the Broadband Technologies Opportunities Program, part of the $4.7 billion supported infrastructure deployment at unserved and underserved communities (ARRA & REA, 2009). In addition, the Missouri Broadband Grant Program was created in 2018 and distributed $5 million in funding in 2020 to assist providers, communities, counties, and regions in building broadband infrastructure in unserved and underserved areas of the state (Missouri Office of Broadband Development, 2020).

In addition to funding infrastructure deployment, there is increasing acknowledgment that access alone is not the only barrier. Many communities also need support to encourage adoption and increase digital literacy. In late 2021, the Infrastructure Investment and Jobs Act was signed into law. This Act includes $65 billion aimed to close the digital divide and increase access "to reliable, high speed, and affordable broadband" (NTIA, 2021). Also, the NTIA Digital Equity Act Programs promote adoption for targeted populations such as low-income households and rural residents.

Since 2015, most federal funding has been focused on deployment projects in unserved (< 10/1 Megabits per second or Mbps) and underserved (< 25/3 Mbps) communities. However, these benchmarks are increasing as internet applications have proliferated, especially in a post-COVID world. The new National Telecommunications and Information Administration (NTIA) Broadband Equity, Access, and Deployment (BEAD) Program considers those without 25/3 Mbps as unserved and treats those without 100/20 Mbps as underserved (NTIA, 2021).

In summary, the U.S. federal government and the states are funding and stimulating the deployment of broadband infrastructure to make it accessible to all citizens. Policymakers aim to maximize the societal benefits of the provided funds. Funding by government agencies partially addresses financial barriers to rural broadband access. Besides financing, other barriers exist to deploying broadband infrastructure in rural communities. Additional barriers include technology, equipment costs, adoption, management, and regulations (Canfield, Egbue, Hale, & Long, 2019). Understanding the impact of the different barriers provides decision-makers with a foundation for identifying effective ways to address the identified barriers.

1.2. RESEARCH OBJECTIVES AND CONTRIBUTION

This dissertation aims to contribute to the understanding of barriers to the deployment of broadband infrastructure in rural communities, evaluate the impact of this critical infrastructure in rural communities, and propose analytical tools to support local stakeholders considering different broadband options.

Publication 1: A framework integrating the decomposed Theory of Planned Behavior, Theory of Reasoned Goal Pursuit, and Stakeholder Theory is used to uncover stakeholder dynamics that influence how Regional Planning Commissions contribute to the deployment of broadband infrastructure in Missouri. Although Regional Planning Commissions often advocate for the necessity of broadband infrastructure, they also struggle with low self-efficacy and inadequate expertise to support broadband planning efforts. This framework could be generalized to understand actions and decisions by other intergovernmental organizations that have convening power and face similar power dynamics with their stakeholders.

Publication 2: A benefit-cost analysis (BCA) of a broadband project is conducted for a hypothetical county defined using data from various governmental agencies for rural counties in a Midwest state. The model considers the change in tax revenue as a means to monetize the impact of rural broadband. The cost associated with treating problematic internet use is monetized as mental health expenditure. A sensitivity analysis of the BCA suggests that the initial revenue of the county, as well as the year-over-year population change, impact the net present value of the broadband infrastructure projects to a greater extent versus other model parameters like the unemployment rate.

Publication 3: Evaluating the social impact of improved broadband infrastructure in an underserved community is more challenging than in an unserved community due to more complex causal pathways. Pre-post surveys were used to evaluate the impact of improved access to the internet in a small, underserved community in northwest Missouri. These comparisons suggest changes in using the internet for employment, education, and health could not be directly attributed to the internet intervention. Instead, the internet intervention was associated with quality-of-life benefits related to the ability to use multiple devices at once. This study has implications for the design of future evaluation studies.

Publication 4: To aid in the development of community-driven wireless broadband infrastructure, a socio-technical reference architecture was discovered. The validation of the fit-for-use of the socio-technical reference architecture was performed with the input of two other community-driven broadband projects. This reference architecture may support communication within interdisciplinary teams for consensus-based decision-making as well as with external stakeholders for expectation setting.

Understanding the impact of broadband infrastructure on residents and local governments enables federal and state policymakers to maximize the positive effect of available resources. Similarly, optimizing the contribution of local intergovernmental organizations such as the Regional Planning Commissions should improve the likelihood of success for the deployment and adoption of broadband infrastructure. Also, the proposed socio-technical reference architecture could assist in identifying and disseminating best practices in planning, designing, and deploying broadband solutions to interconnect communities to the internet.

PAPER

I. PUSH THEM FORWARD: CHALLENGES IN INTERGOVERNMENTAL ORGANIZATIONS' INFLUENCE ON RURAL BROADBAND INFRASTRUCTURE EXPANSION

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ABSTRACT

Many rural US communities lack access to adequate broadband services. This paper draws on semi-structured interviews conducted in 2019 with 16 Regional Planning Commissions to uncover dynamics of how these intergovernmental organizations contribute to the deployment of broadband infrastructure in rural Missouri. The proposed framework integrates the decomposed Theory of Planned Behavior (TPB), the Theory of Reasoned Goal Pursuit, and Stakeholder Theory. Many participants reported a low level of involvement in broadband infrastructure initiatives even though supporting infrastructure development to promote economic growth is one of the Regional Planning Commissions' primary goals. Regional Planning Commissions are highly influenced by four primary stakeholder groups, (1) residents and businesses, (2) local governments, (3) internet service providers, and (4) state and federal government, which vary in terms of priorities and power. While defining the region's priorities with elected officials,

Regional Planning Commissions often “push them forward” to recognize the necessity of broadband infrastructure. However, Regional Planning Commissions also struggle with low self-efficacy and inadequate expertise to support broadband planning efforts. The proposed framework could be generalized to understand actions and decisions by other intergovernmental organizations that have convening power and face similar power dynamics with their stakeholders.

1. INTRODUCTION

Over the last decade, rural America had higher poverty rates and fewer jobs added when compared to their metro counterparts (Cromartie, Dobis, Krumel, McGranahan, & Pender, 2020; USDA, 2020). Having adequate broadband infrastructure is critical for supporting economic growth, civic engagement, and resilience (Ashmore, Farrington, & Skerratt, 2017; Conroy & Low, 2021; Pai, 2018; Roberts, Anderson, Skerratt, & Farrington, 2017; B. E. Whitacre & Manlove, 2016; B. Whitacre, Gallardo, & Strover, 2014), especially in the context of the COVID-19 pandemic (Ali, 2020; Maixner, 2021; Smith, 2020). Fulfilling the need for adequate broadband infrastructure represents a significant business opportunity for telecommunication companies. However, the opportunity to maximize profit is highest in areas with high population density (Galloway, 2007) and most rural communities have a low population density. As a result, state and federal government agencies administer programs to incentivize the deployment of broadband infrastructure and services in rural communities (FCC, 2020; LaRose et al., 2014; LaRose, Strover, Gregg, & Straubhaar, 2011; Missouri Office of Broadband Development, 2020; USDA, 2018).

This study aims to contextualize the network of influence among rural broadband stakeholders who vary in power and expertise and develop an integrated theoretical framework for explaining the mechanisms behind rural broadband planning barriers. We conducted a series of semi-structured interviews in 2019 (pre-COVID-19) with Missouri Regional Planning Commissions (RPCs) to identify barriers for rural broadband infrastructure expansion (Canfield, Egbue, Hale, & Long, 2019; Valentín-Sívico, Canfield, & Egbue, 2020). Qualitative analysis suggests that despite emphasizing the importance of broadband infrastructure for rural communities' economic development, few RPCs reported playing an active role. To describe and explain this phenomenon, we derive a theoretical framework that integrates the decomposed Theory of Planned Behavior (TPB), the Theory of Reasoned Goal Pursuit, and Stakeholder Theory to explain planning dynamics for rural broadband infrastructure.

This is particularly critical for technologies, such as broadband, which have not traditionally been a focus of these organizations. The theoretical and practical contributions of this work include (1) demonstrating how behavioral theories can be used to inform the motivations of actors within complex organizational networks, (2) applying this approach to the challenge of expanding rural broadband, which makes an interesting test case because of the need for public-private partnerships, and (3) illuminating the role of RPCs in this ecosystem. Ultimately, this framework supports the development of interventions to reduce these planning barriers.

2. BACKGROUND

2.1. RURAL BROADBAND FUNDING IN THE USA

The government can subsidize internet service providers (ISPs) in the form of grants or loans to develop infrastructure in unserved (< 10/1 Megabits per second or Mbps download/upload) and underserved (< 25/3 Mbps) communities (Miller, 2014). The U.S. federal government has been funding rural broadband across multiple agencies using various mechanisms since 2002 (United States Government Accountability Office, 2017). As shown in Table 1, the Federal Communications Commission (FCC) runs the Connect America Fund (Connected Nation, 2018), which provides funding for deployment projects over 10 years. Similarly, the United States Department of Agriculture (USDA) ReConnect Program and Community Connect Program award grants and loans for broadband deployments underserved rural areas (USDA, 2021a, 2021b). As part of the American Recovery and Reinvestment Act (ARRA) of 2009, additional stimulus funds were available. For example, the National Telecommunications and Information Administration (NTIA) managed the Broadband Technologies Opportunities Program, which supported infrastructure deployment in unserved and underserved communities (ARRA & REA, 2009). At the state level, additional funding is being distributed. For example, the Missouri Broadband Grant Program was created in 2018 and distributed $5 million in funding for the first time in 2020 to assist providers, communities, counties, and regions in building broadband infrastructure in unserved and underserved areas of the state (Missouri Office of Broadband Development, 2020).

Table 1. As of 2019, Federal Funding was Primarily Focused on Directly Funding Infrastructure Deployment.

Program	Source	Type	Allowable Projects	Funding (Year)
Connect America Fund II (CAF II)	FCC	Reverse auction	Deployment of at least 10/1 Mbps in unserved high-cost areas	$1.49 B (2018)
ReConnect Fund	USDA	Loans, grants	Deployment of at least 25/3 Mbps in unserved and underserved rural areas	$656 M (2019)
Community Connect Program	USDA	Grants	Deployment of broadband service to the whole community (residences, businesses, and public facilities)	$152 M (2019)
Broadband Technologies Opportunities Program	NTIA (ARRA)	Grants	Middle mile broadband infrastructure, public computer centers, sustainable broadband adoption	$4.7 B (2009-2010)

Historically, stimulus funds (such as ARRA in 2009) have been one of the few sources of funding for broadband planning. Even before COVID-19, funding for rural broadband was increasing with programs like the FCC's Rural Digital Opportunities Fund ($20 billion) (FCC, 2020). However, more recent efforts in response to the COVID-19 pandemic have dramatically increased funding levels for deployment efforts, such as the Coronavirus State and Local Fiscal Recovery Funds and the Capital Projects Fund (U.S. Department of the Treasury, 2021b, 2021a). Many of these funds will be managed by state and local governments, which will need regional planning support. LaRose et al. (2011) suggest that grants may be the most effective if they stimulate competition by private ISPs while also funding community education efforts. However, the government needs better data and mapping to support evidence-based decision-making in the design and implementation of rural broadband investment programs (Hambly & Rajabiun, 2021).

2.2. REGIONAL PLANNING FOR RURAL BROADBAND

Both top-down and bottom-up planning approaches have been investigated and used to bring broadband service to rural communities with varying degrees of success. Research suggests that a community-based approach (i.e., bottom-up) provides a better platform to address the need of rural communities (Salemink, Strijker, & Bosworth, 2017). However, some communities lack sufficient human capital with knowledge and expertise to address the rural broadband gap and need to attract external experts (Ashmore et al., 2017; Techatassanasoontorn, Tapia, & Powell, 2010). Salemink & Strijker (2018) conclude that citizens alone cannot bear the responsibility of finding a solution to their broadband needs. RPCs are positioned to support bottom-up planning processes.

Regional Planning Commissions (RPCs, also known as Councils of Government) are nonprofit intergovernmental organizations that support town and county members for infrastructure and economic development planning by writing grants for federal funds for specific projects (NARC, 2021). RPCs typically have in-house expertise for administering federal funding, performing GIS analysis, and coordinating planning efforts that exceed the capabilities of smaller, local levels of government. Given that the capabilities in towns and counties vary, RPCs offer different services depending on the needs of their region. In addition, RPCs vary in size and staffing, which influences the type of services they offer. Most RPCs provide infrastructure planning support for water, sewage, and transportation. They lead periodic planning efforts to develop a Comprehensive Economic Development Strategy (CEDS), which often highlight a need for broadband, and support emergency preparedness planning. In some cases, the RPCs also run regional programs such as recycling, housing, and workforce development (MACOG, 2020).

Most research on RPCs has focused on improving planning practices, especially for transportation. Evaluation efforts suggest that place-specific plans are critical for success, as local support should be considered when prioritizing efforts (Allred & Chakraborty, 2015; Guerre & Evans, 2009). In addition, RPCs are a major facilitator of knowledge sharing within a region, such that municipalities tend to behave more similarly within a region, regardless of geographic proximity to other municipalities (Mitchell, Davis, & Hendrick, 2021). Little research has focused on how RPCs contribute to the expansion of broadband infrastructure, as most planning literature focuses on urban, rather than rural, regions (Rickabaugh, 2021).

However, RPCs have historically played important roles in broadband planning efforts when funding was available. For example, in 2009-2013, there was a statewide stimulus-funded broadband planning initiative in Missouri called MoBroadbandNow (MoBroadbandNow, 2013; Read & Porter, 2013). RPCs were the primary conveners and outcomes included region-specific plans, survey data collection, and mapping of existing assets and access. Similarly, the Southeastern Wisconsin Regional Planning Commission created an advisory committee of representatives from the public and private sectors, including major wireless and wireline communications service companies and local governmental agencies, to support the creation of public-private partnerships (Schlager, 2008).

2.3. THEORETICAL FRAMEWORKS

2.3.1. Theory of Planned Behavior. The Theory of Planned Behavior or TPB (Ajzen, 1991) has been used to explain and predict behaviors in a large number of domains (Ajzen, 2020), ranging from intentions to use public transportation (Nordfjærn, Şimşekoɨlu, & Rundmo, 2014) to intentions to engage with government-led initiatives through Facebook (Alarabiat, Soares, & Estevez, 2021). As shown in Figure 1 via the white boxes, TPB proposes that attitudes, subjective norms, and perceived behavioral control predict intentions and, ultimately, behavior (Ajzen & Kruglanski, 2019). Since initially proposed, other researchers have expanded on the initial framework to derive the decomposed TPB, which is shown via the grey boxes in Figure 1 (Taylor & Todd, 1995).

Beyond individual behavior, TPB has been used to study the behaviors of individuals within organizations. Examples include the intention to hide knowledge from colleagues inside R&D organizations (Xiong, Chang, Scuotto, Shi, & Paoloni, 2019), the intention to perform and innovate as managers in nonprofit organizations (Reinhardt & Enke, 2020), and employees' intention to support organizational change (Jimmieson, Peach, & White, 2008). In organizational behavior studies, researchers conduct interviews with key senior managers to determine the organization's intentions. Treating the managers' opinions as a proxy for the organization enables the use of TPB at the firm level (Jin, Chai, & Tan, 2012).

While positive attitudes increase intentions, negative attitudes decrease intentions to engage in a behavior. For example, in the context of switching to cloud-based enterprise resources, information technology managers revealed that they were less likely to switch if they were satisfied with their current solution (Mezghani & Muhammad, 2014). In this case, the perceived benefits did not outweigh the risks. The decomposed TPB describes attitude in terms of relative advantage, complexity, and compatibility (Taylor & Todd, 1995).

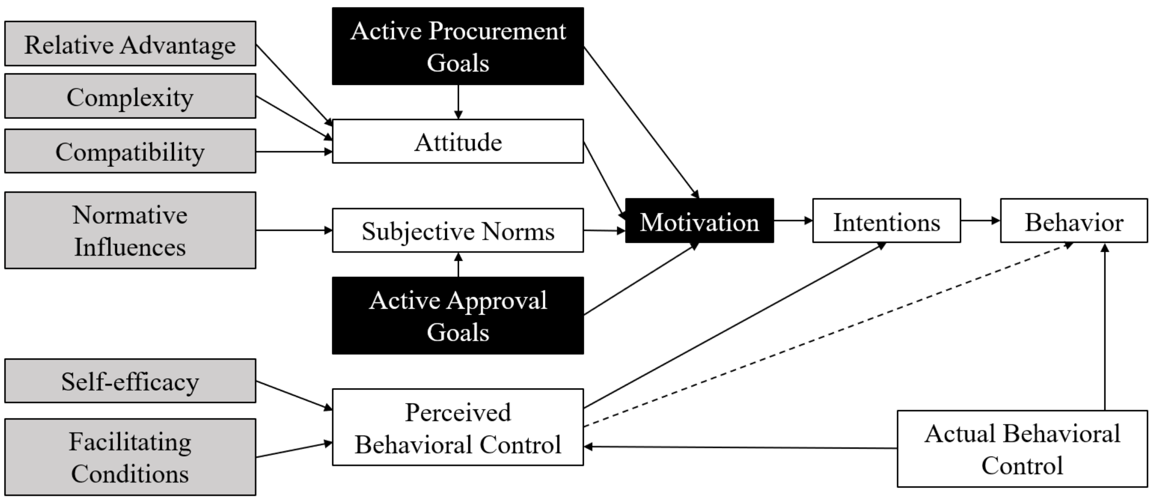

Figure 1. Summary of the original Theory of Planned Behavior (white) with decomposed factors (grey) and added elements for the Theory of Reasoned Goal Pursuit (black).

In addition, people are more likely to intend to engage in a behavior if they perceive that others are engaging in or approve of the behavior. These subjective norms range from descriptive norms, beliefs about whether others perform the behavior, to injunctive norms, the expectation that an individual or group approves or disapproves of performing the behavior. In many cases, subjective norms are influenced by stakeholders outside of the organization. Decomposed TPB suggests that normative influences (e.g., from peers, superiors, mass media) contribute to subjective norms (Taylor & Todd, 1995). For example, interpersonal influence (e.g., word of mouth) was more influential than external influences (e.g., media) in encouraging adoption of proximity mobile payment services in Greece (Giovanis, Tsoukatos, & Vrontis, 2020).

Lastly, perceived behavioral control (e.g., beliefs about relevant skills or resources) is needed to support intentions, otherwise people will not engage in the behavior (Ajzen, 2020). For example, logistics managers perceive corporate policies and firm traditions as constraints on their behavior (Busse, Regelmann, Chithambaram, & Wagner, 2017). In decomposed TPB, perceived behavior control is influenced by self-efficacy and facilitating conditions (Taylor & Todd, 1995).

2.3.2. Goal Systems Theory & Theory of Reasoned Goal Pursuit. In parallel with the development of the decomposed TPB, TPB was also integrated with Goal Systems Theory (Ajzen & Kruglanski, 2019). Ajzen and Kruglanski (2019) proposed integrating TPB (which focuses on behavior) with Goal Systems Theory (which focuses on goals) to improve explanatory power in a new framework called the Theory of Reasoned Goal Pursuit. According to Goal Systems Theory, human action is goal-driven (Kruglanski et al., 2018). The degree to which an individual or organization is determined to pursue a goal is assumed to vary as a function of the value assigned to the goal and by the expectation of attainment. Successfully achieving the desired objective generates a positive effect of satisfaction, and failure to attain the desired goals produces a negative effect of disappointment.

As shown via the black boxes in Figure 1, the Theory of Reasoned Goal Pursuit adds factors related to goals, which influence motivation to perform a behavior. There are two types of goals, (1) procurement goals, which influence attitudes, and (2) approval goals, which influence subjective norms. Procurement goals are the desired outcomes and experiences of the individual (e.g., a goal to lose weight). Individuals may perform behaviors (e.g., go on a diet) despite negative attitudes if they are aligned with their procurement goals. Approval goals are the motivation to seek approval from specific individuals or groups (e.g., choosing to work out because a significant other approves).

This theory is particularly relevant in the context of organizations, where accounting for organizational or external stakeholder goals can significantly improve predictive power. If a behavior is perceived to advance the active goals of the organization, the likelihood of engaging in the behavior increases (Ajzen & Kruglanski, 2019). There is significant variability across domains in terms of how effectively TPB explains the data. As a result, the Theory of Reasoned Goal Pursuit is likely to be more effective in goal-driven contexts like organizations.

2.3.3. Stakeholder Theory. Stakeholders are the groups and individuals that have a valid interest in the activities and outcomes of an organization and on whom the organization relies to achieve its objectives (Freeman, 1984). Thus, internal (e.g., owners and employees) and external (e.g., suppliers, competitors, activist groups, and the government) stakeholders influence the perceptions of individuals within a firm. Generating a stakeholder influence diagram can help public organizations create and sustain coalitions that help realize their particular mission (Bryson, 2004; Freeman, Harrison, Wicks, Parmar, & Colle, 2010).

Although first developed in the context of private firms, Stakeholder Theory has been adapted and applied to study nonprofit and governmental organizations (Best, Moffett, & McAdam, 2019; Bryson, 2004; Falqueto, Hoffmann, Gomes, & Onoyama Mori, 2020; Fraczkiewicz-Wronka, Ingram, Szymaniec-Mlicka, & Tworek, 2021;

Gomes, Liddle, & Gomes, 2010; Krashinsky, 1997; Siriwardhane & Taylor, 2014). For example, in the context of strategic planning at a public university, the most influential stakeholders were those who could exert control over the university, which can be counter-productive to the university's mission to serve students and society (Falqueto et al., 2020).

Several studies have integrated TPB with Stakeholder Theory in an organizational context. For example, Busse et al. (2017) generated an integrated framework to explain the role of energy in logistics and found that managers' perceptions were influenced by a wide range of stakeholders from the organization (e.g., investors, employees), the operating environment (e.g., customers, activist groups), and the broader environment (e.g., technological change, global economic forces). Stakeholder Theory is related to Goal Systems Theory since different stakeholders have different motivations, which inform the goals of an organization and activate specific attitudes and norms (Hilton, Hajihashemi, Henderson, & Palmatier, 2020).

3. METHODS

3.1. DATA COLLECTION

We recruited directors of Missouri RPCs for in-depth semi-structured interviews in June and July 2019. Sixteen (16) of the 19 Missouri RPCs (84%) chose to participate. Each RPC director received an email invitation and up to four reminders. The RPCs that did not participate either did not respond to inquiries or felt that their urban territory was not relevant. Most interviews were conducted in-person at the RPC headquarters, but three were conducted via phone.

The semi-structured interviews lasted 50 to 100 minutes. Each interview was recorded and professionally transcribed. Each interview included questions on regional priorities, existing broadband infrastructure, successes and failures related to expanding broadband access, and strategies for planning and coordinating infrastructure deployment in general. The interview protocol and codebook are available at [link removed for blinded peer-review].

3.2. DATA ANALYSIS

After all the interviews were completed, emerging themes were identified and added to a priori themes from Canfield et al. (2019). These themes were used to develop a codebook (Saldaña, 2010), which became a living document that was revised during coding. The act of coding is a process of identifying segments from qualitative data that relate to a particular theme. Many of the codes we used in the coding process came from the collected data itself, which is an inductive approach to defining the codes (Elliott, 2018).

Each interview was coded independently by at least two coders, and consensus coding was used to finalize the coding of each interview (Hill, Thompson, & Williams, 1997). First, two randomly selected interviews were independently coded by all three members of the research team before finalizing the coding using a consensus approach. As Hill et al. (2005) recommend, each interview's coding was audited by a person not involved in the consensus coding. For the rest of the interviews, the interviews were coded by two team members, while the third member audited the completed interview. After coding, we observed that some of the codes aligned with the constructs in TPB and this guided the development of the proposed integrated framework.

Rural broadband infrastructure stakeholders were identified based on the interview data. We followed Bryson's (2004) recommendation that a broad array of groups should be recognized as stakeholders regardless of their power level. After identifying the stakeholders, we identified which codes were influenced by the different stakeholders. The findings section was shared with the directors of the RPCs who participated in the interviews so they could provide feedback.

4. FINDINGS

This section describes (1) stakeholder influence on RPC intentions and (2) RPC intentions to engage in rural broadband efforts via a theoretical framework that draws on the Theory of Planned Behavior, Goal Systems Theory, and Stakeholder Theory.

4.1. STAKEHOLDER INFLUENCE ON RPC INTENTIONS TO ENGAGE IN RURAL BROADBAND EFFORTS

In the context of rural broadband infrastructure, there are four primary stakeholder groups that vary in terms of their ability to exert influence on RPCs. On the demand side, the stakeholders include residents, business owners, and local governments. On the supply side, stakeholders include ISPs as well as state and federal governments. These stakeholders have different goals and vary in their power to make decisions about rural broadband. In addition, there is variation within stakeholder groups. For example, some rural cooperatives (co-ops) are ISPs and may be more willing to forego short-term profit in the interest of community development. Table 2 summarizes the primary goals of the stakeholders, their level of decision-making power, and how they influence RPCs. As shown in Figure 2, RPCs primarily work with government organizations (solid lines) and secondarily work with other stakeholders (dotted lines).

Table 2. Stakeholder Groups Have Different Goals, Levels of Decision-Making Power, and Influence on Regional Planning Commissions.

Stakeholder Group	Primary Goal	Decision-Making Power	Levers of Influence on RPCs
Residents and Business owners	Quality of Life and Business Efficiency	Low	Adopting broadband and realizing benefits
Local Governments	Economic Development	Low	Setting bottom-up priorities at the county/municipal level and participating in regional broadband planning efforts
Internet Service Providers	Profit	High	Bidding on projects, making deployment decisions, and influencing data quality
State and Federal Government	Equity	Medium	Setting top-down priorities and eligibility requirements for financing

4.1.1. Demand-side Stakeholders. On the demand side, current and potential residents and business owners influence RPCs by perceiving benefits, subscribing to services, and learning from peers. Many residents and business owners want the quality-of-life benefits that accompany broadband access, such as employment, education, health, and entertainment opportunities. Local governments influence RPCs by setting priorities, learning from peers, and participating in broadband planning efforts. Ultimately, the goal of local government is to support economic development to increase their tax base and ability to serve local residents. However, residents and business owners, as well as local governments, have very little decision-making power. Even when they have much to gain from broadband access, the demand-side lacks the authority, expertise, and capital required to invest in and operate broadband infrastructure. RPCs bridge this gap via their convening power to bring together the demand and supply sides.

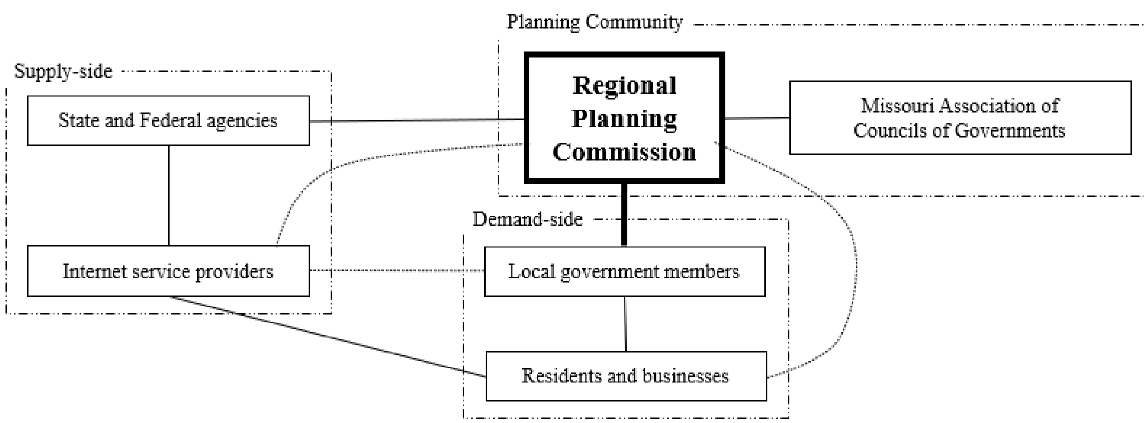

Figure 2. The Regional Planning Commission interacts with the four key stakeholder groups via primary (solid line) and secondary (dashed line) interactions.

Many residents and business owners recognize that they are disadvantaged due to lack of broadband. While there is much discussion of this digital divide between urban and rural areas (Salemink et al., 2017; B. Whitacre, Strover, & Gallardo, 2015), this same dynamic emerges between small towns to create haves and have-nots. RPCs are aware that economic opportunities can go to neighboring communities that have better broadband infrastructure (Q1, P8)[1].

Residents and business owners ultimately make their support for rural broadband known by choosing where to live and operate. There is demand for the small-town way of life, but they do not want to sacrifice modern conveniences, implying that broadband is perceived as a necessity rather than a luxury (Q2, P1). Residents and business owners perceive benefits to rural broadband access. For example, precision agriculture can enable farmers to do more with less (Q3, P3), telecommuting expands job opportunities (Q4, P16), and telemedicine helps individuals that live long distances from hospitals (Q5, P5). Broadband benefits are framed as making rural areas generally more desirable for living and working (Q6, P7).

As residents from rural communities without broadband access interact with family and friends from other locations similar to their own, they learn about the benefits of broadband access and opportunities for realizing similar success. Communities are sensitive to what counts as a valid comparison. They recognize that it is challenging to bring ISPs to rural areas. Seeing successful communities that are similar to their own makes residents aware that gaining access to broadband is a possibility for their communities (Q7, P2). However, not all residents are equally interested in subscribing to broadband services. Some rural counties have an older population who might not need or want the technology. This may contribute to lower adoption rates, which make ISPs less

[1] The (Q#, P#) represents the quote number by participant number. The quotes are found in the Appendix.

likely to want to invest in an area. This also creates a negative feedback loop that discourages younger residents from staying, returning, or moving to the region (Q8, P7).

Local governments vary in their interest and ability to participate in rural broadband efforts. Other infrastructure, such as transportation and water, have historically been under the purview of local governments to operate and maintain. Local governments may feel obligated to focus on those types of infrastructure that are seldomly provided by the private sector (Q9, P3). Thus, in the context of setting priorities, local government officials may not consider broadband to be as important. Given limited budgets due to their smaller tax base, local governments have to focus on public infrastructure systems. Consequently, some local government officials believe broadband is a luxury, rather than a necessity, for rural residents (Q10, P5).

4.1.2. Supply-side Stakeholders. In contrast, ISPs largely control the decision-making process for where to invest in broadband access. To address the poor market factors in rural areas, state and federal governments send signals for where private companies should invest via grants and low-interest loans. On the supply side, state and federal governments influence RPCs by setting priorities, providing funding for planning efforts, and establishing funding eligibility restrictions. The primary goal of the state and federal government is to increase equity by financing unserved areas that lack any broadband access. ISPs make financial investments, with and without public support, to achieve their goals of profitability. In general, ISPs influence the rural broadband landscape by making deployment decisions, determining service affordability, and influencing data quality. In some cases, the actions of the RPCs and the ISPs conflict with each other, limiting the solution space for rural communities (e.g., shifting community from unserved to underserved can reduce future eligibility for federal funding).

There is wide variability within ISPs, which can range from large private companies to entrepreneurs to co-ops. Given the historical role and goals of co-ops to support the local community, RPCs want co-ops to expand broadband infrastructure in the same way thet expanded electrical infrastructure during the first half of the 20th century (Q11, P7). However, co-ops vary in terms of their comfort with risk and some are unwilling to enter the broadband industry, given the steep learning curve required.

State and federal governments set top-down infrastructure priorities through policy initiatives and funding programs. RPCs help local governments meet the requirements and access funding to accomplish regional infrastructure goals. In most cases, this helps local governments maintain and improve traditional infrastructure (i.e., roads, water). However, in the context of broadband, state and federal efforts have come in waves, limiting momentum. For example, when the funding ran out, there was no follow through on the MoBroadbandNow initiative (Q12, P15). In addition, state and federal governments set eligibility requirements prioritizing unserved areas to achieve equity goals. However, several RPCs indicated that some companies prefer not to accept government funding due to the associated rules and requirements. Similarly, many local governments cannot help finance broadband infrastructure projects via matching contributions (Q13, P10).

The FCC publishes a broadband availability map based on data provided by ISPs (FCC, 2019a). One common critique is that areas that could be served by the ISPs within a short time period are defined as served. In addition, the use of data aggregation (rather than household-level data) makes it appear that a county or census block is served, when in fact, only a small portion is served (FCC, 2019b). These data are used to determine the eligibility of different geographical areas for federal funding. Sixty-nine percent (11 out of 16) of the RPCs shared their concern that these data negatively impact federal funding eligibility for some rural communities because they are incorrectly identified as served (Q14, P1).

ISPs are generally motivated to make deployment decisions based on where profitability is highest (i.e., locations with high population density). To reduce capital costs, many ISPs deploy wireless technology in rural areas. Although these wireless technologies may meet the requirements for many residential customers, they do not meet the requirements for attracting large businesses for economic development. Further, this shifts communities to being underserved rather than unserved and can reduce access to federal funding (Q15, P10). In addition, affordability can limit subscriptions and reduce the ISP’s return on investment (Q16, P2; Q17, P1).

4.2. FRAMING RPC INTENTIONS TO ENGAGE IN RURAL BROADBAND EFFORTS

Themes identified from the interviews and associated with each stakeholder group are summarized in Figure 3. Stakeholder perceptions activate specific attitudes and norms from TPB as illustrated by the arrows. This is aligned with the Theory of Reasoned Goal Pursuit, which suggests that organizational goals can counteract individual attitudes if a behavior is expected to serve a specific goal (i.e., procurement goal).

4.2.1. RPCs Intentions and Behavior. The planning community (see Figure 2) includes the RPC directors and staff as well as the state-level organization, the Missouri

Association of Councils of Governments. RPCs primarily describe themselves as (1) facilitators who connect different stakeholders and (2) planning experts who support local government goals with an emphasis on economic development. Although they lack rule-making authority, RPCs can leverage their power to convene. RPCs increase connections across silos to integrate and coordinate the efforts of various stakeholders to meet a common goal and enable different stakeholders to share their knowledge and experience (Clark, Lowitt, Levkoe, & Andrée, 2020; LeoGrande, 2018). Ultimately, because RPCs sit between local and state-level governments, they are able to balance local interests with larger agendas (Q18, P7). Although RPCs primarily serve as a pull to move forward the objectives of their constituent governments, they can also act as a push to encourage local government officials to consider other viewpoints (Q19, P13). However, actual behavioral control may moderate the intention to expand rural broadband infrastructure. As predicted by the Theory of Reasoned Goal Pursuit, the RPCs' intention to expand rural broadband is directly associated with their goal to facilitate their region's economic development opportunities.

4.2.2. Attitudes Toward Broadband Efforts. In TPB, a positive attitude, described by relative advantages and perceived complexity, is associated with a higher intention to act. As the end users of the broadband infrastructure, residents and businesses ultimately define the relative advantages of having access to the technology. The perceived difficulty of implementing and sustaining rural broadband infrastructure contributes to perceived complexity, which leads to a negative attitude about rural broadband infrastructure efforts. Of the 16 interviews, 15 participants had a positive attitude about rural broadband. The dissenting participant described that the lack of

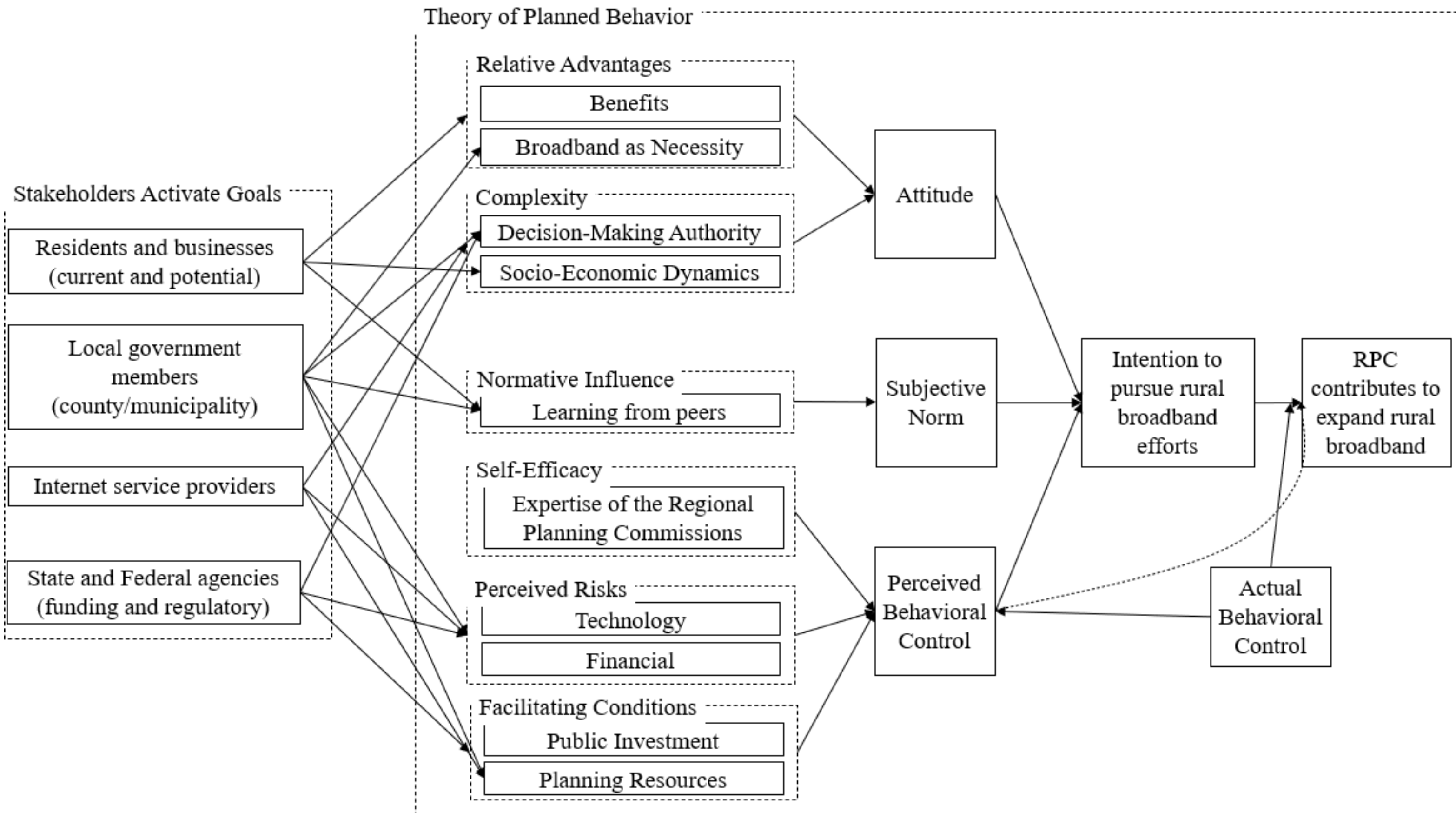

Figure 3. Framework illustrates how the stakeholders in rural broadband influence the Regional Planning Commissions' intention to pursue rural broadband efforts.

broadband had negatively impacted rural communities by reducing economic development and education opportunities. However, they did not perceive the benefits to outweigh the costs. They described an inherent tradeoff between a rural lifestyle and access to modern conveniences (Q20, P14).

4.2.2.1. Relative advantages. RPCs perceived numerous benefits to expanding rural broadband infrastructure and access, focusing on those contributing to their economic development mission consistent with the Theory of Reasoned Goal Pursuit. These advantages are listed in Table 3, which shows the number of interviews in which specific advantages were mentioned. RPCs primarily focused on advantages related to location desirability, business efficiency, jobs, and education.

Location desirability was frequently mentioned in the context of ensuring that professionals, families, and businesses want to live and operate in rural areas. For example, rural areas may struggle to recruit and retain high-quality professionals, such as teachers and doctors. For many people, particularly families, not having broadband access at home is a deal-breaker for moving to a new area:

> *"When we're talking about community development, [the] county has a tough time, or a lot of these smaller communities have a tough time, retaining teachers. You're trying to bring a new family to your area and then keep them there. The whole idea of thinking that you might not be able to access internet at your house, I mean that's a ... no chance, you know?"* (Q21, P13)

Similarly, RPCs are often involved in recruiting new businesses (e.g., manufacturing plants) to a region. Internet access that is acceptable for households may not be adequate for these larger economic development goals to bring in larger employers (Q22, P2).

Table 3. The frequency of perceived advantages of broadband access. Most RPCs focused on economic development opportunities to align with their goals.

Advantage	Frequency
Location desirability	13
Business Efficiency	13
Jobs	11
Education	11
Agriculture	10
Healthcare	9
Entertainment	6
Emergency services	4
Tourism	4

Fundamentally, the discussion of relative advantages is focused on whether broadband is a luxury or a necessity. Some local government officials debate the need for residential broadband service in rural communities because they consider it to be more of a luxury - but residents' expectations are changing (Q23, P14). In contrast, others focus on the long-term consequences of broadband access on economic development potential and local property values (Q24, P15). Although having some type of internet service positively impacts rural housing values, having a high-speed internet connection does not necessarily translate to a higher house value (Deller & Whitacre, 2019).

4.2.2.2. Complexity. Constraints related to terrain, decision-making authority, prioritization of infrastructure, eligibility for state and federal funding, and affordability all contribute to perceptions of complexity. In general, perceptions of high complexity (or difficulty) lead to negative attitudes about using RPC resources and capabilities to increase broadband access and adoption. For example, unsuitable terrain (e.g., hills, valleys, dense forest that restrict wireless technologies) adds complexity to the deployment of broadband infrastructure (Q25, P9).

In addition, the distributed nature of decision-making and difficulty assigning who is responsible for rural broadband infrastructure efforts contributes to perceptions of complexity. Local governments acknowledge their responsibility for other types of infrastructure such as water, wastewater, and transportation but do not universally consider broadband infrastructure to be part of their obligations (Q26, P8). In many cases, local public sector actors perceive themselves as powerless. Local communities are at the whim of companies to decide whether it is economically feasible to provide service. State and federal governments can have a role in providing and administering funding, but that is the extent of their influence:

> *"Well, right now I think largely it's the providers themselves, just a private market driven solution. If certainly the government decided to do some stimulus or something, then they'll obviously play a role in that. But right now, I think in our area it is largely just those providers that whenever they feel like it's time to move in a direction they do."* (Q27, P2)

The RPCs can make recommendations and encourage their local government members to address the need for rural broadband infrastructure. However, the needs for other types of infrastructure often get a higher priority versus broadband infrastructure (Q28, P3). In addition, there is significant debate regarding whether government funding should be focused on unserved or underserved areas. There is concern that only prioritizing unserved areas (as many federal funding opportunities do) ultimately further disadvantages underserved areas (Q29, P15).

Eligibility criteria can be difficult to meet, depending on the local economy. Communities may have a broader definition of industry than government funders, who want to prioritize other goals, such as American manufacturing. For example, improved broadband access can make communities more appealing for tourism, which can increase activity in the service sector and boost the local economy (Q30, P6). In addition, many state and federal funding programs require match or cost share from local communities, which is often difficult for rural areas (Q31, P10). RPCs can evaluate their local members' situation and advise them against moving forward with a grant application that may ultimately disadvantage the community. Local governments may struggle to recover from economic recessions, compared to private companies (Q32, P11).

State and federal funding agencies and ISPs can impact the service affordability for residents and businesses. Unfortunately, affordability of broadband for rural residents negatively impacts an ISP's return on investment and thus their willingness to invest in certain areas. More affluent rural areas have more success attracting ISP investments in broadband (Q33, P15).

4.2.3. Subjective Norms About Broadband Efforts. RPCs' perception of stakeholders' expectations for engaging in broadband infrastructure expansion constitutes an integral part of the subjective norm. Each stakeholder group's expectations are weighted differently depending on their significance to RPCs. According to the Theory of Reasoned Goal Pursuit, the ability to gain critical stakeholders' approval is of paramount importance.

Learning about other rural communities that have broadband infrastructure available for their residents and businesses generates a greater level of interest in broadband. The act of learning from the success of others becomes a descriptive norm that reinforces intention and the behavioral means to attain it (Ajzen & Kruglanski, 2019). From the perspective of local governments and RPCs, understanding the approach used by other communities to finance and deploy the infrastructure could be beneficial. Some of the strategies used by other communities could be adapted and used for the benefit of the local communities (Q34, P3):

> *"So, you know, seeing those success stories and different solutions and partnerships that were formed to make them happen, that's always, it's inspiring, and so you want to know about those. You want to share those with the folks around this table to kind of get them thinking, you know, could we do something like that? Or maybe well we can't do that, but we could do this, you know, that they think they kind of serve as examples to help with that brainstorming, to throw something out there that this has worked."* (Q35, P7)

4.2.4. Perceived Behavioral Control of Broadband Efforts. Perceived behavioral control refers to the RPCs' expectations that their attempts to expand rural broadband infrastructure will be successful. The RPCs' self-efficacy, the perceived risk associated with rural broadband projects, and the facilitating conditions for these projects influence perceived behavior control.

4.2.4.1. Self-efficacy. The RPCs have expertise in navigating the funding processes for state and federal agencies. However, many RPCs have limited experience supporting broadband infrastructure projects. Five of the interviewed RPCs (31%) expressed concerns regarding their limited knowledge and experience with broadband infrastructure. Although some RPCs have been involved in advancing rural broadband infrastructure, lack of experience drives concerns in this area:

"It's been in the private sector versus the public sector for so long that I don't think the public sector knows how to approach [broadband infrastructure]. [...] I know in the Northeast there's been a couple communities that have been successful. I know RPCs assisted, so I'm not saying they're not doing anything. I'm just saying, it's a new problem, and it's been given off to the private sector for so long, we don't know how to approach it." (Q36, P10)

Participants described that their limited expertise is likely leading to missed opportunities for them to assist their communities in advancing rural broadband (Q37, P6). Training, knowledge sharing, and other initiatives may be valuable for increasing self-efficacy (Q38, P3).

4.2.4.2. Perceived risks. Perceived risks negatively influence the perceived behavioral control unless adequate mitigation strategies are defined. The perceived risks are generally associated with the projects' finances and available technology. Three RPCs mentioned that broadband technology, which requires a significant capital investment, could become obsolete after a short period. This is primarily a concern for wireless technologies that are frequently deployed in rural areas (Q39, P14). The main financial risk for ISPs is an inability to achieve their expected return on investment due to low levels of adoption (Q40, P7). The availability of cheaper and better technology could enable competition and result in losses for the original ISPs.

Another technology risk is that the speeds supported by the deployed technology will quickly be inadequate. The FCC's definition of high-speed broadband has changed over the years as the bandwidth required by internet applications grows:

"And that's part of the problem with the capacity is what was acceptable five years ago and what was considered to be high-speed broadband capacity, five years later now, has grown way beyond that." (Q41, P12)

Therefore, from the perspective of RPCs, future-proofing broadband infrastructure is key – but it is unclear how to mitigate this risk, which intersects with constraints around funding eligibility. Most co-ops are focusing on installing fiber optic cable, which can provide gigabit speeds, in order to ensure a future-proof investment but this involves high up-front capital investment.

4.2.4.3. Facilitating conditions. The absence of facilitating conditions represents a barrier for RPCs participating in rural broadband advancement. However, their presence may not necessarily encourage the behavior by default (Taylor & Todd, 1995). One critical factor is the intervention of state and federal agencies that administer funding programs to stimulate broadband infrastructure deployment in rural communities. Public investment is required to improve the return on investment of ISPs and to reduce their financial risk (Q42, P15). However, all government funding mechanisms are not considered to be equally effective. For instance, grant funding is considered more effective than loans (Q43, P4). In addition, the allocation of federal funding is tied to the FCC broadband map, which limits eligibility. Many RPCs expressed frustration about some regions not being eligible because the map shows there is broadband in the region when this is not the case. Many communities experience this same frustration throughout the US (Tibken, 2021). Some are hopeful that a solution is being worked on:

> *"How are you going to do a good planning without good maps and good information? We've got some efforts in Missouri that try to put better maps together, so if those work out maybe we'll have better information."* (Q44, P16)

The RPCs rely on their established interpersonal network to facilitate conversations between key stakeholders such as local government officials and ISPs. In doing so, the RPCs use their convening power to achieve adequate broadband access for their regions. However, some RPCs indicated their last broadband-related project was during the MoBroadbandNow statewide initiative or that they do not have a strategy for broadband infrastructure (Q45, P16).

5. DISCUSSION

RPC efforts to expand rural broadband access are influenced by both internal and external forces. In this study, we develop an integrated framework to demonstrate the complexity of forces both encouraging and discouraging RPCs to leverage their convening powers to build public-private partnerships, apply for state and federal funding, and engage in planning efforts to prioritize broadband deployments. RPCs intend to engage in efforts to advance broadband infrastructure in rural communities to achieve economic development goals. The priorities for the RPCs are set by their executive boards, which are usually composed of elected officials from their member governments. However, having priorities and corresponding funding being defined by the executive board may limit the RPC's ability to be effective and efficient (Seltzer & Carbonell, 2011; Washington, 2007). In TPB terms, the actual behavior control does not reside within the RPCs, and this constitutes a barrier for them to support efforts to expand rural broadband infrastructure.

The demand-side stakeholders, residents/businesses and local governments, have limited power and influence on rural broadband infrastructure investments. These stakeholders influence RPC attitudes about the benefits of broadband access, particularly in the desirability of a location for residents, professionals, and new employers. On the supply-side, ISPs ultimately decide where to make investments and are incentivized by state and federal funding to serve areas that are not otherwise economically feasible. In contrast, perceptions of complexity related to unsuitable terrain, lack of decision-making authority, prioritization of other infrastructure, eligibility issues for state and federal funding, and lack of affordability contribute to negative attitudes. Perceptions of norms are largely influenced by seeing successes in other communities and seeing what might be possible with improved broadband access as well as how they got there. However, RPCs tended to also have low perceived behavioral control. They described inadequate knowledge and expertise in the public sector, technological and financial constraints, and inadequate public investment.

The integrated framework proposed here can support the development of interventions to reduce broadband planning barriers, which can be tested in future research. For example, it could be valuable to improve perceived behavioral control by increasing self-efficacy via interventions that increase knowledge and experience related to broadband. This could be a “broadband curriculum” to ensure all RPCs and other stakeholders (e.g., local elected officials) have a baseline understanding of broadband technologies. For example, the University of Missouri System has launched a “Digitally

Connected Community Guide" course to provide training and guidance for community stakeholder groups, including public officials (Mobroadband.org, 2021). Additionally, there could be value from decision tools such as benefit-cost-risk analysis to support efforts to prioritize broadband infrastructure (Valentín-Sívico, 2020). Providing tools and support for the public sector may improve communities' abilities to advocate for themselves and realize the public-private partnerships that are needed for successful rural broadband deployment.

In addition, this framework can be generalized and adapted to study behaviors of other organizations that face similar stakeholder dynamics and convening power, such as business improvement districts, community-based organizations, and economic development corporations (Abrams, Davis, & Moseley, 2015; Bauroth, 2009; Morçöl & Wolf, 2018). Most of these organizations are nonprofits with public governance and are controlled by publicly-appointed directors (Mead & Warren, 2016). There is growing interest in understanding the role of regional intergovernmental organizations and how they influence regional outcomes (Miller et al., 2018). This framework can also be applied to emerging technologies, such as autonomous and electric vehicles, which require coordination between public and private actors to ensure sufficient infrastructure access.

There are two primary limitations to this work, which can become the basis of future work. First, the data are limited to Missouri and may not generalize to other states, particularly those outside the Midwest. For example, other states, such as Colorado, Maine, and Minnesota, have more robust state-level funding and planning support (Wit & Read, 2020). In addition, the data were collected pre-COVID-19, and many of these dynamics may have since shifted or become more extreme. The COVID-19 pandemic dramatically shifted public sentiment regarding the importance of broadband access and fewer are likely to perceive it as a luxury. Future work should compare how RPCs are interacting with various stakeholders groups to support rural broadband expansion across states and over time to identify effective planning processes for new infrastructure.

6. CONCLUSION

Facilitating organizations, like RPCs, play a crucial role in navigating bottom-up vs. top-down priorities for infrastructure expansion, but they range widely in terms of outcomes, abilities, and institutional power. The proposed integrated framework reveals the dynamics and challenges contributing to this heterogeneity. Rural broadband planning involves many stakeholders, who could benefit from collaboration (e.g., public-private partnerships) but there are often few incentives to do so. For example, local public sector actors struggle to find private sector partners and prioritize efforts (Falch & Henten, 2010). In addition, local governments often have limited financial resources to provide cost share.

As local governments re-evaluate their priorities and look for opportunities to take advantage of additional federal funding (e.g., 2021 Infrastructure Investment and Jobs Act), RPCs will likely be much more involved in broadband infrastructure projects within their region. Funding that supports planning, like the the NTIA's Broadband Equity, Access, and Deployment (BEAD) Program fills a gap for these organizations. Ultimately, RPCs are likely to play an important role in expanding rural broadband efforts as public pressure for access and available funding increases.

APPENDIX

PARTICIPANTS QUOTES

Table A.1. Participants' quotes in support of our findings and observations. [2]

(Q#, P#)	Quote
Q1, P8	So, when you're talking economic development and business attraction and talent attraction, that's where we've got to get to or we're going to be sitting here with cable broadband while our neighbors have fiber and they're 30 minutes away. Where are folks going to live, work, and play?
Q2, P1	I think for rural broadband, small towns are drying up. They're losing population because they're moving to another town that has it [broadband service]. They like the small-town way of life, but they want the utilities and the conveniences, and they want the connectivity with the rest of the world. And so, if they see it in another town, they're moving to the other town.
Q3, P3	Well, I think [broadband is] important for our farmers. There's fewer and fewer of them. More and more land that they're trying to farm, that they need to, to make a profit. I think it's having the infrastructure for them, so that they can do precision ag in some of these areas.
Q4, P16	From an economic development standpoint, it just has ... the ability to work from home for folks. That's something that can change society and so if you can do your same job working wherever ... Just to keep rural America thriving, people don't feel like they have to live in a big city to have a good job, they're just going to work from home. If you're going to work from anywhere with a good internet connection, you can live in rural America too to have that, so I think that's just one of the big benefits.

[2] (Q#, P#) represents quote # and participant #.

Table A.1. Participants' quotes in support of our findings and observations. (Cont.)

Q5, P5	Also in those rural communities, more and more of their healthcare options are going away, so the nearest hospital may now be an hour away from them. So, it makes it more difficult for them to get healthcare, whereas if they had access to broadband internet, then they could have access to telemedicine where they can just video conference with their doctor instead of having to drive an hour to see their doctor.
Q6, P7	This is a beautiful area to live in with the rivers and the streams and just the natural beauty, slower pace, … there's the opportunity for folks to live here and do business here, you know, from home. So, the economic benefit is that they could work here and live here and earn a good living, you know, through the internet.
Q7, P2	[Our communities] look around, and they see what other communities our size are doing in whatever it is. … So, I think there is certainly some influence. I think if our community saw that somebody of similar context was successful in either ... building out some infrastructure on their own and it's the publicly owned infrastructure, or they had come up with some way to attract a private provider to come in, I think they would take note of that.
Q8, P7	In some of our counties, we do have a little older population, and they're probably going to be less likely to jump on the [broadband] bandwagon. […] Our ability to attract younger folks to the area is limited without it because that's an expectation.
Q9, P3	I see that's something that cities and counties, communities ... roads, bridges, water, sewer ... They're more willing to invest in and have that local, whereas they know fiber, somebody else, like [an ISP] … Somebody else is going to come in and do that. And be responsible for it.
Q10, P5	The rural communities, they don't have the population base that the urban communities do, which means their tax base is smaller, which means they just don't have the money to do those types of infrastructure projects. I think a lot of them still see broadband internet access as a luxury, not as a necessity. So, I feel that they are often more focused on what they deem as necessities, such as basic utilities and city services, streets, air, and all those basic things.

Table A.1. Participants' quotes in support of our findings and observations. (Cont.)

Q11, P7	I think the cooperatives have a role to play, too, and I guess that's kind of where they have the network in place in my mind. I really liken this to the electrification of America quite frankly. That it was through those groups and federal resources that they were able to come together and do that. I think it's going to take that similar type of effort to really get us, you know, to have broadband to the same level that we have electricity, really.
Q12, P15	We did do broadband planning, but the funding was specific for this plan, and they didn't have any kind of contingency or continuity planning for the broadband to continue moving forward.
Q13, P10	Well, the cities are worried about taking on any new financial risk. The carrier is worried about not getting a return on their investment. Then as far as the grant side, it's hard to convince a private sector company to move forward with a federal funding application, because they're concerned about what strings are attached to that federal funding. […] The other thing is, federal grants are reimbursable, so for a very small company with such large amounts of money, do they have the money to move forward first?
Q14, P1	One of the problems that we had with MoBroadbandNow, is if a provider could install within a week to your community, you are also considered served. And that is ... well, it was a fallacy in my mind. Because with that statement, and with that mindset, and really that definition of broadband connectivity, I mean that's the other part of why the map is skewed, because technically they could have, but they decided not to.
Q15, P10	Right now, we have a lot of small telcos moving in wanting to do fiber backbones but then do primarily wireless service. That can actually take us out of those federal funding opportunities too, because now they have service, but it's still not good enough service for economic development. It's not good enough service. It's not going to give you the kind of upload speeds you need for certain business.
Q16, P2	You're talking about again, economically depressed areas. Serving them broadband is just going to be very expensive on a per customer basis, and you're dealing with individuals who just don't have a lot of income. It's going to be difficult to pay $100 or something for high-speed internet. So, then how do the providers finance getting that out there at a price that people can afford but not lose their business over the cost? I think it's just basically how do you get it out there and charge a rate that is even close to reasonable?

Table A.1. Participants' quotes in support of our findings and observations. (Cont.)

Q17, P1	There's a ceiling on how much people can afford to spend, especially in the rural areas, on broadband. Yes, it's not water and sewer, it's not the major infrastructure that's needed, it's on the leisure side for some things. But if it comes down to it, are they going to pay for their water bill, their sewer bill, or their broadband bill?
Q18, P7	So that's kind of been more our role, has been more in the convening and making sure the right people are at the table and knowing where the gaps are and where the opportunities are.
Q19, P13	Because, like I said, some of these counties and county commissioners in this area are retired farmers. They are not really sure what they're getting into and not very progressive. So, it's like trying to push, "Hey, this is what you need to be thinking about. This is where your eyes, where your mind needs to be at for this," and trying to push them forward with progressive thoughts and trying to get the county or city or whatever moving in the right direction.
Q20, P14	So, we try to have the best of both worlds. We want to live down by the river, we don't want it to flood, and we want color TV, and we want five-minute ambulance response time, and we want high-speed, fast internet at $25 a month. You're not going to get it. So that's reality… It's not a good proposition to put high-speed affordable broadband in rural areas.
Q21, P13	When we're talking about community development, [the] county has a tough time, or a lot of these smaller communities have a tough time, retaining teachers. You're trying to bring a new family to your area and then keep them there. The whole idea of thinking that you might not be able to access internet at your house, I mean that's a ... no chance, you know?
Q22, P2	One of the big benefits is …the economic development, being able to attract industry that needs that high-speed internet because they're transferring massive files and plans.
Q23, P14	I'm going to call it a luxury; for a lot of people. Because they don't use it for their business, they don't use it for health-related reasons […] You had a dirt road when you moved here. You didn't have broadband when you moved here.

Table A.1. Participants' quotes in support of our findings and observations. (Cont.)

Q24, P15	I'm looking at broadband as a utility. So, it's just like electric, everyone needs it nowadays. You might as well just say, 'If your house doesn't have broadband, you're going to have a harder time selling that piece of property.' It's just like you have an outhouse instead of a bathroom in your house.
Q25, P9	A major reason of why we're not getting broadband access is because we are hilly, and we have a lot of trees. And so, it's hard for the people to get a tower to reach a lot of homes. And so, the cost per home is so high, that nobody will take the risk.
Q26, P8	Well, I think also our local governments, I think they accept that they should be responsible for basic utilities, to the extent that they are able such as water, wastewater, roads and bridges and that sort of infrastructure. So as far as decision making, I think they would like to see broadband in their communities, but they don't feel that is a city or county owned idea. It really takes someone with that level of expertise to come in and provide.
Q27, P2	Well, right now I think largely it's the providers themselves, just a private market driven solution. If certainly the government decided to do some stimulus or something, then they'll obviously play a role in that. But right now, I think in our area it is largely just those providers that whenever they feel like it's time to move in a direction they do.
Q28, P3	Not that we don't think it's important, but compared to sewer, water, things that communities have to deal with and pay for, those tend to take precedence. And those projects never seem to be in short supply.
Q29, P15	And I know there's areas that have no service at all. But if we focus, as a state, if we focus on those areas that have no service at all, I don't feel that this broadband initiative is going to be successful. We also need to look at areas that are underserved or may have service but only one provider. Because it is a statewide issue. It's not just those areas that have no service.
Q30, P6	We had started to look at working with [local ISP] on a grant for last year to get internet at the campgrounds. But our challenge was ... to identify a business that would be using the internet. … it had to be like a light manufacturer and around the lake, there's just not any around the lake. I mean, it's all tourism-based. And so, we couldn't move forward with that project because we couldn't identify any businesses that would benefit from it. You had to have that business benefiting, and then if the tourist, or the people that were camping, benefited, okay, well, that was just an add-on. But we couldn't find a business that would benefit, so we couldn't move forward with it, so that was unsuccessful.

Table A.1. Participants' quotes in support of our findings and observations. (Cont.)

Q31, P10	I have one small city that qualifies for these grants, but they currently have trouble even paying for their current infrastructure and maintaining it. Everything, streets to their water, it's bad. They're like, we want to apply for this! I'm like, no. You qualify, but mm-mm, negative.
Q32, P11	Because if they have a downturn, there's usually some money over here in reserves. Or they go bankrupt, and somebody buys them. You know? Or it's the market whereas the public entity is not market based.
Q33, P15	…if we didn't have the affluent community, the retirement communities, would they [local co-op ISP] have been able to deploy it throughout their entire region? Because they cover a large section of the lake area where we have those million-dollar, multimillion-dollar homes. And that's also one of the other questions I have in regards to the other co-ops. What are their consumers look like? Are they a more affluent consumer, or are they really more of the middle or lower class consumers that wouldn't be able to buy into that one gigabyte even if it was available?
Q34, P3	A year or two ago, [we] went to [the] American Planning Association Conference. ... There were several communities up there that talked about how they did broadband, ... And so, it did give me some opportunities to go back and say, "Okay, this is how another community does this. Have we considered this as a group, that that might be an option for a community?" ... I think there is tremendous value in that, in networking, and looking at how others have done it because there's no sense of recreating a path if somebody's had a successful formula, if you can use it. It doesn't always work that way, but at least it gives you an idea and a frame of reference.
Q35, P7	So, you know, seeing those success stories and different solutions and partnerships that were formed to make them happen, that's always, it's inspiring, and so you want to know about those. You want to share those with the folks around this table to kind of get them thinking, you know, could we do something like that? Or maybe well we can't do that, but we could do this, you know, that they think they kind of serve as examples to help with that brainstorming, to throw something out there that this has worked.

Table A.1. Participants' quotes in support of our findings and observations. (Cont.)

Q36, P10	It's been in the private sector versus the public sector for so long that I don't think the public sector knows how to approach [broadband infrastructure]. [...] I know in the Northeast there's been a couple communities that have been successful. I know RPCs assisted, so I'm not saying they're not doing anything. I'm just saying, it's a new problem, and it's been given off to the private sector for so long, we don't know how to approach it.
Q37, P6	You know it's probably ... there may be funding for broadband, we're just not tapping into it. So, for us, water and wastewater projects, general infrastructure projects, even streets, and that, is that we're so familiar with those type of projects, and just not familiar with broadband enough to go after funding. So it may be that there's spending out there. We just haven't tapped into it.
Q38, P3	We have several members of our economic development community who, I think, are more focused on broadband than probably we are. […] Now, they're trying to pull me along, catch me up. So, we're saying we need things like broadband 101 to educate community city officials, just to even understand the terminology.
Q39, P14	How do we know investing millions of dollars in a technology that we know now isn't going to be obsolete five years from now? I think that's a huge factor that people hesitate on now. I think that they don't know how long the most current and successful technology is going to be that state-of-the-art technology, until something else comes along and makes that investment obsolete. Where it's, "Gosh. I wish we would've waited two years. We would've had so much faster, with less investment.
Q40, P7	Right now, I think it's really coming down to the numbers. I think it's very much of a, you know, number of people who want it, are willing to pay for it and what's it going to cost. And that's going to come out in the black when all is said and done.
Q41, P12	And that's part of the problem with the capacity is what was acceptable five years ago and what was considered to be high-speed broadband capacity, five years later now, has grown way beyond that.
Q42, P15	There is some support for public investment. I think there's opportunities in the public investment because we're relying solely on the private sector now to provide this, and they're not willing to provide it in areas that they don't have that return on their investment. So, I think that the public involvement is going to be necessary.

Table A.1. Participants' quotes in support of our findings and observations. (Cont.)

Q43, P4	Most important is to provide seed grant funding so that the first steps can be taken with lower risk to the companies that have the best chance of sustaining those internet access efforts. Providing loan money as part of the enticement to invest is not adequate.
Q44, P16	How are you going to do a good planning without good maps and good information? We've got some efforts in Missouri that try to put better maps together, so if those work out maybe we'll have better information.
Q45, P16	No. I hate to admit this, but we really don't have a strategy for our region, honestly. We should, in theory, go through a planning process, or two planning processes. Nobody seems to be leading the effort, and the companies or co-ops are doing what they want to do.

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II. IMPACT OF BROADBAND INTERNET ON THE WELL-BEING OF RURAL COUNTIES: A BENEFIT-COST ANALYSIS

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ABSTRACT

Access to broadband internet is of paramount importance for the support of economic activity in both urban and rural communities. Having access to high-speed internet is essential for rural communities to attract new enterprises, support the expansion of existing businesses, as well as for attracting and retaining their local population. Variations of economic activity directly impact the amount of tax collected for the support of the local community. Having a reliable high-speed internet infrastructure contributes to the protection and potential expansion of the tax revenue for rural counties. To achieve the successful planning and deployment of the required rural broadband infrastructure, towns and local governments incur different costs. Even when there might be federal funding available to promote the implementation of rural broadband, often, local fund matching is required. Also, there are negative externalities associated with high-speed internet, some of these being cyber-bullying, online gaming addiction, and online gambling addiction. A benefit-cost analysis (BCA) of a broadband project is conducted for a hypothetical county defined using data from various governmental agencies. A proposed model considers the change in tax revenue as a means to monetize the impact of rural broadband. The cost associated with treating

problematic internet use is monetized as mental health expenditure. A sensitivity analysis of the BCA reveals that the initial revenue of the county, as well as the year-over-year population change, impact the net present value of the broadband infrastructure projects to a greater extent versus other model parameters like the unemployment rate.

1. INTRODUCTION

Broadband internet is an essential tool for economic activity, and this is no different in rural communities. The Federal Communications Commission (FCC) states that “broadband is a foundation for economic growth, job creation, global competitiveness and a better way of life” (FCC, 2011). The agency defined closing the digital divide as their #1 strategic goal and estimates that up to 6 million rural businesses and homes could benefit from the Rural Digital Opportunity Fund (RDOF) (Pai, 2018; FCC, 2020). The United States Department of Agriculture (USDA) estimates that rural broadband and the adoption of next generation precision agriculture could lead to a potential $47-65 billion in annual gross benefit for the USA (USDA, 2019).

The U.S. Federal Government is providing financial support to close the digital divide. Through the RDOF, the FCC will direct up to $20.4 billion over ten years period to address the digital divide (FCC, 2020), while the USDA ReConnect Program will be providing up to $600 million in funding to facilitate the deployment of broadband in rural USA (USDA, 2018).

As consumers and businesses benefit from access to rural broadband, this should have repercussions at the finances of local governments such as towns and counties. Still, not all impacts related to broadband are positive. There are several adverse effects associated with high-speed internet, some of these being cyber-bullying, online gaming addiction, dissemination of fake news, distribution of illegal media content, and online gambling addiction. Also, spending too much time online can lead to sedentarism, which, in turn, is associated with obesity (DiNardi, Guldi, & Simon, 2019; Matusitz & McCormick, 2012).

The benefit-cost analysis (BCA) presented in this paper takes into account the cost of treating problematic internet use (PIU). Considering the negative externalities of broadband internet as part of a BCA is a gap addressed in the current research. The objective of the BCA is to understand the overall impact of broadband on the financial well-being of rural counties. The next sub-sections provide additional details regarding the benefits and costs of the technology.

1.1. BENEFITS OF RURAL BROADBAND

The adoption of broadband in rural areas increases income growth while decreasing unemployment growth (Whitacre, Gallardo, & Strover, 2014). Broadband constitutes an essential tool enabling the diversification of products and services provided by rural small businesses (Pant & Odame, 2017). Having access to rural broadband enables residents to telecommute. And telecommuting allows residents to save on transportation costs while reducing the risks associated with driving between work and their place of residence. Considering only the commuting time and fuel savings, Hambly & Lee (2019) report that a residential telecommuter who telecommutes five days a week could expect an annual cost saving of up to CAD$23,964.

Rural broadband has been found to increase the value of homes. Molnar, Savage, & Sicker (2019) found that single-family homes in rural neighborhoods with access to a 25Mbps broadband connection sale for a price that is 2.5% higher than similar homes in communities with access to a slower internet of 1Mbps.

1.2. COSTS OF RURAL BROADBAND

The most obvious costs of broadband infrastructure are the costs of planning, designing, and deploying the infrastructure. Much of the challenge associated with rural broadband infrastructure has been found to be associated with a low return on investment due to high capital investment and low population densities in rural communities (Canfield, Egbue, Hale, & Long, 2019). The cost for each broadband infrastructure project varies depending on the mix of technology used, the terrain of the region, and the size of the project (number of homes and businesses to be impacted by the internet network). Additionally, the broadband infrastructure needs to be maintained and operated to ensure its proper operation. In their BCA study, Grant & Tyner (2018) considered these two cost categories.

In addition to these costs, there are some negative externalities local governments should take into account when evaluating their investment in broadband infrastructure. Many of the adverse effects associated with broadband internet are related to what is generally called problematic internet use (PIU), also known as internet addiction. It is a behavioral addiction involving human-machine interaction. People dealing with PIU have a hard time disengaging from their online activities and feel an urge to connect to the network when they are offline (Tikhonov & Bogoslovskii, 2012). Several internet activities can lead to PIU, both individually or in combination: general web surfing, online shopping, online gambling, online pornography, online gaming, social media, streaming media, role-playing games, auction websites, and massively-multiplayer online games.

None of the referenced literature studied these adverse effects of the internet focused in rural areas. In Korea, the sample for a nationwide online gaming study included participants from three metropolitan districts, five districts in midsized cities, and four rural counties (Kim et al., 2017). The subset of participants addicted to online gaming tended to be young patients with a higher proportion of single unemployed adults, and higher rates of thinking, planning and attempting suicide when compared with individuals with no addiction to online gaming.

In a PIU study involving a population sample from Chicago, USA and Stellenbosch, South Africa, Ioannidis et al. (2018) found that the relationship between PIU and role-playing-games, online gambling, use of auction websites, and streaming media were moderated by age. Higher levels of PIU were associated with older age. Among young participants (25 and younger), high PIU scores were associated with attention deficit hyperactivity disorder and social anxiety disorder. In contrast, older participants (older than 55) were associated with generalized anxiety disorder and obsessive-compulsive disorder.

Untreated addictions could have adverse effects on the people suffering from them, their family and friends, as well as society as a whole. The mental health expenditure addresses the associated cost of treating those who seek help for their condition. Columb & O'Gara (2018) studied the situation with online gambling in

Ireland. In this study, the researchers wanted to obtain insights associated with this addictive internet activity. Three quarters (75%) of the surveyed participants had to borrow money or sell personal property to finance their online gambling activity. According to participants in this study, online gambling is more addictive than gambling through other non-online venues. While the majority of participants (64.4%) could recognize they potentially had an addiction problem, few were seeking help treating this condition.

2. METHODOLOGY AND DATA

Having access to adequate broadband infrastructure within a county can be a tool to unleash economic opportunities for the community, both for businesses as well as consumers. The economic activity within a county should impact the revenue of the county. A relationship between the county revenue and a series of economic indicators is used for the BCA. The BCA model assumes that the population growth and the unemployment rate are indicators of the economic performance of rural counties, and they impact the county revenue. One assumption of the model is that the benefit of adequate broadband infrastructure changes over time. The analysis monetizes the impact of broadband using the change of revenue in the county with respect to the initial revenue at the beginning of the broadband infrastructure project.

Considering that the discussed negative externalities are associated with mental health conditions, the BCA analysis incorporates the impact of treating these conditions by including the mental health expenditure within the model. It takes into account the change in mental health expenditure as a means to capture the potential adverse effects of broadband in the form of some of the externalities, such as online gambling addiction and online gaming addiction. It is important to note that the conducted BCA is from a county government perspective. Even when counties contribute to the treatment of mental health conditions, usually, this represents a fraction of the associated costs. Private citizens and other governmental programs cover some of the expenses.

The model used as the basis for the completed BCA analysis is presented in Equations (1) through (9), and the nomenclature used to represent the different parameters in the model are presented in Table 1. Equation (1) shows that the initial per capita revenue is calculated by dividing the county revenue by the county population at time *0*. Similarly, Equation (2) presents that the initial per capita mental health expenditure is obtained by dividing the county expenditure in mental health by the county population at time *0*. The model assumes a constant year over year (*y/y*) change in population as well as in the unemployment rate. Therefore, the population and the unemployment rate in a given year depends, respectively, on the population and the unemployment rate at time *0*, as well as the corresponding rate of change. Equation (3) shows how to calculate the county population at the end of the year *i*. The county population at the end of the year *i*, equals the initial population plus the experienced changed given the year-over-year change in population. Note that $i \in \{1,2,\ldots,20\}$ as the span for the broadband infrastructure project is 20 years. The change in the unemployment rate with respect to the initial unemployment rate in the county is

Table 1. Nomenclature Definition and Identification of Benefit and Costs Parameters.

Economic Characteristic	Nomenclature	Benefit or Cost
Initial Per Capita Revenue	R_{PC_0}	-
Initial Revenue	R_0	-
Initial Population	P_0	-
Initial Per Capita Mental Health Expenditure	$MH\ Exp_{PC_0}$	-
Initial Expenditures in Mental Health	$MH\ Exp_0$	-
Population at the end of year *i*	P_i	-
y/y Population Change	*y/y PC*	-
Change in Unemployment Rate at end of year *i* with respect to year 0	ΔuR_i	-
Initial Unemployment Rate	uR_0	-
y/y Change in Unemployment Rate	*y/y change in uR*	-
Change in Revenue at end of year *i* with respect to year *0*.	$\Delta\ Revenue_i$	Benefit
Change in Mental Health Expenditure at end of year *i* with respect to year *0*	$\Delta\ MH\ Exp_i$	Cost
Equivalent Annual Cost of the capital investment for year *i*	$CI_{EAC\ i}$	Cost
Annual Operating Cost for year *i*	OC_i	Cost
Capital Investment	*CI*	-
Benefits at the end of year *i*	B_i	Benefit
Costs at the end of year *i*	C_i	Cost
Discount Rate	r	-

calculating by subtracting the unemployment rate at the end of the year *i* minus the initial unemployment rate at time *0*. This is shown in Equation (4). The proposed model reflects that an increase in the unemployment rate would cause a reduction in the county revenue, and a decrease in the unemployment rate would cause an increase in the county revenue. The proposed relation is captured by Equation (5), where the initial county revenue at time *0* is subtracted from the revenue at the end of the year *i* to calculate the change in county revenue with respect to the revenue at time *0*. In the case of the mental health expenditure by the county, the proposed model reflects that an increment in the unemployment rate would be associated with an increase in this expenditure. In contrast, a decrease in the unemployment rate would cause a reduction in mental health expenditure. The calculation of the change in mental health expenditure by the county on the year *i* with respect to the expenditure at time *0*, is presented by Equation (6).

$$R_{PC_0} = \frac{R_0}{P_0} \quad (1)$$

$$MH\ Exp_{PC_0} = \frac{MH\ Exp_0}{P_0} \quad (2)$$

$$P_i = P_0 * \left(1 + {}^{y}\!/_{y}\, PC\right)^i \quad (3)$$

$$\Delta uR_i = uR_0 * \left(1 + {}^{y}\!/_{y}\, change\ in\ uR\right)^i - uR_0 \quad (4)$$

$$\Delta\ Revenue_i = R_{PC_0} * P_i * \left(1 - \frac{\Delta uR_i}{uR_0}\right) - R_0 \quad (5)$$

$$\Delta\ MH\ Exp_i = MH\ Exp_{PC_0} * P_i * \left(1 + \frac{\Delta uR_i}{uR_0}\right) - MH\ Exp_0 \quad (6)$$

$$B_i - C_i = \Delta\ Revenue_i - \Delta\ MH\ Exp_i - CI_{EAC\ i} - OC_i \quad (7)$$

$$CI_{EAC\ i} = \frac{r * CI}{1-(1+r)^{-20}} \quad (8)$$

$$NPV = \sum_{i=1}^{20} \frac{B_i - C_i}{(1+r)^i} \quad (9)$$

B_i - C_i represents the annual difference between the benefit and the costs for the year *i*. From Equation (7), it can be observed that the benefits of the rural broadband infrastructure project for the year *i* are represented by the change in revenue at the end of the year *i* with respect to the county revenue at time *0*. The annual cost for the year *i* is calculated by adding the equivalent annual cost of the capital investment, the annual operating cost, and the change in mental health expenditure for the year *i* with respect to the mental health expenditure at time *0*. The equivalent annual cost of the capital investment is calculated using Equation (8) (Kenton, 2019). Using the computed annual $Benefit_i - Cost_i$, the NPV of the project is calculated using Equation (9) (Kenton, 2020).

In the model, the revenue of the county depends on the initial per capita revenue, the initial unemployment rate, the new population, and the new unemployment rate for each of the 20 years in the project analysis. The overall assumption of the model is that having access to an adequate broadband infrastructure enables a county to retain its population and attract new residents while supporting economic activity, so the unemployment rate decreases year-over-year (*y/y*). Even when this is the foundational logic of the model, the sensitivity analysis considers scenarios where the population increases *y/y*, as well as the unemployment rate increases *y/y*.

The county used as the basis of the completed BCA is represented within the baseline scenario in Table 2. To identify the value for these characteristics, several data sets were used. The referenced data were associated with the counties in the state of Iowa. Given that our focus is broadband infrastructure in rural counties, the considered data was filtered to only include the counties with at least 60% of their population living in rural communities. The percentage of the population living in rural communities was obtained from the 2010 Census (U.S. Census Bureau, 2020). The initial revenue and the initial expenditure in mental health were identified considering the budget for fiscal 2020 for the counties in Iowa (Iowa Department of Management, 2020). The population and the unemployment rate percent were identified using data from the 2018 American Community Survey (ACS) (U.S. Census Bureau, 2020).

The revenue considered in this analysis includes revenue figures from property taxes, other county taxes, licenses and permits' fees, charges for services, and the use of money and properties. The value for the different parameters associated with the hypothetical county (R_0, P_0, $MH\ Exp_0$, and uR_0) were identified using the median for the corresponding variables. These economic characteristics of the county of interest are part of the baseline scenario presented in Table 2.

Table 2. Economic Characteristics Scenarios Considered in the Sensitivity Analysis. The Baseline Scenario Contains the Economic Characteristics of the Hypothetical County.

Economic Characteristic	**Nomen-clature**	**Baseline Scenario**	**Worst Case Scenario**	**Best Case Scenario**	**Referenced Data Set**
Initial Revenue	R_0	\$8.2M	\$3.2M	\$19.5M	2020 Iowa Counties Budget
Initial Population	P_0	11,223	3,726	25,626	2018 ACS
Initial Expenditures in Mental Health	$MH\ Exp_0$	\$441.3K	\$153.6K	\$1.7M	2020 Iowa Counties Budget
Initial Unemployment Rate	uR_0	2.8	4.9	1.0	2018 ACS
Capital Investment	*CI*	\$28.1M	\$36.1M	\$15.4M	USDA Approved Projects
y/y Population Change	*y/y PC*	4.8%	-2.0%	10.6%	U.S. Census
y/y Change in Unemployment Rate	*y/y change in uR*	-1.5%	1.0%	-2.9%	U.S. Census
Discount Rate	*r*	7%	11%	3%	OMB
Annual Operating Cost	OC_i	\$1.5M	\$2.0M	\$1.0M	Grant & Tyner (2018)

2.1. SENSITIVITY ANALYSIS

In addition to the initial county economic characteristics, the model uses other economic characteristics used in Equations (1) - (9). As part of the completed sensitivity analysis, the initial values of the county of interest become part of the baseline scenario. Table 2 presents the three scenarios considered as part of the sensitivity analysis, as well as the source of the referenced data set.

Similar to how the initial county characteristics were defined considering the median of the corresponding parameter from the referenced data set, the worst and best case for these characteristics were defined considering the corresponding minimum and maximum values. In the case of the capital investment, the list of all approved broadband infrastructure projects by the USDA (up to May 9, 2020) was used to calculate the mean, median, and first quartile of the cost per resident (ArcGIS, 2020). These computed per capita costs were multiplied by the total population associated with the different scenarios to identify the value of the capital investment for the different scenarios. The experienced population growth from 2010 to 2018 (using the 2010 Census and the 2018 ACS data) were considered to define the *y/y* population change for the different scenarios of the sensitivity analysis. The baseline *y/y PC* was defined as ½ the median of the experienced growth. The worst case was defined as ¼ of the slowest experienced growth. And, the best case was defined as the 3rd quartile fastest experienced growth. The factors used to identify the baseline case and the best case scenarios were used as they represent conservative population change rates that are within the population growth experienced by the Iowa counties between 2010 and 2018. The factor used for identifying the worst case scenario represents a slower population growth than the slowest growth experienced by the considered Iowa counties. The discount rate used by the federal government for the analysis of various projects is published by the Office of Management and Budget (OMB) annually. The considered scenarios for the discount rate were selected considering historical values published by the OMB (Office of Management and Budget, 2019). To choose the annual operating costs, the BCA performed by Grant & Tyner (2018) was used as a reference. In their analysis, the NPV of the operating costs was slightly lower than the capital cost.

3. RESULTS

The obtained results are presented in two sub-sections. The first sub-section presents the BCA model predictions for the hypothetical county once it completes the investment in adequate broadband infrastructure as part of a 20 years project. The second sub-section presents the obtained results for the sensitivity analysis.

3.1. PREDICTED EFFECT OF INVESTING IN ADEQUATE BROADBAND INFRASTRUCTURE

An NPV of $18.1M is obtained using the model with the baseline scenario, which includes the characteristics of the hypothetical county. The benefit of the broadband infrastructure for the defined rural county exceeds the costs associated with the project. Looking at the NPV, the rural county could expect to recover the capital invested in the rural broadband infrastructure, it’s associated annual operating costs, as well as the increment on mental health expenditure and still have a surplus. Figure 1 presents the cash flow diagram of the break-even analysis predicted by the model. The annual benefit exceeds the annual costs starting from the seventh year after the rural broadband infrastructure is available.

3.2. RESULTS OF THE SENSITIVITY ANALYSIS

The sensitivity analysis reflects that the initial county revenue, as well as the year-over-year population change, are the two parameters that have a more significant impact on the predicted NPV. The sensitivity analysis is completed by keeping all the economic characteristics included in the model on their baseline value while varying one parameter at a time to its worst and best case values, as described in Table 2. The benefit and costs are computed for the 20 years of the project, and the NPV is calculated using the corresponding discount rate. Table 3 presents the resulting NPV for each scenario of the sensitivity analysis, as well as the percent effect on the NPV for each 1% change on the corresponding parameter for the worst case and the best case variations.

The initial population and the initial unemployment rate are not presented in Table 3 as variations in these parameters do not cause any change in the NPV. This behavior can be understood by taking a close look at the model Equations (1) – (9). In the case of the initial population, looking at Equations (1), (3), and (7), it can be observed that the initial population gets canceled out. Therefore, changing the value of the initial population P0 has no effect on the project NPV. Similarly, in the case of the initial unemployment rate (uR_0), considering Equations (4) and (6), it can be observed that uR_0 gets canceled out.

Considering the percent effect on the NPV per 1% chance in parameter, both for the best case and worst case, the two parameters with a more significant impact on the

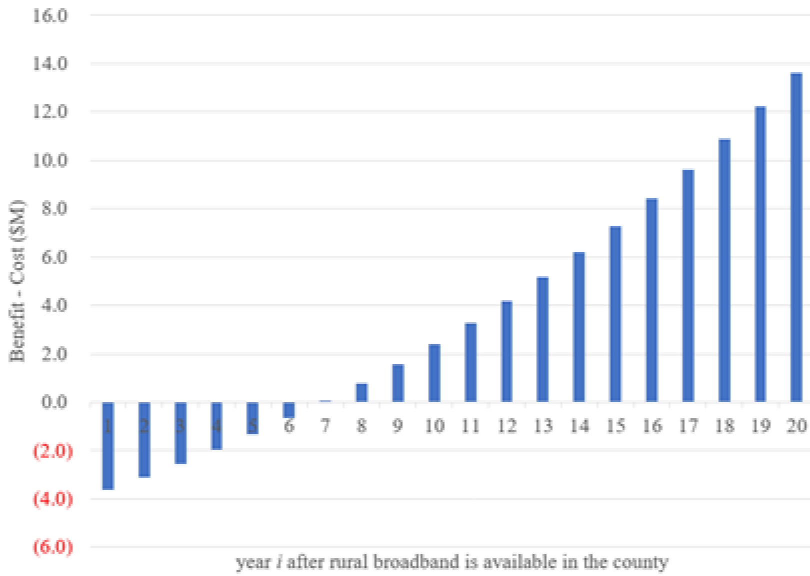

Figure 1. The Cash Flow Diagram of the Break-Even Analysis Shows that B_i - C_i Becomes Positive Starting from Year Number Seven.

Table 3. The Percent Effect Change on Net Present Value (NPV) Per 1% Change in Each of the Model's Parameter Reflects that the Initial County Revenue and the Year-over-Year Population Change Are the Two Parameters with Greater Impact on the NPV. An NPV of $18.1M is Obtained Using the Baseline Scenario.[3]

Economic Characteristic	**Worst Case: NPV**	**effect on NPV per 1% Δ (Worst)**	**Best Case: NPV**	**effect on NPV per 1% Δ (Best)**
Initial Revenue	**-$20.6M**	**3.5%**	**$106.7M**	**3.5%**
Initial Expenditures in Mental Health	$19.1M	-0.1%	$13.6M	-0.1%
Capital Investment	$10.1M	-1.6%	$30.8M	-1.6%
***y/y* Population Change**	**-$48.0M**	**2.6%**	**$133.7M**	**5.4%**
y/y Change in Unemployment Rate	-$14.9M	-1.1%	$33.6M	-0.9%
Discount Rate	-$0.5M	-1.8%	$52.4M	-3.3%
Annual Operating Cost	$12.8M	-0.9%	$23.4M	-0.9%

[3] The table included in the published version of the paper (Valentín-Sívico, 2020) was wrong. Table 3 in this page of the dissertation includes the correct calculations. The conclusions of the sensitivity analysis remain the same.

project NPV are the initial revenue (R_0) and year-over-year population change (*y/y PC*). Keeping the value for all other parameters at their baseline value and focusing on the results of the sensitivity analysis for these two top influencing factors leads to a linear relationship where the initial revenue can predict the NPV for the given value of the *y/y PC*. This linear relationship is represented in Figure 2. Looking at the resulting lines,there seems to exist a relationship between the slope of the lines and the *y/y PC*. The higher the *y/y PC*, the higher the slope of the corresponding line.

Figure 3 presents the relationship between two parameters of particular interest: the *y/y PC* and the *y/y* change in *uR*. In this graph, once again, it can be observed the significant effect of the *y/y PC*. The faster the population growth, the higher the predicted

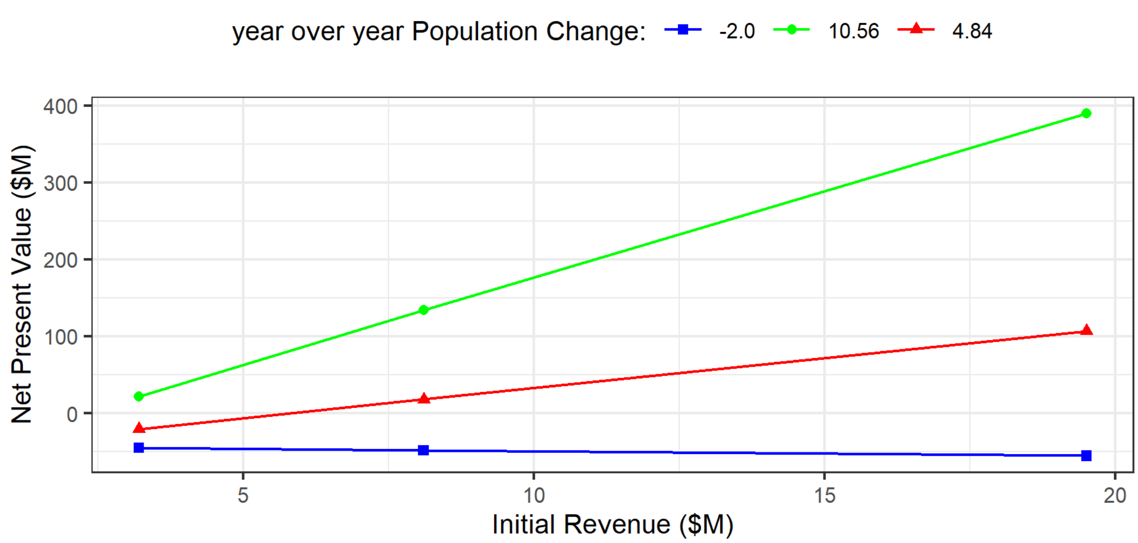

Figure 2. Linear Relationship Between the Project Net Present Value (NPV) and the Initial Revenue Which is the Most Significant Factor for the NPV.

value of the project NPV. On the other hand, to have the unemployment rate increasing year-over-year leads to a higher drop in the expected NPV for the scenario when the population grows the fastest.

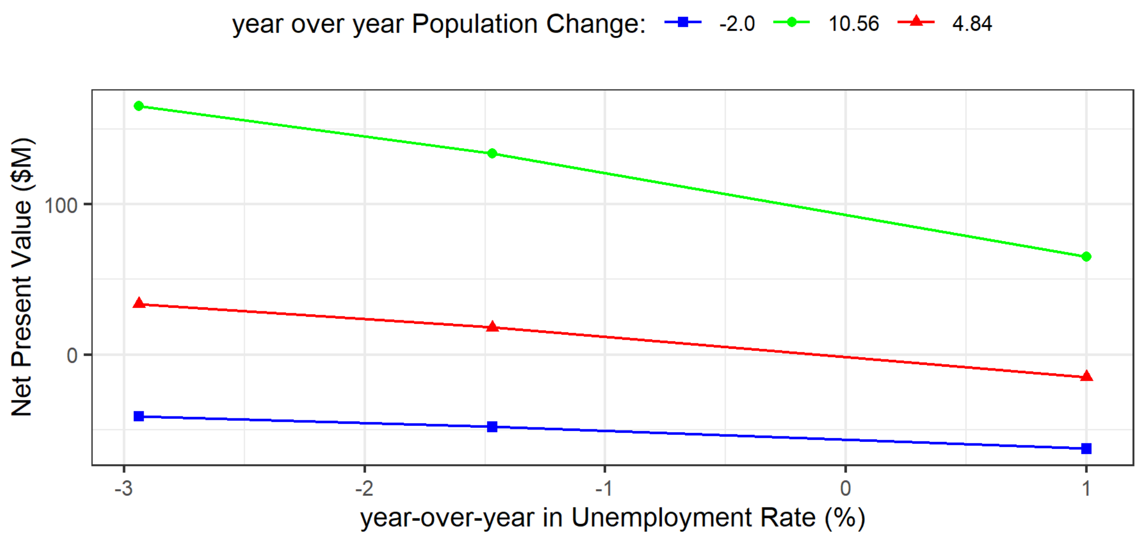

Figure 3. A More Drastic Drop in the Project Net Present Value is Associated With a Year-Over-Year Increase in Unemployment When the Population is Growing Faster.

4. CONCLUSIONS AND RECOMMENDATIONS

A net present value of $18.1M was predicted by the model for the rural broadband infrastructure project considering the baseline scenario. This baseline scenario included the identified economic indicators for the defined hypothetical county. This NPV suggests that a county with these characteristics can expect to recover the money invested in the broadband infrastructure, pay for the operation of the network, and cover the mental health expenditure associated with problematic internet use. To consider the negative externalities associated with the PIU as a cost in the BCA is a contribution made by the current research. Governments and organizations should consider the costs of treating conditions such as PIU when evaluating their potential investment in rural broadband.

The sensitivity analysis revealed that the initial county revenue, as well as the *y/y PC*, are the two model parameters with a more significant impact on the expected NPV of the rural broadband project. Even when the *y/y* change in *uR* does not have such a high impact on the predicted NPV, having a year-over-year increase in unemployment has a more significant effect when the county experiences a higher year-over-year population growth.

Broadband internet can bring benefits to rural counties. Regional Planning Commissions in Missouri see broadband as a critical infrastructure that supports the economic development in rural communities (Valentín-Sívico, Canfield, & Egbue, 2020). Each county should consider its economic reality and should carefully evaluate if investing in adequate broadband infrastructure is best for their community. Broadband can be a tool for rural counties as they exercise their resiliency. It could represent a means to improve the situation with high unemployment rate.

Even when access to rural broadband is a prerequisite to enabling economic opportunities, adopters must get training on how to use the technology to their benefit. Pant & Odame (2017) conducted a series of interviews with individuals and groups to identify the benefits of having broadband internet in rural areas in Ontario, Canada. The researchers concluded that having broadband internet service was not the only requirement to enable success stories for small businesses. Additional support services, such as business development services, networking events in which small business owners interact with other entrepreneurs as well as suppliers, and branding and marketing services were required to enable small businesses to maximize their access to broadband internet.

To the extent a rural county can keep a low unemployment rate and increase the county population, the easier it would be for the county to recover any required investment in rural broadband infrastructure, and to see a positive impact in the county finances.

The considered model enables the evaluation of the effect of different economic parameters on the expected NPV of a rural broadband project, and provide a means to compare the impact of the various parameters. As previously stated, the model takes into account the negative externalities associated with the PUI. The model aims to capture an increase in mental health costs as a higher percentage of the population gets access to a technology that has the potential to generate a psychological dependency. Detailed research should be conducted to identify how rural broadband impacts the prevalence of these mental conditions within rural communities, and what type of expenditures by the local government is required to counterbalance the undesired situation. Other costs were not incorporated into the model used for the BCA. The costs associated with other interventions, such as those suggested by Pant & Odame (2017), were not incorporated in the BCA. Future BCA should account for these additional costs.

The change in the county revenue is the only considered benefit of the adequate broadband infrastructure. The model does not take into account any direct revenue stream associated with charges for accessing the broadband internet service, or from a leasing fee to a private company for operating the infrastructure.

Another limitation of the model is that it assumes the population change, as well as the change in the unemployment rate, remains constant year-over-year for the duration of the broadband infrastructure project. Even when this is not realistic, it is a simplified method to reflect cumulative changes over time. Future versions of the BCA might benefit from using a Monte Carlo analysis approach.

As part of future research, a study should evaluate the effect of rural broadband on the finance of rural counties. A study like this should be able to validate or revoke the assumptions made on the proposed model in this paper.

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III. EVALUATING THE IMPACT OF BROADBAND ACCESS IN A SMALL UNDERSERVED RURAL COMMUNITY ON EMPLOYMENT, EDUCATION, AND HEALTH-RELATED INTERNET USAGE

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ABSTRACT

Having adequate access to the internet at home enables economic opportunities and quality of life for households. However, despite increased investment in response to the COVID-19 pandemic, millions of households in the rural United States still lack adequate access to high-speed internet. A wireless broadband network was deployed in Turney, a small underserved rural community in Northwest Missouri. In addition to collecting pre-post data for this internet intervention, pre-post survey data were collected from similar nearby communities to serve as a control group. Some of the interested participants in Turney were unable to be connected to the network due to technical constraints, which created an additional comparison group in the post-survey. These comparisons suggest two primary findings, (1) changes in using the internet for employment, education, and health could not be directly attributed to the internet intervention and (2) the internet intervention was associated with quality-of-life benefits

related to the ability to use multiple devices at once. This study has implications for the design of future evaluation studies and provides recommendations for identifying appropriate outcome variables, executing recruitment strategies, and selecting the timing of surveys.

1. INTRODUCTION

Broadband access has become a top concern for federal and state policymakers as the digital divide threatens to leave behind rural communities. Recent Federal Communications Commission (FCC) estimates suggest that at least 14.4 (22.3%) million rural residents have inadequate broadband service (FCC, 2020). This affects rural communities' ability to retain residents, gain tax revenue, and attract employers.

As a result, in response to the COVID-19 pandemic, the federal government authorized $87 billion in funding for broadband access and adoption. This includes the Infrastructure Investment and Jobs Act which includes $65 billion to address the digital divide in the U.S.A, American Rescue Plan which includes $20.4 billion funding digital equity policies, and Consolidated Appropriations Act which includes $1.6 billion for connecting minority communities, connectivity in tribal lands, and general broadband infrastructure deployment (Congressional Research Services, 2021; NTIA, 2021; Tomer & George, 2021). These funds will be administered by different federal agencies, such as the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration, as well as by the states and U.S. territories.

Given this large increase in available funding, there is an opportunity to conduct evaluations to estimate the impact of these government programs. Evaluations support evidence-based policy-making efforts to increase the efficiency of government spending. Infrastructure investments have economic impact (Stupak, 2018) as well as social impact, which has been linked to the social economy (Zamojska & Próchniak, 2017). The social economy seeks to meet social needs, solve social dilemmas, and create social innovations. Social impact is difficult to quantify and the scope may vary between stakeholders.

To date, most studies have estimated the impact of broadband access and adoption in the United States aggregated at national and state levels. Typically, these studies focus on estimating the average effects of one specific impact, such as household income, housing value, or student performance in large geographical areas. However, this approach can make it challenging for a particular community to understand potential impacts. Few studies have explored multiple impacts within a single community over time to understand the impacts of improved broadband (for an example at a regional level, see Palmer-Abbs, Cottrill, & Farrington (2021)). This study presents a pre-post comparison for community members who did and did not receive new wireless internet service in a small rural community in Northwest Missouri.

1.1. IMPACT OF BROADBAND ACCESS AND ADOPTION

Numerous studies have identified benefits associated with increased access and adoption of broadband across (1) education, (2) health, and (3) employment-related outcomes. Online learning is increasingly considered an option for K-12 and higher education students. However, those without access to a reliable and robust internet connection cannot participate in virtual school options (Kelley & Sisneros, 2020). Independent of their socioeconomic background, students without access to the internet at home have lower performance in school and on standardized tests, complete homework at lower rates, and are less likely to attend college or university (Hampton, Fernandez, Robertson, & Bauer, 2020). Many students with no access to support for their schoolwork live in deep rural communities (Reisdorf, Yankelevich, Shapiro, & Dutton, 2019).

In the context of healthcare, broadband access enables the use of patient-centered care, which uses health information technologies (Sun, Wang, & Rodriguez, 2013). Patient-centered care encourages personalized care by enhancing collaborative decision-making involving patients and their health service providers. Telehealth can expand access to health services while creating opportunities for cost reductions (American Hospital Association, 2016).

Similarly, in the context of employment, broadband access generally enhanced business start-up activity in rural communities, with the highest impact in remote rural counties (Conroy & Low, 2021). High levels of broadband adoption in rural communities reduce unemployment growth and positively impact income growth (Whitacre, Gallardo, & Strover, 2014). Increases in broadband adoption levels are associated with an increase in median household incomes (Whitacre & Gallardo, 2014).

1.2. APPROACHES FOR BROADBAND IMPACT EVALUATIONS

As summarized in Table 1, both quantitative and qualitative approaches have been employed to evaluate broadband impact. Ideally, broadband impact would be evaluated via a randomized control trial to make causal inferences. However, it is not practical to randomly assign communities to receive broadband or not. Instead, a quasi-experimental approach like difference-in-differences can be used. This design controls for changes over time (treated vs. control group) to determine how much of the effect can be attributed to an intervention (pre vs. post comparison). However, it can be challenging to identify an appropriate control group and is not recommended for small sample sizes. For correlational analysis, regression using public federal data enables an understanding of the impact at an aggregated level over large geographic areas. However, there is poor resolution at the community level. At the community level, it is possible to conduct pre-post surveys. By using the same participants for a within-subject design, there is higher statistical power. In addition, pre-post interviews can be valuable at the community-level to collect rich data on experiences and perceptions. However, qualitative data collection and analysis can be costly and time-consuming. Quantitative and qualitative approaches can also be combined in mixed methods to benefit from both. Overall, the design of a broadband impact evaluation varies depending on the intervention, population, and expected impacts.

2. METHODS

The survey materials, de-identified data, and R code for this analysis are available in the Open Science Framework repository https://osf.io/v6dmj/?view_only=5ab98c3ec2c14082b4de03199108e52e.

Table 1. Summary of impact evaluation approaches employed in the literature.

Approach	Benefits	Drawbacks	Key Examples
Difference-in-differences design	Allows for causal inference. Can be used at individual or group levels.	Need a control population similar to intervened population. Not recommended for small sample sizes.	Briglauer, Dürr, Falck, & Hüschelrath, (2019), Kim & Orazem (2017)
Analysis of federal data sets from FCC, U.S. Census, etc.	High data coverage	Aggregated over large geographic areas	Isley & Low (2022), Whitacre et al. (2014)
Pre-post surveys (within-subject analysis)	Participation by the same participants increases the power in the statistical analysis.	Cannot control for changes over time	LaRose et al. (2011)
Mixed methods	Benefits of both quantitative and qualitative data	High cost and time-consuming	Collins & Wellman (2010), Ashmore, Farrington, & Skerratt (2017)
Pre-post interviews (qualitative analysis)	Rich qualitative data	High cost and time-consuming	Rampersad & Troshani (2013)

2.1. STUDY DESIGN

Participants completed a pre-survey and post-survey to evaluate the impact of the faster, higher bandwidth internet intervention. Participants were recruited from Turney, the target community, as well as 13 additional control communities with similar characteristics (see details in the Appendix). A between-subject comparison was conducted to compare Turney to the control group for both the pre and post-survey. In addition, a within-subject comparison was conducted within the Turney sample. A significance level of $\alpha = 0.05$ was used in the analysis.

2.2. TARGET COMMUNITY

Turney is a village in Clinton County located approximately 46 miles from Kansas City in Northwest Missouri, see Figure 1. It is a small rural community that covers 0.5 square miles with approximately 78 households and a total population of 206 residents. There are no schools in Turney, so students attend the nearby Lathrop R-II School District. In addition, there are no hospitals or healthcare facilities. The closest hospital is the Cameron Regional Medical Center, located 12 miles away.

In terms of internet access, Turney is an underserved community because it is at the edge of several existing networks, none of which fully serve the community. For most residents, their access did not meet the FCC definition of broadband, which is 25 megabits per second (Mbps) of download and 3 Mbps of upload (or 25/3 Mbps). The primary existing providers, which each cover different parts of Turney, are CenturyLink (wired, 40/7 Mbps) and KC Coyote (wireless, 10/1 Mbps), while a few households are within GRM Networks (fiber) territory. One respondent reported having fiber service from GRM Networks. Ultimately, Turney was targeted for this study because United Fiber, a local internet service provider affiliated with a rural electric cooperative who partnered on this project, owns fiber infrastructure 2 miles from Turney.

2.3. INTERVENTION

As part of a larger project, a wireless broadband system was installed in Turney in September 2021. United Fiber installed a point-to-point mmWave link from their fiber infrastructure to the tallest point in Turney on top of a grain elevator (or grain leg). Households were provided routers to connect to the wireless signal, which was

Figure 1. Turney, MO is located approximately 46 miles northeast from Kansas City, MO.

distributed as a point-to-multipoint signal via a proprietary wireless standard, Long Term Ubiquiti (LTU). Each household connected to the wireless network received at least 100/50 Mbps. At installation, average speeds were 280/63 Mbps. User-reported speed tests suggest that users observed average speeds of 161/61 Mbps. All participants in the wireless network received free broadband service during the duration of the study. In addition, connected households received an email every two weeks highlighting local resources and training related to distance education, telemedicine, entrepreneurship, and other ways to leverage their new internet service.

2.4. RECRUITMENT

Households were initially recruited via a mailed pre-survey in August 2021, which could be mailed back via a pre-addressed envelope or completed online (QR code and link provided). All participants were incentivized to participate via a raffle for $10 Starbucks gift certificates. In total, 200 surveys were mailed to reach households within a 3 mile radius of the center of Turney (12 returned as undeliverable). As part of the pre-survey, these households indicated their interest in receiving free broadband wireless service during the study's duration. Since control community households were not offered free internet service, we oversampled by mailing 700 surveys to randomly selected households (20 returned as undeliverable). To increase participation, we also held in-person events in Turney to increase awareness and answer questions about this project. An ice cream social was hosted in June 2021, and a network kick-off in September 2021. During the network kick-off event, residents could complete the pre-survey.

In total, 43 households expressed interest in connecting to the network in Turney, and 29 households were connected between October 2021 and February 2022 (see Figure 2). All interested households were not able to be connected due to technical issues, such as line-of-sight, that prevented adequate wireless signal from reaching their homes.

For the post-survey, the same households were mailed a follow-up survey in both Turney and the control communities. The post-survey was mailed in April 2022 to allow a minimum of 3 months between the pre and post-surveys. Incentives for participation varied for the 3 groups, (1) Turney households connected to the network (referred to as connected Turney) could receive an additional month of free service if their survey was returned within 3 weeks, (2) Turney households that responded to the pre-survey but could not receive broadband service (referred to as unconnected Turney) could receive a $50 Casey's gift card, and (3) households from the control communities as well as any

Turney households that did not respond to the pre-survey could enter a raffle for a $50 Casey's gift card. For the post-survey, households that did not participate in the pre-survey were considered to be part of the control group. A small number of responses were received from households that were not targeted by a mailing, e.g., due to address forwarding. When the response was within the study region, it was included. One survey response was dropped because it was from outside of northwest Missouri. To increase participation in the Turney connected group, 11 certified letters were mailed to participants who had not yet completed the post-survey in May 2022.

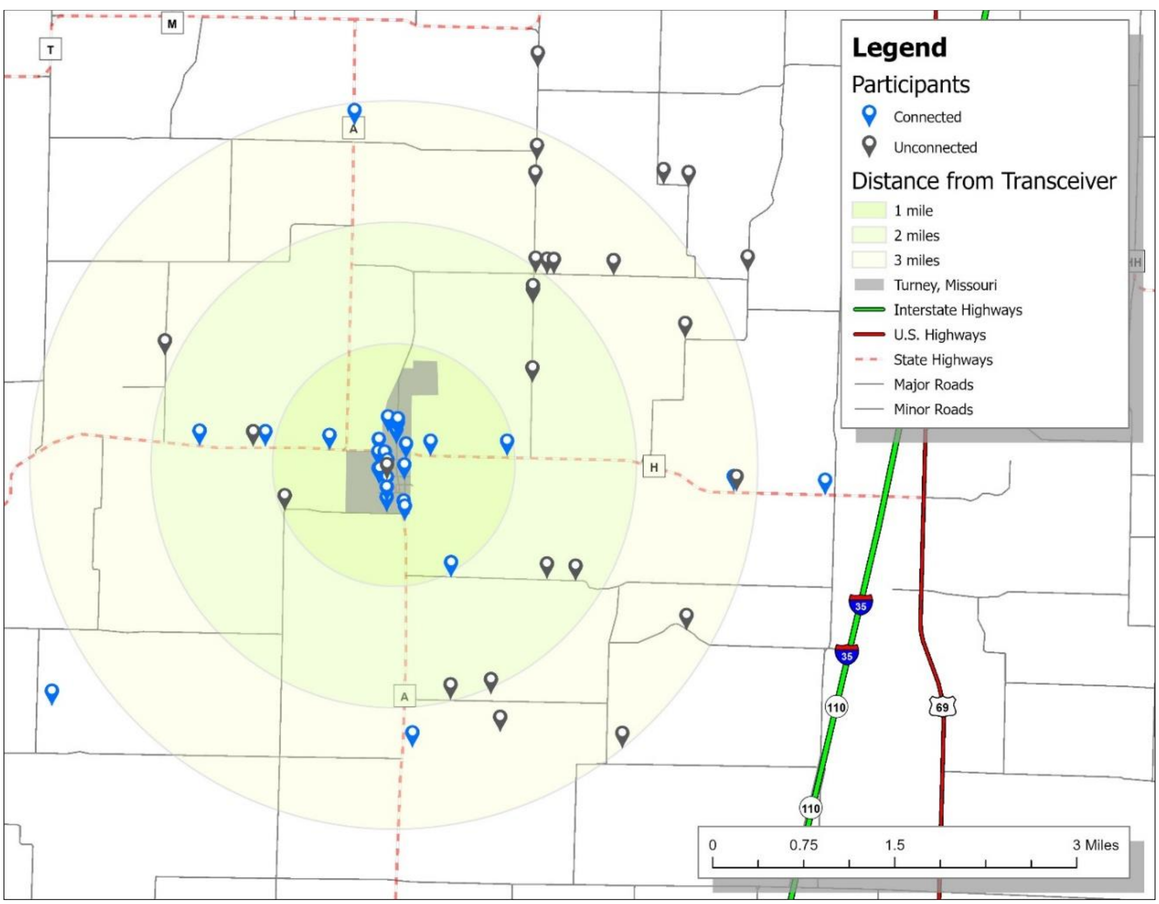


Figure 2. Map of connected and unconnected households in Turney

2.5. MEASURES

The surveys collected information on (1) internet access at home, (2) internet use at home, (3) interest in internet access, and (4) demographics. The primary dependent variable was the use of the internet at home for employment, education, and health purposes.

To measure internet access at home, we asked a series of multiple choice questions where participants could "check all that apply." This included challenges using the internet at home, concerns about internet safety, types of computing devices, how they got help using the internet or a device, and how they connected to the internet at home.

To measure internet use at home, we asked a series of binary questions (yes, no, not sure) about how the household had used the internet in the last 3 months. These included activities related to employment (e.g., working remotely), education (e.g., distance learning), and health (e.g., telehealth visits). In addition, we asked about more generic online activities, such as the use of social networks, video/voice calls, streaming, gaming, online shopping, financial services, and government services. In addition, participants reported whether they had earned money or saved money due to the internet. Participants also reported any issues using the internet (multiple choice) as well as their current monthly cost.

To measure interest in internet access, we asked a series of questions about how they would use improved high-speed internet service as well as expectations for their internet provider. Participants reported whether they would engage in high-bandwidth activities (e.g., home-based business, distance education, gaming) on a 5-point Likert scale that ranged from “definitely not” to “definitely would.” To evaluate digital literacy, participants reported their confidence in performing basic internet activities (e.g., searching for information, using word processing, using teleconference applications) on a 5-point Likert scale that ranged from “not confident” to “completely confident.” In addition, participants reported preferences for characteristics of their internet provider and willingness to pay for improved internet service.

Lastly, participants reported demographics for their households as well as for them individually. At the household-level, participants reported household size, employment status for adults, school enrollment (K-12 and higher education), ages, and income. At the individual-level, participants reported their age, race, gender, and level of education.

In the pre-survey, Turney residents could indicate interest in participating in the internet intervention. To allow matching between pre and post surveys, participants provided their home address and the first name of the person who completed the survey. In the post-survey, some questions were removed, primarily from the interest in internet access section (confidence in performing tasks was still measured). For connected Turney households, a series of open-ended questions were added to the post-survey to solicit their experiences and how the internet intervention had influenced their use of the internet in the three areas of focus, employment, education, and health.

3. RESULTS & DISCUSSION

3.1. SAMPLE

As reported in Table 2, there was a higher response rate in Turney than the control group, likely due to increased incentives to participate and recruitment efforts. As shown in Figure 3, the control group included participants from many communities with no systematic pattern. For the pre-survey, most participants submitted it online in both Turney as well as the control group. However, for the post-survey, more participants from unconnected Turney and control communities responded by mail. The same proportion of survey responses were submitted online for the connected Turney when compared to the Turney pre-survey.

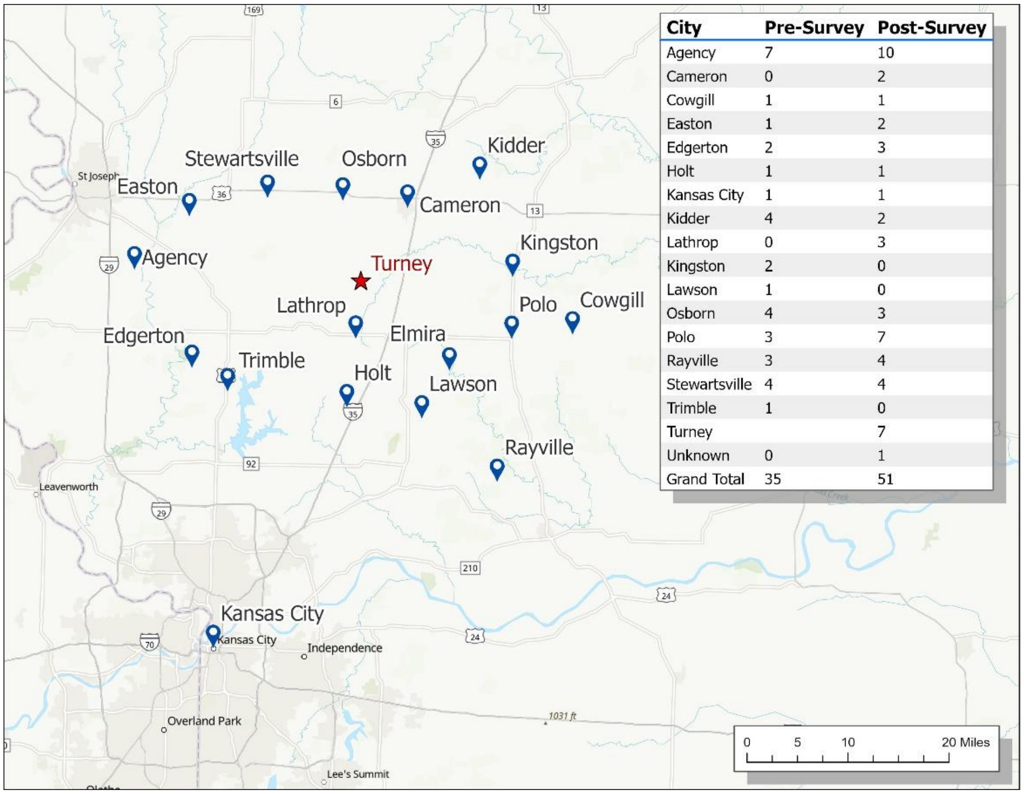
For the Turney sample, in most cases (32/35 = 91%), the same individual responded to the household-level survey for both the pre and post-survey. In the control group, there were 10 repeat respondents. The survey respondents were 54 years old on average (SD = 17, Min = 20, Max = 91) across both surveys. Of the respondents, 93% were White, 57% were women, and 38% had completed a Bachelor's degree or higher.

No significant difference was found between the 3 post-survey groups regarding the number of adults responding to the survey who had a Bachelor's degree or higher. Thirty percent (30%) of connected Turney and 62% of the unconnected Turney post-survey participants reported having a Bachelor's degree or higher. This is a much higher rate than the U.S. Census, which reports that 6.8% of Turney residents 25 years and older graduated from college (see Table A.2 in the Appendix).

Overall, the Turney sample was largely representative of the population based on a comparison to U.S. Census data. The median income is \$54,000, and 9% of the population live below the poverty line (U.S. Census Bureau, 2022). This is consistent with the survey data, which suggest that the median household income is \$35,000-\$65,000. In addition, the median age is 41 years old (U.S. Census Bureau, 2022). This is also consistent with the survey data, which suggests the median age range is 25-44 years old. Although a high percent report internet access at home (>90%), the service received by the vast majority of households does not meet the FCC broadband definition (>25/3 Mbps). As reported in the Appendix, the household size, number of children in K-12, and number of residents enrolled in higher education are also consistent between the pre-survey and Census data. As reported in the Appendix, there were no differences in household characteristics between the connected Turney, unconnected Turney, and Control groups except for the number of employed adults per household, $F(2,86) = 3.28$, $p = .04$.

Table 2. Response rates for the pre and post-survey. Response rates in Turney were higher than the control group.

	Pre-Survey			**Post-Survey**			
	Turney	Control	Total	Connected Turney	Unconnected Turney	Control	Total
Responses (N)	54	35	89	20	16	52	88
Submitted Online (N, %)	35, 65%	19, 54%	54, 61%	13, 65%	5, 31%	26, 50%	43, 49%
Delivered Surveys	188	680	868	29	27	812	868
Response Rate (%)	29%	5%	10%	69%	59%	6%	10%



City	Pre-Survey	Post-Survey
Agency	7	10
Cameron	0	2
Cowgill	1	1
Easton	1	2
Edgerton	2	3
Holt	1	1
Kansas City	1	1
Kidder	4	2
Lathrop	0	3
Kingston	2	0
Lawson	1	0
Osborn	4	3
Polo	3	7
Rayville	3	4
Stewartsville	4	4
Trimble	1	0
Turney		7
Unknown	0	1
Grand Total	35	51

Figure 3. Map of survey respondents in Control group.

3.2. QUALITY OF INTERNET INTERVENTION

Pre-survey data suggest that Turney had lower quality internet service than the control group, consistent with their classification as an underserved community. Three Turney participants reported not having internet at home, while 2 participants from the control group reported so. A higher proportion of Turney households (78%) relied on slower technologies such as hotspot, satellite, fixed wireless, DSL, and dial-up compared to the control group (38%), $\chi^2(2, N = 83) = 12.38$, $p < .001$. Discussions with community members suggest that a large proportion relied on cellular hotspots specifically. As a result, more Turney households (85%) reported that their internet service was slow or unstable compared to the control group (51%), $\chi^2(1, N = 89) = 10.37$, $p = .001$. Very few Turney households reported having no challenges using the internet at home (4%). This suggests that the primary difference between Turney and the control group before the internet intervention was internet quality.

In addition, pre-survey data suggest that there were no differences in digital literacy between Turney and the control group. Both groups reported using the internet similarly for applications such as as social networks, video/voice calls, streaming, gaming, online shopping, and government services. As reported in the Appendix, Turney residents reported being somewhat confident ($M = 3.15$, $SD = 0.40$) across a range of basic internet tasks, such as emailing, searching for information, filling online forms, and using word processing applications similar to the control group ($M = 3.13$, $SD = 0.62$), $t(11.98) = 0.05$, $p = .961$.

The post-survey data suggest that the internet intervention improved service quality when comparing the connected and unconnected Turney groups. Fewer connected Turney households (45%) reported experiencing slow or unstable internet compared to the unconnected Turney group (87%), $\chi^2(1, N = 35) = 4.71$, $p = .030$. In addition, more connected Turney households (50%) reported having no challenges using the internet at home compared to the unconnected Turney group (13%), but these proportions are not statistically significantly different from each other, $\chi^2(1, N = 35) = 3.62$, $p = .057$. This suggests that there was a measurable effect of the internet intervention based on improvements in speed and stability, but some challenges with using the internet at home persisted. The primary benefit reported by connected Turney households was the ability to use multiple devices at the same time due to increased bandwidth.

Over the duration of the study period, there were challenges with reliability due to technical limitations of wireless technology. Line-of-sight is required for access, which can be attenuated by rain depending on the distance from the transceiver (Anders, 2022), and there were several hardware malfunctions that caused outages that lasted multiple days. As a result, the improved service quality was inconsistent throughout the study. There was a wide range of feedback (solicited biweekly) as listed below:

- “Never fails us. Always able to hook up to internet and speed is always good.”
- “A lot better, with the exception of occasionally losing connection during heavy rain storms.”
- “Internet was unreliable and slow at our house. Ended up having to give up on it and return to previously used provider.”

These reliability issues may have reduced the impact of the intervention for some households and, more broadly, contribute to preferences for wired rather than wireless internet solutions.

3.3. SOCIAL IMPACT OF AN INTERNET INTERVENTION

In the pre-survey, Turney residents reported using the internet for education more than the control group, despite having lower quality service. As reported in Table 3, more Turney households reported engaging in distance learning and using the internet to do homework at home. However, there were no differences in employment and health-related activities. This may be attributed to the timing of the surveys for the two groups, since the data collection period was longer for Turney and extended into the school year. Overall, this suggests that in a between-subjects comparison, there were few differences

Table 3. Internet usage for the previous 3 months in the pre-survey. Turney residents reported using the internet more than the control group for education, p < .05 is bolded.

Internet use	Turney		Control			
	M	*SD*	*M*	*SD*	*Chi-Squared*	*p*
Employment Cumulative Count	1.06	0.86	0.84	0.92		
work from home	0.54	0.50	0.41	0.50	$\chi^2(1, N = 82) = 0.91$	.339
search/apply for job	0.25	0.44	0.31	0.47	$\chi^2(1, N = 80) = 0.13$	.720
self-employment at home	0.29	0.46	0.13	0.34	$\chi^2(1, N = 80) = 2.18$	.140
Education Cumulative Count	1.4	1.27	0.7	0.92		
distance learning	0.40	0.49	0.09	0.30	$\chi^2(1, N = 82) = 7.61$	**.006**
homework at home	0.43	0.50	0.16	0.37	$\chi^2(1, N = 81) = 5.40$	**.020**
search education-related info	0.61	0.49	0.44	0.50	$\chi^2(1, N = 81) = 1.73$	.188
Health Cumulative Count	1.64	1.13	1.58	0.97		
search for health-related info	0.71	0.46	0.59	0.50	$\chi^2(1, N = 81) = 0.78$	.377
telehealth	0.34	0.48	0.28	0.46	$\chi^2(1, N = 79) = 0.10$	.758
use online patient portal	0.58	0.50	0.65	0.48	$\chi^2(1, N = 81) = 0.21$	.647

in how Turney residents used the internet compared to others who had higher service quality. Ultimately, Turney residents reported wanting better internet service to gain quality of life benefits. As reported in Figure 4, the top intended use for improved internet service was video streaming.

In the post-survey, there were no significant differences in internet use for employment, education, or health in the 3 groups. As reported in Table 4, even the unconnected Turney group used the internet at a similar rate for these purposes. This suggests that other factors that are consistent on a regional level, such as social influence, may have a bigger influence on internet usage behavior than access to a better service alone.

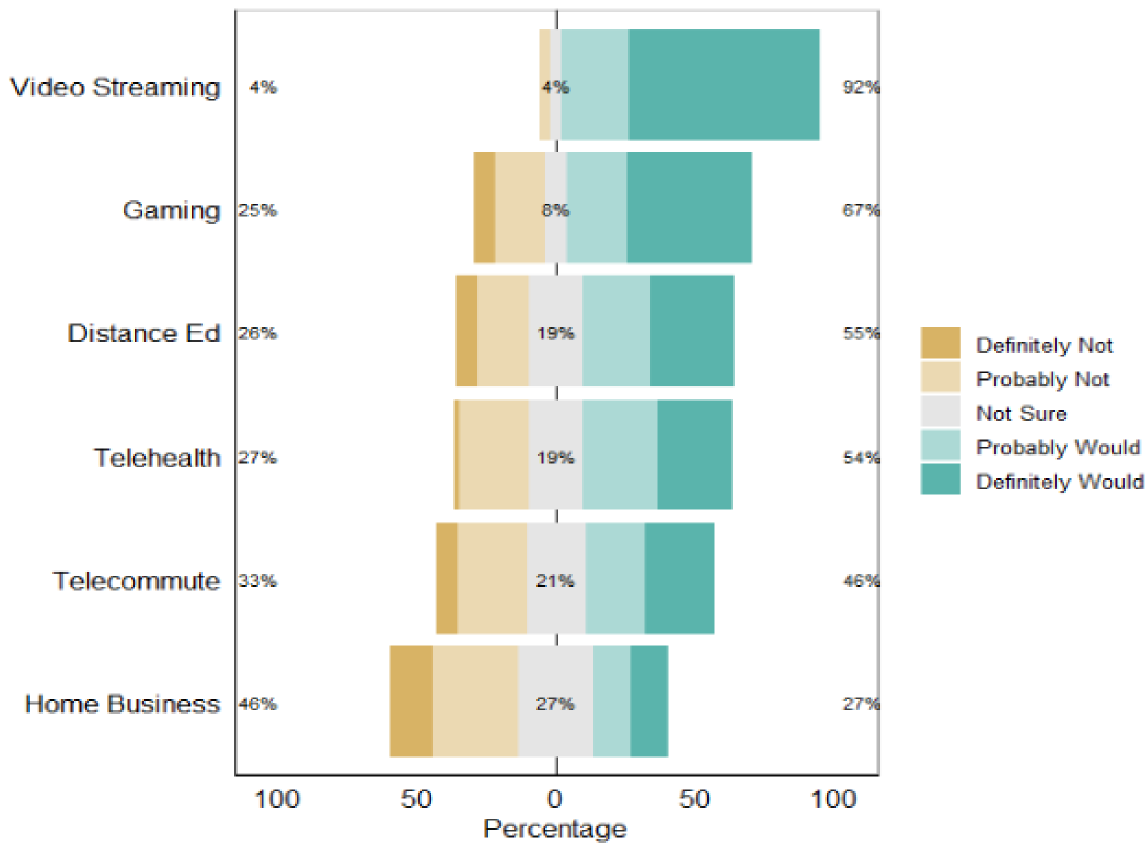


Figure 4. Intended uses of improved internet by Turney residents. Turney residents were primarily interested in quality-of-life benefits like video streaming.

In a within-subject comparison, there were no significant differences in employment, education, or health internet use between the pre and post-survey responses for Turney residents (see Appendix). Exploratory analysis reported in Table 5 suggests that there is very weak evidence of increased internet use in the connected Turney group that can be attributed to the internet intervention. For employment, more households reported using the internet to search and apply for jobs in the connected Turney group, but this may be attributed to the shifting labor landscape more broadly. For example, despite having lower quality internet service, unconnected Turney households reported engaging in more self-employment at home in the post-survey. For education, the strongest shift was in the control group, likely due to the timing of the post-survey, which was during the school year. For health, connected Turney households reported using the internet more for searching for health-related information and using online patient portals. However, the unconnected Turney and control groups also reported increases for these uses, suggesting that external factors such as the evolving COVID-19 pandemic may have driven behavior. Ultimately, this suggests that a complex set of factors influence internet usage behavior beyond access and quality of service alone.

Qualitative data on the impact of the internet service suggests that even though the effects were not statistically significant, there is anecdotal evidence that participants perceived benefits of the new internet service. Table 6 provides a summary of the qualitative responses regarding the impact of the improved internet intervention on employment, education, and health. Benefits were observed across all three categories. As reported in Table 7, more participants reported benefits related to employment than education and health. For education and health, more participants reported no change or did not respond, than reported benefits.

Table 4. Internet usage for the previous 3 months in the post-survey. There were no significant differences in how groups used the internet for employment, education, and health.

	Connected Turney		Unconnected Turney		Control			
	M	*SD*	*M*	*SD*	*M*	*SD*	*Chi-Squared*	*p*
Employment Cumulative Count	0.95	0.97	1.31	0.75	0.72	0.91		
work from home	0.37	0.50	0.69	0.48	0.37	0.49	$\chi^2(2, N = 81) = 4.72$	.094
search/apply for job	0.32	0.48	0.23	0.44	0.23	0.43	$\chi^2(2, N = 79) = 0.52$	.771
self-employment at home	0.26	0.45	0.38	0.51	0.17	0.38	$\chi^2(2, N = 80) = 2.99$	.224
Education Cumulative Count	1.47	1.22	1.38	1.19	0.98	1.15		
distance learning	0.42	0.51	0.46	0.52	0.21	0.41	$\chi^2(2, N = 80) = 4.86$	.088
homework at home	0.42	0.51	0.31	0.48	0.29	0.46	$\chi^2(2, N = 80) = 1.06$	.589
search education-related info	0.65	0.49	0.62	0.51	0.52	0.50	$\chi^2(2, N = 81) = 1.10$	.576
Health Cumulative Count	1.74	0.99	1.75	1.22	1.59	1.06		
search for health-related info	0.80	0.41	0.77	0.44	0.67	0.47	$\chi^2(2, N = 82) = 1.32$	.518
telehealth	0.26	0.45	0.33	0.49	0.28	0.45	$\chi^2(2, N = 81) = 0.19$	.910
use online patient portal	0.70	0.47	0.69	0.48	0.65	0.48	$\chi^2(2, N = 82) = 0.17$	.917

Table 5. Exploratory analysis of pre-post changes in internet use. Bolded values represent cases where the number of people using the internet for that application increased, but none of the within-subject changes were statistically significant.

	Connected Turney		**Unconnected Turney**		**Control**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
Employment						
work from home	40	37	68	69	41	37
search/apply for job	**17**	**32**[a]	33	23[b]	31	23[b]
self-employment at home	38	26[b]	**21**	**38**[a]	**12**	**17**[a]
Education						
distance learning	40	42	**40**	**46**[a]	**9**	**21**[a]
homework at home	38	42	48	31[b]	**16**	**29**[a]
search education-related info	**60**	**65**[a]	62	62	**44**	**52**[a]
Health						
search for health-related info	**64**	**80**[a]	79	77	**59**	**67**[a]
telehealth	35	26[b]	33	33	28	28
use online patient portal	**56**	**70**[a]	**60**	**69**[a]	66	65

[a] increased by at least 5% from pre-survey to post-survey
[b] decreased by at least 5% from pre-survey to post-survey

4. CONCLUSION

This study evaluates the impact of faster, higher bandwidth wireless internet access in a small underserved rural community in Missouri. In addition to collecting pre-post survey data for an internet access intervention, pre-post data were collected from demographically similar nearby communities to serve as a control group. Ultimately, some of the interested participants in the target community (Turney) were unable to be connected to the network due to technical constraints. This created an additional comparison group in the post-survey. There are two primary findings, (1) changes in using the internet for employment, education, and health could not be directly attributed

Table 6. Qualitative data on perceived benefits of internet intervention.

Employment	
work from home	"I am a teacher so I use the internet to create lesson plans daily. This program has allowed me to prep on the weekends from home."
search/apply for job	"Perfect, always able to have connection to find jobs or have zoom interviews"
self-employment at home	"I have a small online business. I utilize social media platforms and etsy to advertise and sell my products. I've been able to post more and stay in contact with customers more efficiently."
Education	
distance learning	"My daughter also takes online college classes and she no longer has issues getting assignments submitted due to poor service."
homework at home	"Grandson uses it for school."
search education-related info	"Watching more 'how-to' videos, in regards to cooking, fixing things, not really "higher" learning. Just more related to making one's life better."
Health	
search for health-related info	"Look things up more about health than before."
telehealth	"We have been able to utilize the telehealth visit through our doctor's office. This has saved time and money. Less gas and not needing to take time off work to attend a face to face appointment."
use online patient portal	NA

Table 7. Summary of the received qualitative response regarding the impact of the improved internet intervention on employment, education, and health.

	Employment	Education	Health
Positive impact	10	6	5
No change	3	5	7
No response	4	6	6
Do not use the internet for this purpose	3	1	2

to the internet intervention, and (2) the internet intervention was associated with quality-of-life benefits related to the ability to use multiple devices at once.

First, there were no significant within-subject differences in internet usage behavior for connected Turney households after the internet intervention. However, there was evidence that households had fewer issues accessing the internet due to the intervention. Participant feedback indicated that participants increased their existing usage rather than changing their behavior. For underserved communities, it may be more common to see these types of marginal benefits. These results suggest that other factors beyond access and quality of service influence internet usage behavior. Given the consistent internet usage behavior across groups, there are likely regional forces such as social influence and market conditions that are more influential. In general, the Turney sample had average digital literacy, suggesting that this was not a major barrier to usage. Other studies have found that digital literacy training, access to affordable devices, and subsidies are key programmatic elements for increasing adoption and changing internet usage behavior (LaRose et al., 2011; Whitacre, Strover, & Gallardo, 2015).

Second, instead of achieving social impact measures related to employment, education, and health, participants were primarily motivated to get better internet to achieve quality-of-life benefits. As reported in Figure 4, most Turney participants intended to use improved internet service for video streaming and gaming. These types of uses benefit from higher bandwidth because it means that one household member can be streaming without eliminating access for the remaining household members. Only half of the Turney sample was interested in distance education, telehealth, and telecommuting. Quality-of-life can be an important consideration for small rural towns that are competing with other similar towns for residents and employers. For example, if a young couple is choosing whether to move back to their hometown or the next town over, they are highly likely to consider broadband access in their decision. Similarly, new firms also consider broadband access when making decisions about starting operations in a location (Kim & Orazem, 2017; Krause & Reeves, 2017).

Reliability issues are a major limiting factor for wireless technologies. Many Turney residents were hesitant to participate in this study due to previous negative experiences with wireless technologies. As a result, a multi-tiered recruitment approach was required to ensure sufficient participation. Ultimately, one household dropped out of the study due to frustration with inadequate reliability. However, many households, particularly those in the center of town close to the transceiver, reported very high satisfaction with the service quality.

4.1. LIMITATIONS AND IMPLICATIONS FOR BROADBAND EVALUATION DESIGN

It is challenging to evaluate the impact of broadband access in an underserved community where there are competing technologies to facilitate access. The difficulty in demonstrating the impact on an underserved community should not prevent decision-makers from funding broadband projects in these communities. Without the proper investments in updating internet infrastructure, underserved communities would continue to experience constraints on their economic opportunities (Philip & Williams, 2019). This study had three primary limitations that can inform future broadband evaluations, (1) identification of appropriate outcome variables, (2) recruitment challenges, and (3) survey timing.

In terms of outcome variables, underserved communities may benefit more from quality-of-life measures than social impact measures. In Turney, residents were already using the internet for employment, education, and health purposes. In fact, the usage behavior was largely consistent between groups and in the pre-post comparison. However, limited bandwidth prevented households from using multiple devices simultaneously (e.g., allowing two people to work remotely) and certain high-bandwidth applications (e.g., streaming). In this study, we did not focus on measuring those outcomes, leading to non-significant results. Future studies should put increased emphasis on these types of outcomes to better measure the benefits that community members perceive. Also, future studies should aim to quantify how much participants use the internet for the applications of interest instead of having a binary indicator for the activities of focus. This can be achieved with objective (i.e., sensors) or subjective (i.e., survey response) methods. Researchers should consider how to protect the privacy of participants if using data from sensors to avoid recruitment challenges.

In terms of recruitment, achieving a high participation rate can be difficult in small rural communities. For example, LaRose et al. (2011) used door-to-door in-person surveys due to a low response rate in two Texas counties. Similarly, a study in Colorado also combined face-to-face and online recruitment mechanisms (Colwell, Schumann, & Shakfa, 2018). In this study, 27 survey responses were initially collected in Turney from a direct mailing. The remaining 27 responses were recruited by a combination of in-person events, door-to-door engagement by the ISP, and word-of-mouth. We extended recruitment over 7 months (August 2021 to February 2022) in Turney to (ideally) achieve a minimum sample size of 30 connected households. As a result, Turney participants were much more aware of the purpose of the study, which may have influenced their responses. It is unclear if participants were more likely to over-estimate or under-estimate their internet use behavior to justify the provided access. Future studies should plan to use a combination of recruitment strategies and could benefit from ensuring that the same recruitment methods are used for all groups, if possible.

In terms of timing, the extended recruitment period in Turney shifted the timing of data collection so it was not consistent between groups. While the pre-survey data collection spanned August 2021 to February 2022 for the Turney sample, all of the control group data were collected in August 2021 (i.e., the end of summer break) in response to the initial mailing. This directly affected the results, leading to significant differences in reported internet usage for the Turney sample in the pre-survey (Table 3) as well as pre-post differences in the control group (Table 5). As a result, it is difficult to discern the impacts on education-related internet usage. Future studies should ensure that education-related behavior are only measured during the academic school year to avoid outliers associated with the summer months. In addition, this study focused on short-term impacts that occurred in the last 3 months. However, it may take longer for social impacts to emerge. Future studies would benefit from longitudinal data collection to evaluate which types of social impact are observed over time.

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APPENDIX

1. CONTROL COMMUNITY SELECTION

The control communities included: Agency, Cowgill, Easton, Edgerton, Elmira, Holt, Kidder, Kingston, Osborn, Polo, Rayville, Stewartsville, and Trimble. The control communities were identified based on community characteristics, such as total population, the number of households, percentage of adults with a bachelor's degree or higher, percentage of 16 years old and older who are in the labor force, mean commute time, percentage of self-employed individuals, median household income, percentage below poverty, and percentage of households reporting internet access using cable, fiber optics or DSL (Digital Subscriber Line). The data used to identify the control communities came from the U.S. Census Bureau American Community Survey (2019 ACS 5-Year Estimates). Table A1 summarizes these characteristics for Turney and the control communities.

2. SAMPLE CHARACTERISTICS

Table A2 summarizes the comparison of household characteristics for the 3 sub-groups versus those reported by the ACS for Turney. The survey data were collected

Table A.1. Summary of Turney demographics compared to control communities.

Description	Turney	Osborn	Stewartsville	Easton	Trimble	Edgerton	Holt	Elmira
Population in Households	255	380	733	203	616	580	414	34
Households	91	175	310	104	252	215	154	13
Bachelor's Degree or Higher	10.3%	10.7%	19.1%	6.2%	10.9%	21.4%	12.0%	14.8%
Population 16+ yrs in labor force	71.6%	67.1%	67.5%	53.3%	62.9%	68.0%	69.4%	60.7%
Mean travel time to work (minutes)	22.6	23.2	26.9	21.0	27.5	42.6	31.0	N
Self-employed in own not incorp. business	11.1%	1.0%	12.0%	4.2%	3.4%	4.2%	4.4%	0.0%
Median household income (dollars)	52,250	55,125	51,875	43,182	53,409	57,250	53,889	-
Total Population 65+	3.5%	17.4%	12.7%	25.1%	14.1%	16.7%	14.5%	23.5%
One race - White	90.2%	96.6%	95.9%	87.2%	98.2%	89.7%	90.1%	100.0%
Percent below poverty level	7.8%	2.6%	9.0%	13.3%	15.1%	15.2%	16.9%	0.0%
Broadband such as cable, fiber optic or DSL	52.7%	51.4%	56.8%	35.6%	45.6%	40.9%	49.4%	61.5%

Table A.1. Summary of Turney demographics compared to control communities (Cont.).

Description	Turney	Rayville	Agency	Cowgill	Kidder	Kingston	Polo
Population in Households	255	282	248	84	91	96	228
Households	91	72	733	221	215	201	489
Bachelor's Degree or Higher	10.3%	0.0%	18.6%	5.3%	12.2%	6.1%	5.9%
Population 16+ yrs in labor force	71.6%	38.3%	564	165	178	267	387
Mean travel time to work (minutes)	22.6	N	21.6	30.6	30.5	29.9	36.8
Self-employed in own not incorp. business	11.1%	0.0%	3.0%	13.9%	1.3%	14.5%	7.4%
Median household income (dollars)	52,250	-	71,364	35,000	41,875	33,500	43,125
Total Population 65+	3.5%	0.0%	12.3%	13.1%	30.7%	14.1%	13.7%
One race - White	90.2%	100.0%	91.4%	89.6%	100.0%	92.9%	94.1%
Percent below poverty level	7.8%	0.0%	12.6%	18.1%	12.1%	17.6%	16.6%
Broadband such as cable, fiber optic or DSL	52.7%	0.0%	74.6%	32.1%	33.0%	44.8%	42.5%

differently than the U.S. Census for the employed adults, which made comparisons of the number of employed adults per household less informative. The surveys collected employment status for 18+, but the U.S. Census collects data for 16+.

3. CONFIDENCE LEVEL OF HOUSEHOLDS PERFORMING COMMON TASKS ONLINE

Figure A1 presents the input from Turney households on how confident they felt performing a series of everyday activities online.

Table A.2. Household characteristics in general did not vary between groups, and the Turney sample was largely representative of the population.

Household characteristic	Turney (Census)	Connected Turney	Unconnected Turney	Control		
	M	*M (SD)*	*M (SD)*	*M (SD)*	*F*-test/chi-squared	*p*
Household size (N)	2.6	2.8 (1.2)	3.2 (1.5)	2.6 (1.6)	$F(2,86) = 1.00$	.371
Children enrolled in K-12 (N)	0.7	0.21 (0.42)	0.42 (0.50)	0.34 (0.48)	$F(2,86) = 1.37$	.259
Residents enrolled in higher-ed (N)	0.3	0.21 (0.42)	0.15 (0.37)	0.14 (0.36)	$F(2,86) = 0.30$	.739
Employed adults per household (N)	1.37	1.54 (1.1)	1.69 (0.84)	1.09 (0.95)	$F(2,86) = 3.28$	**.04**
Bachelor's degree or higher[4]	6.8%	30% (47%)	62% (51%)	38% (49%)	$\chi2(2, N = 83) = 3.43$	.180
Household income of >$35K (%)	$54,000	68% (48%)	86% (36%)	81% (40%)	$F(2,72) = 1.08$	.344
Internet service at home (%)	90%	93% (26%)	96% (20%)	94% (24%)	$F(2,85) = 0.13$	.874

[4] The American Community Survey collects the educational attainment data for all adults 25 years and older. The pre and post-survey collected the educational attainment only for the adult responding to the survey.

Figure A2 presents the input from Control households on how confident they felt performing a series of everyday activities online.

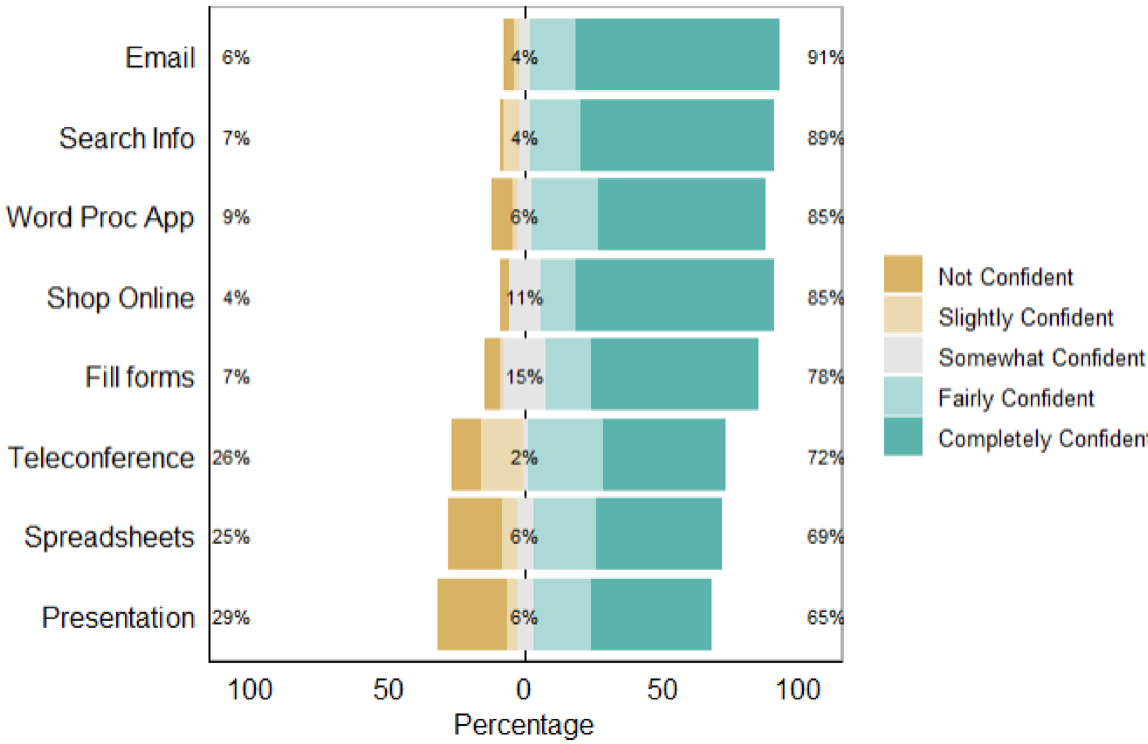

Figure A.1. Turney households reported average confidence in performing everyday online tasks such as shopping online, searching for information, and participating in teleconference meetings.

4. WITHIN-SUBJECT COMPARISONS

Turney residents who received improved internet access did not report a change in usage for work, education, or health applications. Table A3 summarizes the statistical analysis. The McNemar test, also known as paired chi-square, provides a way to of testing hypotheses for subjects who participate in an intervention. The 3 main assumptions for the test include (1) having a nominal variable with two categories and one independent variable with two connected groups, (2) the two groups in your dependent variable must be mutually exclusive, and (3) the sample must be a random sample (statisticshowto.com, 2022).

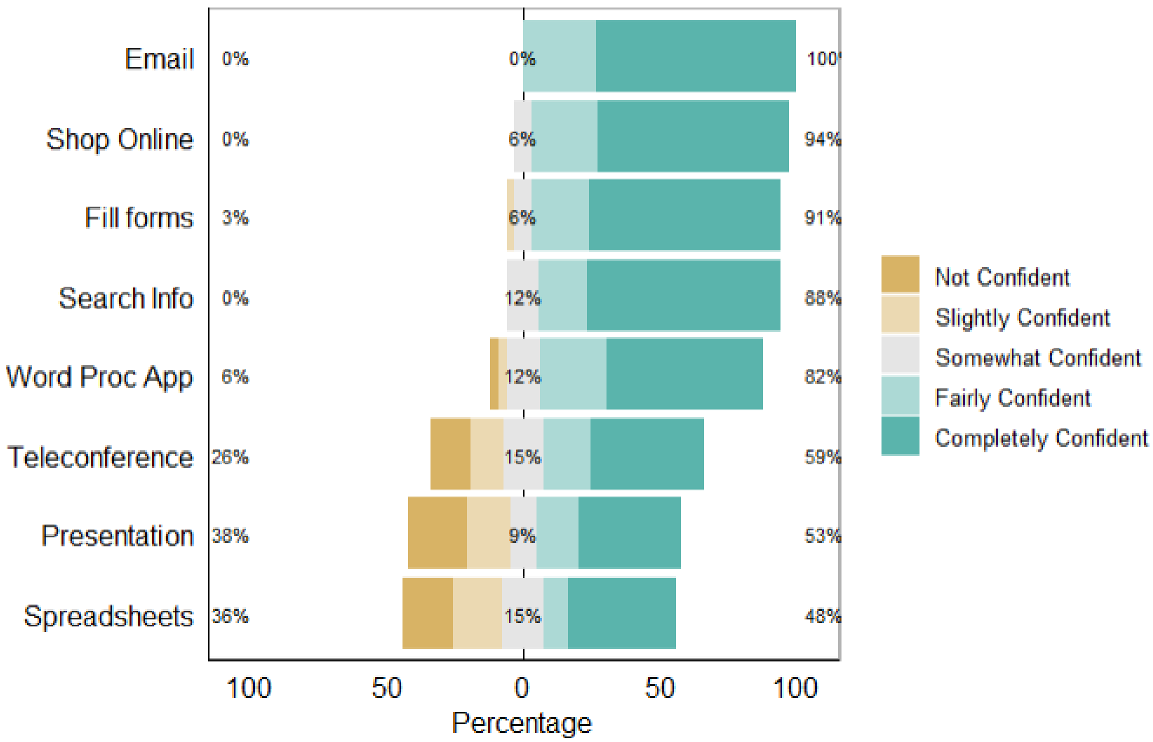

Figure A.2. Control households reported above average confidence in performing everyday online tasks such as shopping online, searching for information, and below average participating in teleconference meetings.

5. ROBUSTNESS CHECKS

5.1. EXCLUDING DELAYED PRE-SURVEYS

Three households were connected to the wireless network before they answered the pre-survey. These households were instructed to answer the pre-survey considering their reality before receiving the internet service. Removing their response does not change the study conclusions. Table A4 presents internet use for Turney versus Control excluding the households connected to the network before answering the pre-survey. Table A5 summarizes the within-subjects comparison of internet use before and after the intervention excluding the households connected to the network before answering the pre-survey.

Table A.3. Within-subject comparison (pre vs. post) for connected Turney households

Internet use	pre-survey		post-survey			
	M	*SD*	*M*	*SD*	*McNemar's Chi-Square*	*p*
Employment Cumulative Count	1.06	0.87	0.95	0.97		
work from home	0.53	0.51	0.37	0.50	$\chi^2_{McNemar}(1, N = 18) = 1.12$	.289
search/apply for job	0.17	0.38	0.32	0.48	$\chi^2_{McNemar}(1, N = 17) = 0$	1.0
self-employment at home	0.39	0.50	0.26	0.45	$\chi^2_{McNemar}(1, N = 17) = 0$	1.0
Education Cumulative Count	1.33	1.19	1.47	1.22		
distance learning	0.33	0.49	0.42	0.51	$\chi^2_{McNemar}(1, N = 17) = 0$	1.0
homework at home	0.39	0.50	0.42	0.51	$\chi^2_{McNemar}(1, N = 17) = 0$	1.0
search education-related info	0.63	0.50	0.65	0.49	$\chi^2_{McNemar}(1, N = 18) = 1.12$	.289
Health Cumulative Count	1.56	1.15	1.74	0.99		
search for health-related info	0.74	0.45	0.80	0.41	$\chi^2_{McNemar}(1, N = 18) = 0.25$	.617
telehealth	0.28	0.46	0.26	0.45	$\chi^2_{McNemar}(1, N = 18) = 0.17$	.683
use online patient portal	0.58	0.51	0.70	0.47	$\chi^2_{McNemar}(1, N = 18) = 0$	1.0

5.2. INCLUDING MULTIPLE SURVEYS FROM SAME HOUSEHOLD

Five Turney households and 1 control household answered the pre-survey multiple times. In our initial data anaysis we only included the first received survey. In the post survey, 3 Turney served and 2 control households submitted 2 surveys each. In some instances, the same adult responded more than once, while in other occasions different adults responded to the survey. Including all received surveys does not change the study conclusions. Table A6 summarizes the internet usage including all returned surveys.

Table A.4. Internet usage for the previous 3 months in the pre-survey. Turney residents reported using the internet more than the control group for education, $p < .05$ is bolded. (Excluding participants who got service prior to answering pre-survey.)

Internet use	Turney		Control			
	M	*SD*	*M*	*SD*	*Chi-Squared*	*p*
Employment Cumulative Count	1.11	0.86	0.84	0.92		
work from home	0.55	0.50	0.41	0.50	$\chi^2(1, N = 79) = 1.11$	.292
search/apply for job	0.27	0.45	0.31	0.47	$\chi^2(1, N = 77) = 0.03$	.855
self-employment at home	0.31	0.47	0.13	0.34	$\chi^2(1, N = 80) = 2.65$	.103
Education Cumulative Count	1.5	1.27	0.7	0.93		
distance learning	0.43	0.50	0.09	0.30	$\chi^2(1, N = 79) = 8.61$	**.003**
homework at home	0.46	0.50	0.16	0.37	$\chi^2(1, N = 78) = 6.37$	**.012**
search education-related info	0.63	0.49	0.44	0.50	$\chi^2(1, N = 78) = 2.11$	.146
Health Cumulative Count	1.73	1.11	1.53	0.95		
search for health-related info	0.74	0.44	0.59	0.50	$\chi^2(1, N = 78) = 1.22$	.268
telehealth	0.36	0.49	0.28	0.46	$\chi^2(1, N = 79) = 0.26$	.612
use online patient portal	0.62	0.49	0.66	0.48	$\chi^2(1, N = 81) = 0.01$	.907

Table A7 presents the within-subject comparison for the Turney served households pre-survey vs post-survey and including all returned surveys.

Table A8 presents the internet usage in the previous 3 months in the post-survey for the 3 groups (connected Turney, unconnected Turney, and Control).

Table A.5. Within-Subject Comparison for the Turney served households pre-survey vs post-survey. (Excluding participants who got service prior to answering pre-survey.)

Internet use	Turney Served pre-survey		Turney Served post-survey			
	M	*SD*	*M*	*SD*	*McNemar's Chi-Square*	*p*
Employment related activities	1.14	0.86	0.95	0.97		
work from home	0.53	0.52	0.44	0.51	$\chi^2_{McNemar}(1, N = 14) = 0.25$	.617
search/apply for job	0.21	0.43	0.38	0.50	$\chi^2_{McNemar}(1, N = 13) = 1.33$	.248
self-employment at home	0.43	0.51	0.31	0.48	$\chi^2_{McNemar}(1, N = 13) = 0.17$	.683
Education related activities	1.50	1.22	1.47	1.22		
distance learning	0.40	0.51	0.50	0.52	$\chi^2_{McNemar}(1, N = 14) = 0$	1.0
homework at home	0.43	0.51	0.50	0.52	$\chi^2_{McNemar}(1, N = 13) = 0$	1.0
search education-related info	0.73	0.46	0.71	0.47	$\chi^2_{McNemar}(1, N = 15) = 0$	1.0
Health related activities	1.93	1.00	1.74	0.99		
search for health-related info	0.87	0.35	0.88	0.33	$\chi^2_{McNemar}(1, N = 15) = 0$	1.0
telehealth	0.36	0.50	0.31	0.48	$\chi^2_{McNemar}(1, N = 13) = 0$	1.0
use online patient portal	0.73	0.46	0.76	0.44	$\chi^2_{McNemar}(1, N = 15) = 0.5$	.480

Table A.6. Internet usage for the previous 3 months in the pre-survey. Turney residents reported using the internet more than the control group for education, p < .05 is bolded. (Including all returned surveys.)

Internet use	Turney		Control			
	M	*SD*	*M*	*SD*	*Chi-Squared*	*p*
Employment Cumulative Count	1.00	0.85	0.88	0.93		
work from home	0.48	0.50	0.42	0.50	$\chi^2(1, N = 89) = 0.10$	.757
search/apply for job	0.28	0.45	0.33	0.48	$\chi^2(1, N = 87) = 0.09$	.758
self-employment at home	0.26	0.44	0.12	0.33	$\chi^2(1, N = 87) = 1.62$	.204
Education Cumulative Count	1.35	1.25	0.70	0.92		
distance learning	0.38	0.49	0.09	0.29	$\chi^2(1, N = 89) = 7.13$	**.008**
homework at home	0.42	0.50	0.15	0.36	$\chi^2(1, N = 88) = 5.59$	**.018**
search education-related info	0.60	0.49	0.45	0.51	$\chi^2(1, N = 88) = 1.22$	.269
Health Cumulative Count	1.66	1.11	1.58	0.97		
search for health-related info	0.73	0.45	0.61	0.50	$\chi^2(1, N = 88) = 0.89$	.344
telehealth	0.34	0.48	0.30	0.47	$\chi^2(1, N = 86) = 0.01$	.908
use online patient portal	0.59	0.50	0.67	0.48	$\chi^2(1, N = 89) = 0.25$	.617

Table A.7. Within-Subject Comparison for the Turney served households pre-survey vs post-survey. (Including all returned surveys.)

Internet use	Turney Served pre-survey		Turney Served post-survey			
	M	*SD*	*M*	*SD*	*Chi-Squared*	*p*
Employment related activities						
work from home	0.58	0.51	0.41	0.50	$\chi^2(1, N = 34) = 0.38$	.540
search/apply for job	0.18	0.40	0.32	0.48	$\chi^2(1, N = 33) = 0.17$	.678
self-employment at home	0.55	0.52	0.32	0.48	$\chi^2(1, N = 33) = 0.78$	.378
Education related activities						
distance learning	0.45	0.52	0.45	0.51	$\chi^2(1, N = 33) = 0.00$	1.0
homework at home	0.36	0.50	0.45	0.51	$\chi^2(1, N = 30) = 0.02$	.900
search education-related info	0.83	0.39	0.65	0.49	$\chi^2(1, N = 35) = 0.54$	.464
Health related activities						
search for health-related info	0.83	0.39	0.78	0.42	$\chi^2(1, N = 35) = 0.00$	1.0
telehealth	0.36	0.50	0.27	0.46	$\chi^2(1, N = 33) = 0.02$	.893
use online patient portal	0.67	0.49	0.65	0.49	$\chi^2(1, N = 35) = 0.00$	1.0

Table A.8. Internet usage for the previous 3 months in the post-survey. There were no significant differences in how groups used the internet for employment, education, and health. (Including all returned surveys.)

	Connected Turney		Unconnected Turney		Control			
	M	*SD*	*M*	*SD*	*M*	*SD*	*Chi-Squared*	*p*
Employment Cumulative Count	1.05	1.05	1.31	0.75	0.73	0.92		
work from home	0.41	0.50	0.69	0.48	0.37	0.49	$\chi^2(2, N = 86) = 4.37$	.112
search/apply for job	0.32	0.48	0.23	0.44	0.22	0.42	$\chi^2(2, N = 84) = 0.74$	.690
self-employment at home	0.32	0.48	0.38	0.51	0.18	0.39	$\chi^2(2, N = 85) = 3.13$	.209
Education Cumulative Count	1.55	1.26	1.39	1.19	1.02	1.16		
distance learning	0.45	0.51	0.46	0.52	0.22	0.42	$\chi^2(2, N = 85) = 5.34$	.069
homework at home	0.45	0.51	0.31	0.48	0.30	0.46	$\chi^2(2, N = 85) = 1.70$	.427
search education-related info	0.65	0.49	0.62	0.51	0.54	0.50	$\chi^2(2, N = 86) = 0.89$	.642
Health Cumulative Count	1.68	1.04	1.75	1.22	1.63	1.06		
search for health-related info	0.78	0.42	0.77	0.44	0.69	0.47	$\chi^2(2, N = 87) = 0.89$	.640
telehealth	0.27	0.46	0.33	0.49	0.29	0.46	$\chi^2(2, N = 86) = 0.14$	.932
use online patient portal	0.65	0.49	0.69	0.48	0.67	0.48	$\chi^2(2, N = 87) = 0.06$	.970

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IV. A SOCIO-TECHNICAL REFERENCE ARCHITECTURE TO REPRESENT COMMUNITY-DRIVEN WIRELESS BROADBAND PROJECTS

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ABSTRACT

Private internet service providers are less interested in servicing rural communities because the low population density negatively impacts their return on investment. Therefore community leaders and concerned citizens are exploring alternate ways to accelerate broadband infrastructure deployment. A reference architecture can aid in defining a long-term infrastructure solution space by consolidating insight from solution architectures and support efforts to compare alternatives. In this study, we (1) discover a reference architecture for community-driven wireless broadband, (2) implement the reference architecture in a solution architecture for a project in Turney, MO, and (3) evaluate fit-for-use by interviewing two other broadband project teams. Other socio-technical reference architectures include the viewpoints of users and operators. In this context, we articulate a community viewpoint. Our results suggest that this reference architecture is an effective representation of community-driven wireless broadband and could be an effective communication tool to support project management.

In these types of diverse interdisciplinary teams, reference architectures can represent the problem space and provide a common vocabulary.

1. INTRODUCTION

Nearly 17% of rural U.S. residents do not have access to adequate broadband service. High-speed internet or broadband is defined as service that meets or exceeds 25 megabits per second (Mbps) of download and 3 Mbps of upload (25/3 Mbps) (Federal Communications Commission, 2021). However, this is not solely a problem in rural communities. Almost 14 million urban households do not have broadband subscriptions due to adoption challenges, such as digital literacy and affordability (Fishbane & Tomer, 2020). As a result, many communities are taking matters into their own hands to address this challenge.

Community-driven broadband is a broadband initiative led by place-based stakeholder committees as a grassroots response to the lack, or perceived lack, of adequate access in their community (Ashmore, Farrington, & Skerratt, 2017). These projects are often led or supported by community-based organizations. This can vary from well-established organizations that frequently apply for grants from the federal government (Jackson & Gordon, 2011) to concerned citizens that organize themselves to work with their local governments (Trostle, 2017) to private citizens that share their internet with interested neighbors, acting as a micro internet service provider or ISP (Maccari, Gemmi, Lo, & Karaliopoulos, 2019). However, not all community-based organizations have the same level of technological expertise, which is an important element in the success of community-driven broadband projects (Ashmore et al., 2017; Wallace, Vincent, Luguzan, & Talbot, 2015).

One way to address this technical knowledge gap is to recruit consultants and technology partners (Techatassanasoontorn, Tapia, & Powell, 2010). However, the knowledge asymmetries between different project members can still represent a significant challenge (Jackson & Gordon, 2011). Cloutier et al. (2010) indicate that reference architectures contribute to effective communications between diverse stakeholders.

In this work, we propose a socio-technical reference architecture to assist organizations working on community-driven wireless broadband projects. This study aims to address two primary research questions:

(1) Can community-driven broadband be represented in a reference architecture for replication across different communities?

(2) What is the perceived value of replicable representation?

2. BACKGROUND

2.1. SOCIO-TECHNICAL SYSTEMS

Community-driven broadband is an example of a complex socio-technical system. Socio-technical systems have a human and a technical component (Handley, 2019). The engineering of systems with hardware and software components that facilitate complex social functions requires a deep understanding of the social constructs that exist in the system and how the interaction of individuals, hardware, and software supports the overall social objectives of the system (Palmer et al., 2021).

There is increasing interest in modeling complex systems' social or human elements as part of system architectures. Baxter & Sommerville (2011) indicate that using a socio-technical approach when developing systems delivers better value to stakeholders and is better accepted by end users. Socio-technical factors should be taken into account at all stages of the system life-cycle (Baxter & Sommerville, 2011), especially early in the design process (Bhada, Canfield, & Wyglinski, 2021; Bourimi, Barth, Haake, Ueberschär, & Kesdogan, 2010; Handley, 2019, 2022).

Using a socio-technical systems design approach helps different stakeholders understand 'the problem' that the system intends to address and agree on the requirements for a solution. Attaining an appropriate balance between the various requirements constitutes the basis for a system that will be acceptable to the end-users while delivering the expected benefits for additional stakeholders. The human component of socio-technical systems can encompass many types of stakeholders, such as operators and users. In fact, the success of the system implementation is defined by a range of stakeholders, and each stakeholder category is likely to have different success criteria depending on the viewpoints (Baxter & Sommerville, 2011).

The human component of systems has been incorporated into a wide variety of systems domains such as energy (Adil & Ko, 2016; Lee & Gloaguen, 2015; Melese, Stikkelman, & Herder, 2016), health (Scheplitz, 2022), transportation (Songhori, Dongen, & Rajabalinejad, 2020), smart cities (Cunha, Rosetti, & Campos, 2020), and broadband (Bhada et al., 2021). For example, Nam et al. (2021) proposed a socio-technical architecture for a healthcare application allowing sharing of data in real-time between different organization types and patients. Developing the proposed architecture included the consultation of various stakeholders to define a series of standards to avoid customization of data requirements. Similarly, van Dijck & Jacobs (2020) evaluated the socio-technical aspects of electronic identification in the context of online transactions. Based on their study, they argue that developing electronic identification services requires going beyond engineering ingenuity and legal compliance because these systems involve negotiation of conflicting political and social values.

2.2. REFERENCE ARCHITECTURE

A reference architecture should capture the essence of existing architectures and the vision for future needs (Cloutier et al., 2010). This provides multiple benefits. For example, the reference architecture supports effective communication and guides the instantiations of future architectures. Reference architectures facilitate conversations between experts and non-experts. Other advantages of reference architectures are reduced cycle times, cost, and risk while increasing quality and interoperability. Historically, reference architectures did not include a socio-technical framework and only focused on the technical aspects of systems (Fokum & Frost, 2010; Sefid-Dashti & Habibi, 2014).

However, there is increasing emphasis on including the social parts of systems. Socio-technical reference architectures span domains such as virtual communities (Ghatasheh, 2011) and internet of things systems (Kearney & Asal, 2019). Some systems are human-centered, so the human is the core emphasis of the design. For example, Cipolloni et al. (2015) proposed a reference architecture for equipped-human systems.

This is a human or group of humans who have been equipped to perform some task(s), such as a firefighting company. This serves to clearly articulate the characteristics of the human, equipment, task, environment, and objective. Articulating the human viewpoint is useful for defining task allocations across the human members of the system (Handley, 2021).

Reference architectures are discovered, rather than designed or developed. Knowledge can be mined from patterns from existing architectures (Muller, 2012). A reference architecture then becomes a blueprint for future architectures. Reference architectures can be articulated for a specific instance as a solution architecture. While a reference architecture is mined, a solution architecture is developed. While a reference architecture is abstract, a solution architecture is specific to a design space. While a reference architecture evolves, a solution architecture commits. As highlighted in Figure 1 there is a cyclical relationship between reference and solution architectures. The experimentation that is involved in a solution architecture can prompt changes that are represented in the more generalized reference architecture.

While the concept of a reference architecture has existed for decades (Cloutier et al., 2010), this approach has only more recently been applied in the context of socio-technical systems. This type of approach has not been applied to more complex system-level scenarios that incorporate economic and policy elements.

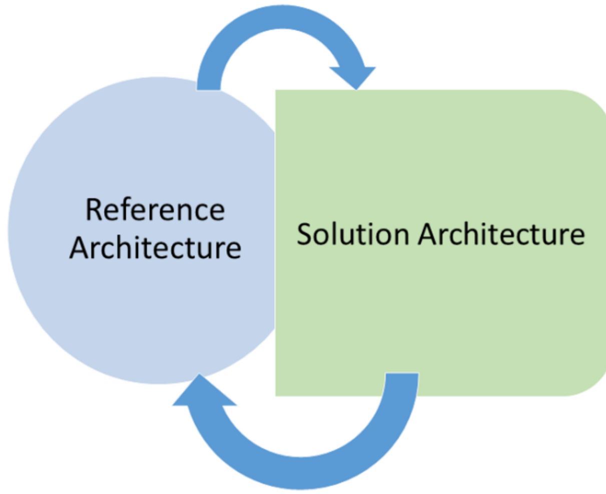


Figure 1. There is a cyclical relationship between the reference and solution architectures.

3. METHODS

In this case, the reference architecture was originally derived from experiences implementing a community-driven broadband project in Turney, MO as part of Project OVERCOME. Project OVERCOME is an initiative administered by US Ignite funded by the National Science Foundation and Schmidt Futures to create a cohort of 7 proof-of-concept projects to expand broadband access in rural and urban underserved communities (US Ignite, 2021). The project in Turney is a collaborative effort that includes team members from Missouri University of Science & Technology, Worcester Polytechnic Institute, University of Missouri Extension, Maximize NWMO (a nonprofit focused on development in the region), and United Fiber (an ISP that is a subsidiary of a rural electric cooperative).

A solution architecture for Turney is reported. Data sources include the U.S. Census 2015-2019 American Community Survey (ACS), a community survey, and direct interactions with the community. The community survey (see Paper III) was used to collect data about household characteristics, such as the number of residents, children enrolled in school (K-12), residents enrolled in higher education, employed adults, access to the internet, and income. In total, 54 households from Turney answered the community survey. These data supplement the information available from the U.S. Census.

To evaluate the reference architecture, we measured fit-for-use by interviewing 2 other community-driven broadband project teams from the Project OVERCOME cohort. The interviews lasted 50-75min and included 2 participants from each team. All interviews were conducted in May 2022 near the end of the project cycle. Each interview consisted of 4 main parts, (1) community structure, (2) constraints, (3) technology structure, and (4) fit-for-use feedback. For the community structure, participants described the community or neighborhood and compared their observations to U.S. Census data to identify any inconsistencies. The U.S. Census data were based on the zip code, which was often a larger area than the project area. For the constraints, participants highlighted how geographic, technological, economic, demographic, and regulatory constraints influenced technology choices. For the technology structure, participants described the deployed broadband system and the extent to which this technology solution fits the community's needs. Lastly, for the fit-for-use feedback, participants described whether the discussion was helpful. In addition, they reviewed the proof-of-concept solution architecture for Turney and discussed whether this framework would be helpful at the beginning of the project and whether it could be used as a communication tool. All participants were provided a copy of the solution architecture for their project after the interview. The full interview protocol is provided in the Appendix.

4. SOCIO-TECHNICAL REPRESENTATION

4.1. COMMUNITY-DRIVEN WIRELESS BROADBAND REFERENCE ARCHITECTURE

In the context of community-driven wireless broadband, the goal of the reference architecture is to support efforts to define the problem(s) to be addressed. This reference architecture uses a static, rather than dynamic, representation to describe the problem space. In these communities, which are not served by existing market mechanisms, there is no one-size-fits-all solution. Instead, each solution must be tailored to the place and community structure. The reference architecture is an abstract representation of the most important features that need to be considered in the design, implementation, and evaluation phases of the project. The target users of this reference architecture include non-technical experts, such as local residents who are part of county-level broadband committees. Therefore, the representation uses natural language to inform interpretation of the architecture structure.

As shown in Figure 2, the community-driven wireless broadband reference architecture has three main components, (1) Community Profile, (2) Community Structure, and (3) Technology Structure. The Community Profile includes the (a) constraints and opportunities and (b) needs assessment. Data from multiple sources (i.e., U.S. Census ACS, the survey, and interactions with the community) informed the development of the community profile and structure. The constraints and opportunities are framed around available resources or capitals, which is a common framework in social systems derived from rural sociology (Flora, Flora, & Gasteyer, 2015; Scoones, 2009). The geographic constraints (or natural capital) include any features of the

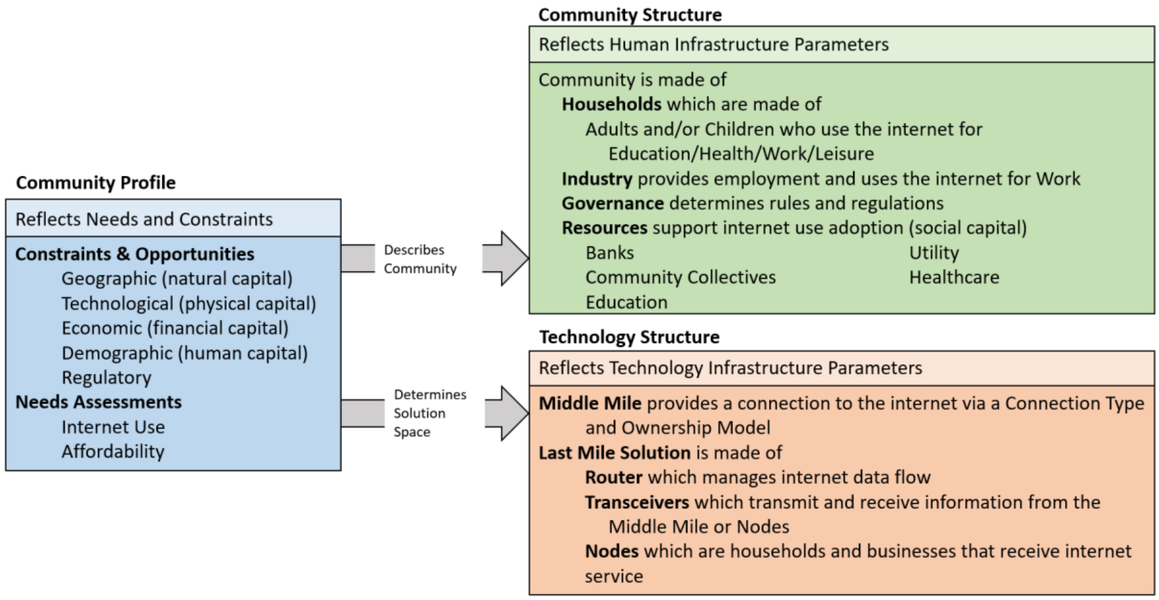


Figure 2. Socio-Technical Reference Architecture for Community-Driven Wireless Broadband Infrastructure

environment, such as terrain and climate. The technological constraints (or physical capital) include any features of the built environment, such as existing structures and infrastructure. Existing structures, such as buildings and towers, as well as natural features can be constraints if they are likely to block wireless signals or can be opportunities if equipment can be installed on them. Access to middle-mile broadband infrastructure as well as reliable electricity is critical for the success of a community-level wireless network. Economic constraints (or financial capital) include all economic resources, such as eligibility for external funding, internal funds, assets, and credit/debit available to communities, as well as market conditions that may influence available resources, such as the number of competitors. The demographic constraints (or human capital) include the skills, knowledge, and capabilities of the local population which may influence adoption. In this case, opportunities related to remote work, distance education, and telemedicine are of particular interest. Some populations, or subsets of the population, may benefit from digital literacy training and free or discounted access to devices to increase adoption. In addition to increasing access, community-driven projects may consider implementing programs to increase adoption as part of their broadband project. Lastly, regulatory constraints include any permitting, licensing, or other regulatory factors. Most construction projects require permits, and some wireless spectrum requires a license to access. Table 1 presents guiding questions for completing the constraints and opportunities section of the Community Profile.

The needs assessment section of the Community Profile captures (a) internet use and (b) affordability. The intended internet use by the targeted end users determines how much bandwidth is required to support their needs. Projects may target residential households or provide services more broadly to residents, businesses, and local institutions. The targeted users determine present and future bandwidth needs. Applications involving the transmission of videos, such as streaming and videoconferencing to support telework, telehealth, and remote learning, require higher bandwidth. Zoom, a common software used for video conferencing, requires from 600/600 kbps for a 1:1 video call using high-quality video to 3.0/3.8 Mbps for a group video call using 1080p HD quality (Zoom, 2022). Similarly, Netflix, a common video streaming provider, requires 1 Mbps of download for a standard definition device to 15 Mbps for a 4K/Ulltra HD (Netflix, n.d.). The bandwidth requirement may vary from household to household depending on the applications of interest, the number of people in the household, and how many applications are to be executed simultaneously. Affordability is influenced by poverty rates and average income as well as household-level willingness to pay. Willingness to pay may vary depending on the quality of service of the technology.

The Community Structure includes information about the (a) households, (b) industry, (c) governance, and (d) resources. Relevant data from households include the number of residents and their age, number of people in school (both K-12 and higher education), and number of employed adults with the need for teleworking. Businesses and industries represent potential users of the broadband service as well as an indication of potential population growth in the community. The government structure supporting the community represents a resource for the community organization working on the community-driven broadband project for financial (e.g., cost share, public private partnerships) and physical (e.g., publicly-owned structures) capital. In addition, governmental agencies may have regulations to which the broadband project must adhere. Community resources such as schools, libraries, churches, and nonprofit organizations represent the social capital of the community. Social capital includes the networks, relationships, and institutional trust that support adoption behavior. Other institutions, such as banks and utilities, support financial and physical capitals.

The Technology Structure includes information about the (a) middle mile and (b) last mile solution. The middle mile provides the interconnection between major internet backbones and the last mile solution. The middle mile is the broadband infrastructure that does not connect directly to end users (Taglang, 2021). The available middle mile options, such as fiber optics and microwave, depend on the location of the community with respect to existing backbones. The last mile solution connects the end user nodes to the internet. The last mile implementation depends on geographic constraints, bandwidth requirements, applicable regulations, and the available budget for the project. The relevant nodes may vary depending on what constitutes the targeted end users for the broadband network.

Table 1. Guiding questions for each constraint and opportunity in the Community Profile.

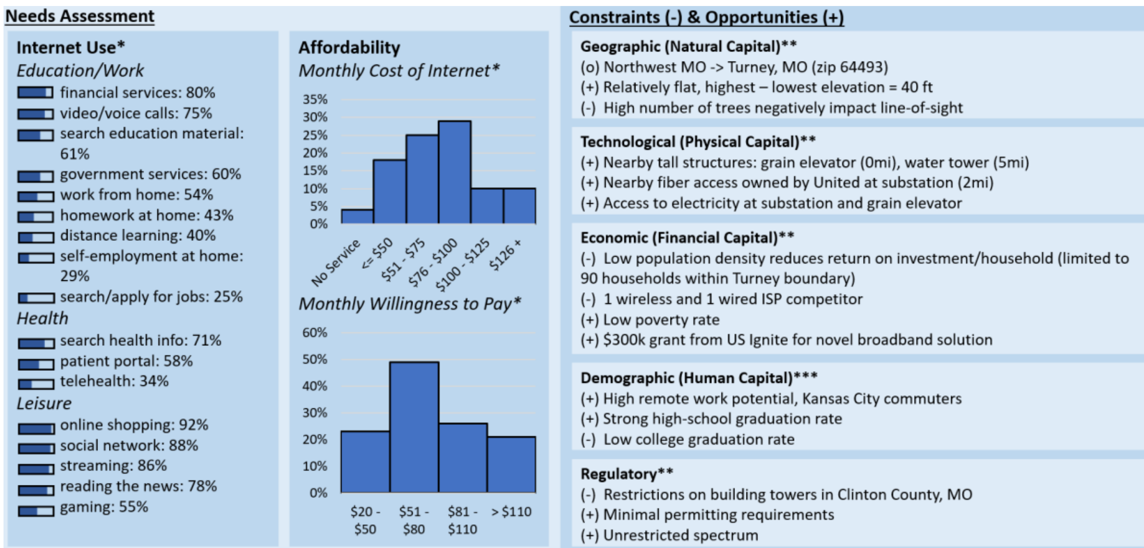
Constraints/ Opportunities	Guiding Questions
Geographic	What is the location of the project? How do hills, valleys, rivers, lakes, and trees impact the network implementation? What natural hazard risks (e.g., wind, rain, flooding) are present in this area?
Technological	What tall buildings or other structures could wireless equipment be installed on? What buildings or other structures could adversely affect wireless signal propagation? How far is the middle-mile network, and can it be accessed? Is there reliable access to electricity to support network components?
Economic	What financial or in-kind contributions can the local government make? What financial or in-kind contributions can local residents make? Does the community qualify for government funding? Does the community qualify for other funding sources, such as grants from nonprofit organizations? Are there incumbent ISPs that the project will compete with?
Demographic	What is the potential for applications such as remote work, distance education, and telemedicine? What is the digital literacy of the population? Would training increase adoption? Are there specific groups (e.g., older residents) that may need support to encourage adoption? Do residents have access to devices for accessing the internet? Would providing devices increase adoption?
Regulatory	What local permits are required? What spectrum licenses are required? What regulations apply to different technologies?

4.2. PROOF-OF-CONCEPT DEMONSTRATION OF SOLUTION ARCHITECTURE

To demonstrate the use of this reference architecture, a solution architecture was generated for Turney. Turney is a small rural community of 255 people (91 households) in northwest Missouri (U.S. Census Bureau, 2020). To facilitate usability, the solution architecture is separated into the three component parts, the Community Profile (Figure 3), Community Structure (Figure 4), and Technology Structure (Figure 5). The goal of the solution architecture in this form is to highlight key information for decision-making, rather than be a repository for all information. As a result, the same information may not be included in all solution architectures based on the same reference architecture.

For Turney, the needs assessment in Figure 3 suggests that residents are using the internet for a wide variety of purposes, and there are low concerns about affordability. The internet use statistics describe how residents are using the internet before the installation of a faster internet option based on a community survey. The high rate of reported usage suggests that there is high digital literacy and a high potential for adoption. The affordability statistics describe what residents were currently paying for internet access (whether it is from an ISP or cellular provider) as well as their monthly willingness to pay. On average, Turney residents were paying more for the internet (median = $76-100/month) than they would prefer (median = $51-80/month). This may be driven in part by the low quality of service from incumbent providers. Overall, there is relatively low poverty in Turney, so this is not highlighted as a key metric.

The constraints and opportunities highlighted in Figure 3 suggest that there are existing resources that can be leveraged for a broadband project. The absence of hills is a favorable geographic property in Turney, but a large number of trees kept interested households from getting service due to poor wireless signal reception. As part of the community's physical capital, the presence of a grain elevator in town provided an elevated structure where the required wireless components could be installed to support

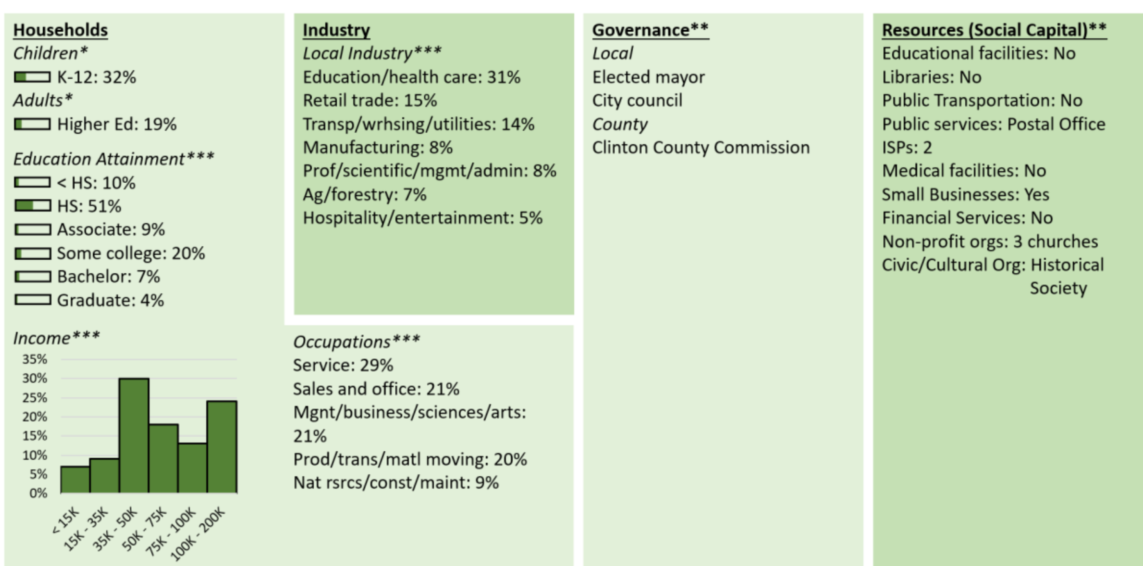


Data Source: *Pre-survey, **Community contact, ***2015-2019 U.S. Census American Community Survey

Figure 3. Community Profile for Turney Solution Architecture

the deployment of the system. Access to the internet backbone was achieved using fiber infrastructure owned and operated by United Fiber. Regarding the financial capital, the funds provided by US Ignite enabled the deployment of the broadband wireless solution. There were competing internet service providers, so some residents were not interested in participating in the free internet as they already had internet service. Regarding human capital, the potential need for teleworking by residents commuting to work has the potential to drive demand for broadband service. The strong high school graduation rate indicates the need to support the K-12 education of children. The low college graduation rate suggests that residents may have difficulty securing remote jobs. In terms of regulations, there were few permitting requirements, and the selected technology provided access to an unrestricted spectrum. Access to the grain elevator shielded the project from local regulations that limit tower building in Clinton County, where Turney is located.

As described in Figure 4, the Community Structure highlights that Turney is primarily a bedroom community with little local industry, likely due to its proximity to the Kansas City metropolitan. As a result, the network users are largely limited to residential households with no opportunities for an anchor institution with high bandwidth needs to subsidize the network infrastructure. The Turney community does not have a school or library in the community. Some residents have jobs that could be accomplished via telework, such as occupations in the management, business, science, and arts category.



Data Source: *Pre-survey, **Community contact, ***2015-2019 U.S. Census American Community Survey

Figure 4. Community Structure for Turney Solution Architecture

As described in Figure 5, the Technology Structure summarizes the key decisions about the wireless broadband solution that impact access and quality of service. Interconnecting to the middle mile fiber infrastructure was implemented using wireless transceivers operating at a transmission rate of 60 GHz. The routing of internet communications in the last mile is managed by a pfSense router, which is an open-source device that enabled the implementation of a proof-of-concept intelligent routing algorithm being tested as part of Project OVERCOME in Turney. The interconnection with the end user nodes is managed using point-to-multipoint transceivers operating at 5 GHz.

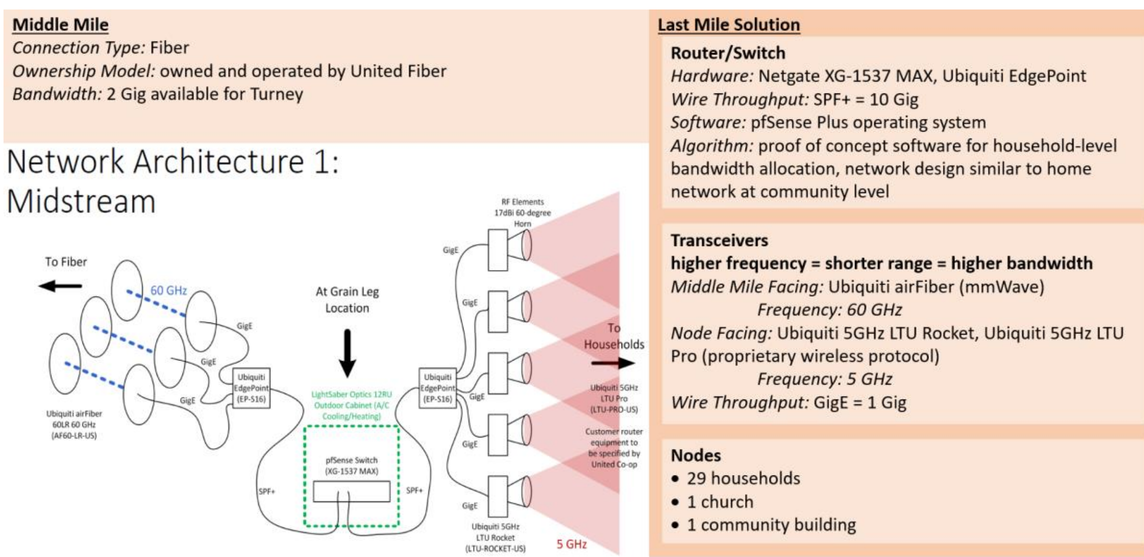


Figure 5. Technology Structure for Turney Solution Architecture

4.3. EVALUATION OF REFERENCE ARCHITECTURE

To evaluate the reference architecture, we measured fit-for-use by interviewing 2 community-driven broadband project teams. The interview protocol was based on the reference architecture to elicit information in a consistent way. In contrast to Turney, these projects focused on urban environments, which provided a valuable comparison to determine the replicability of the reference architecture representation.

For the Community Structure, the communities were predominantly Black and lower income. Similar to Turney, there were strong community ties (high social capital). One of the community-driven broadband projects was led by a team of researchers from a university located in the same city, and some level of interactions have existed throughout the years with the targeted community. A hospital within the community provided a location where they could mount the required wireless equipment. Several large buildings blocked the wireless signal limiting the number of households that could be served with the deployed solution. The second project was led by a nonprofit organization with previous experience providing broadband service in multiple communities within their city. They have processes and organizational structures in place to promote and maintain the required relationship with community leaders.

For the Community Profile, both teams identified a wide range of constraints that limited the technology solution design and effectiveness. For geographic constraints, there were challenges establishing line-of-sight due to tree cover blocking the wireless signal. For technological constraints, there were challenges with buildings blocking wireless signals. In addition, there were challenges accessing reliable electricity because the buildings where equipment was being installed were old and did not have an adequate electrical circuit. At the household level, installations were challenging because there were not enough outlets, and it was difficult to identify an appropriate mounting point that would not damage the homes. In determining an appropriate technology solution, the teams were planning for capacity (i.e., needs assessment/internet use) as well as operations. For economic constraints, both teams had access to funding as part of Project OVERCOME. However, there were challenges identifying sufficient resources due to the high operational and labor costs required to increase adoption and address installation issues. For demographic constraints, both teams identified challenges related to digital literacy and affordability, so they provided free devices and training to connect to and use the internet. In addition, there were challenges managing expectations for wireless connectivity, which is known to have lower reliability than wired solutions (e.g., signal fade due to rain). For regulatory constraints, there were challenges in acquiring construction permits in a timely manner. In addition, it was valuable to reduce costs by using unlicensed or semi-licensed spectrum bands to avoid paying for licenses.

For the Technology Structure, both teams deployed wireless solutions as part of their broadband network. One of the teams was targeting to provide service to two different neighborhoods using the same more advanced wireless technology. Ultimately, they ended up using a different technology for the two neighborhoods. The team needed to make this change in technology because the associated neighborhood could not support the deployment of the required wireless components because the buildings were too old and did not have the required power infrastructure.

Overall, both teams reported that the interviews were helpful for reflecting on what they had learned over the course of their broadband projects. Since it was near the end of the project period, both teams were engaged in drafting reports summarizing project outcomes and found that the interview recovered insights that they hadn't recorded. When asked if the discussion had been useful, one of the interview participants replied:

> *"Can we have a copy of the interview recordings? We have been sharing a lot, and the recording would help us remember the details. It has been a good occasion to reflect on the challenges and keypoint of the project."*

After reviewing the Turney solution architecture, the teams highlighted the importance of adding in a component focused on the Operations Structure, which is a key component of a long-term sustainability plan. Both teams saw potential in using the solution architecture as a communication tool. For example, the architecture representation could support effects to build a common vocabulary and communicate with residents about how the system works:

> *"We have a one-pager we use to communicate with community members. This breaks it down to the next level. It has the potential to help us articulate and have verbage and vocabulary to show that the process is not necessarily linear. That there are some key components that, if we do not have in place, we will be far less successful, if successful at all. It's helpful to have it summed up so we can use it to communicate both internally and externally. This structure has a flow to it that is helpful to be able to reiterate."*

In addition, they identified value in creating shared knowledge within the team to make sure everyone had a common understanding of the project:

> *"It would be super helpful to use it as a tool for sharing knowledge, to provide a common ground that could be understood by people from different backgrounds and different objectives so that everyone is on the same page.*

We struggled a lot during the project, discussing things over and over and going over decisions already made. For me is a shared knowledge tool. If I could go back in time, I would use it from the beginning.“

Ultimately, both teams saw potential for leveraging the reference architecture in their project management.

5. DISCUSSION

This study describes the discovery and implementation of a reference architecture to represent community-driven wireless broadband projects. The value of the reference architecture is demonstrated via a proof-of-concept solution architecture as well as input from two fit-for-use interviews. There are two primary findings, (1) the reference architecture does effectively represent projects and (2) has potential to serve as a communication tool to support project management.

First, as demonstrated by the solution architecture and fit-for-use interviews, the reference architecture is a useful framework for representing community-driven wireless broadband projects across different communities. For example, this framework can be used as a checklist or template for designing a system or reporting out on a solution implementation in a standardized way. Table 1 and the fit-for-use interview protocol represent early attempts at developing these types of tools. In implementation, the solution architecture is unlikely to be static. The information included will likely vary over time as the team learns more and makes decisions about their broadband implementation. As a result, the reference architecture is also not meant to be static over time. A reference architecture captures the essence of existing architectures and should be actively managed to reflect necessary changes (Cloutier et al., 2010).

Second, the fit-for-use interviews suggest that the reference and solution architectures can support efforts to communicate internally and externally about the broadband project. As suggested by the fit-for-use interview participants, it could be used as a knowledge-sharing tool for the team members. A tool to document the decisions already made, which can then be used to explain the reason behind the decisions made. This is consistent with the literature, which indicates that "the Reference Architecture contributes to communication effectiveness" (Cloutier et al., 2010).

This work has two primary limitations, (1) limited scope for the reference architecture and (2) limited sample size for the fit-for-use interviews. As described in the fit-for-use interviews, all aspects of the broadband projects were not represented in the reference architecture. This was a conscious choice to limit the scope of the present study, but could be a fruitful area for future research. In addition, it would be valuable to conduct additional fit-for-use interviews from more diverse projects (e.g., from other countries) to further evaluate replicability. As part of the Project OVERCOME cohort, the teams were in frequent communication, which may have facilitated understanding of the reference and solution architecture. These tools may be perceived as less valuable to an audience that is less familiar with this work.

6. CONCLUSION AND FUTURE WORK

This reference architecture may assist community-based organizations in planning, designing, and deploying wireless broadband infrastructure to serve their target community. In particular, this reference architecture aims to keep the community at the center of the process at all times. This has the potential to serve as a valuable communication tool for managing these types of projects, especially for interdisciplinary teams that vary in terms of technical expertise.

Developing socio-technical reference architectures is a ripe area for future research, particularly in the context of infrastructure projects. Future work should identify additional components to add to the community-driven wireless broadband reference architecture, such as an Operations Structure component. More broadly, there is potential to shift from a static to a dynamic representation. This architecture can be operationalized in a modeling language, such as Systems Modeling Language (SysML), to identify requirements and provide predictive capabilities. In addition, this framework may be able to be extended to other domains. For example, identifying the community profile and structure could support the planning and design of technical solutions in energy, water, transportation, and health (Kramer, Mierzejewski, & Ward, 2000).

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SECTION

2. CONCLUSIONS AND FUTURE WORK

Considering the urgent need for broadband infrastructure in many rural communities, this dissertation aimed to identify the barriers to the deployment of adequate broadband infrastructure in rural Missouri by getting input from the Regional Planning Commissions (RPCs). These intergovernmental organizations support the infrastructure needs of their member governments, enabling economic opportunities within their region. Another area of emphasis within this dissertation was evaluating the impact of access to broadband services to develop analytical tools and data to support local decision-making. Overall:

- Paper I established that there is a problem in that local communities do not have enough resources and tools to help address rural broadband. This leads to information assymetries, which make it challenging for non-technical experts to participate in community-driven broadband efforts.
- Paper II demonstrated one analytical tool, benefit-cost analysis, which could be used by a community to justify public investment. However, this type of analysis can be challenging to scope and determine appropriate assumptions.
- Paper III estimated the impact of improved broadband service in an underserved community, finding that quality-of-life benefits are more

measurable than social impact benefits in the short term. This could be used as an assumption in a benefit-cost analysis.

- Paper IV demonstrates a second analytical tool, a socio-technical reference architecture, which can streamline efforts to communicate within and between diverse teams implementing community-driven broadband projects. This can help reduce information asymmetries by providing a common vocabulary across teams.

Together, these analytical frameworks and data can be used to improve the design of future community-driven broadband systems. Each paper is discussed in more detail below.

The first paper in this dissertation proposes a framework that integrates the decomposed Theory of Planned Behavior, the Theory of Goal Pursuit, and the Stakeholder Theory to highlight the dynamics causing the limited involvement of the RPCs in the deployment of rural broadband infrastructure in Missouri pre-COVID. Even when the RPCs recognize the urgency of the broadband infrastructure to support the economic development and the quality of life within their region, many reported limited participation in support of broadband infrastructure projects.

Both internal and external forces influence the RPC efforts to expand broadband access. The integrated framework demonstrated the complexity of forces encouraging and discouraging RPCs to leverage their convening powers to build public-private partnerships, apply for state and federal funding, and engage in planning efforts to prioritize deployments. Residents and businesses influence RPC attitudes about the benefits of broadband access, particularly in the desirability of a location for residents, professionals, and new employers. In contrast, perceptions of complexity related to unsuitable terrain, lack of decision-making authority, prioritization of other infrastructure, eligibility issues for state and federal funding, and lack of affordability contribute to negative attitudes. Perceptions of norms were largely influenced by seeing successes in other communities and seeing what might be possible with improved broadband access. However, RPCs tended to have low perceived behavioral control. They described inadequate knowledge and expertise in the public sector, technological and financial constraints, and inadequate public investment.

RPCs intend to engage in efforts to advance broadband infrastructure in rural communities to achieve economic development goals. The priorities for the RPCs are set by their executive boards, which are usually composed of elected officials from their member governments (Seltzer & Carbonell, 2011). Washington (2007) suggests that having priorities and corresponding funding defined by the executive board ultimately limits the RPC's ability to be effective and efficient. In TPB terms, the actual behavior control does not reside within the RPCs, which constitutes a barrier for them to support efforts to expand rural broadband infrastructure.

Future work can focus on generalizing and adapting the proposed framework to study behaviors of other organizations that face similar stakeholder dynamics and convening power, such as business improvement districts, community-based organizations, and economic development corporations. In addition, this framework can support the development of interventions to reduce broadband planning barriers, which can be tested in future research. For example, improving perceived behavioral control by increasing self-efficacy via interventions that augment knowledge and experience related to broadband could be valuable. Also, the Covid-19 pandemic most likely changed the perception of local governments on the urgency of having access to adequate broadband services. This could shift the priority for broadband infrastructure in the eyes of local governments, which, in turn, could ask the RPCs to support broadband projects within their region. Another factor that is likely to increase the involvement of the RPCs in advancing the broadband infrastructure is the Broadband Equity, Access, and Deployment (BEAD) Program from the US Department of Commerce National Telecommunications and Information Administration. The BEAD program will provide an initial $100 million to support planning efforts in each state. Getting involved in planning the expansion of broadband infrastructure in their regions may contribute to an increase in the self-efficacy of the RPCs. In the context of broadband, the proposed framework could be leveraged by other states with similar conditions as Missouri where (1) planning at local municipalities and counties is supported by the RPCs, (2) the direction and priorities of the RPCs are defined by their executive boards, and (3) restrictive laws limit the involvement of municipalities and local governments in selling or leasing broadband services to residents.

The second paper in this dissertation presents a Benefit-Cost Analysis (BCA) from a county government perspective. Variations in economic activity directly impact the amount of tax collected for the support of the local community. Having a reliable high-speed internet infrastructure contributes to the protection and potential expansion of the tax revenue for rural counties. The proposed model considers the change in tax revenue as a means to monetize the impact of rural broadband. The cost associated with treating problematic internet use (PIU) is integrated into the model as mental health expenditure. A sensitivity analysis of the BCA reveals that the initial revenue of the county, as well as the year-over-year population change, impact the net present value of the broadband infrastructure projects to a greater extent versus other model parameters like the unemployment rate. When evaluating their potential investment in rural broadband, governments and organizations may incorporate the costs of treating conditions such as PIU in their analysis. To the extent a rural county can keep a low unemployment rate and increase the county population, the easier it would be for the county to recover any required investment in rural broadband infrastructure and see a positive impact on the county finances.

Future work should identify how rural broadband impacts the prevalence of mental conditions associated with PIU within rural communities and what type of government expenditures is required to counterbalance the undesired situation. Also, future work could incorporate other sources of benefits into the BCA. The proposed BCA model considers the change in the county revenue as the only benefit of the adequate broadband infrastructure. A future version of the BCA model could include the direct revenue stream associated with charges for accessing the broadband internet service or from a leasing fee to a private company for operating the infrastructure. Also, future versions of the BCA might benefit from using a Monte Carlo analysis approach to incorporate variations in the model parameters, such as population change and the unemployment rate.

Future work could explore the impact of broadband infrastructure in the context of a rural town after deploying broadband infrastructure. The study should consider the community profile of the targeted town and adjacent localities. The attraction of new businesses constitutes a complex process, and even when broadband is an important requirement for endeavors, entrepreneurs consider other factors (Lafuente, Vaillant, & Serarols, 2010). Not having broadband access can be a dealbreaker, but having it does not guarantee success. Local decision-makers need to consider how broadband infrastructure complements other community attributes.

The third paper in this dissertation presents evaluates the impact of faster, higher bandwidth wireless internet access in a small underserved rural community in Missouri. In addition to collecting pre-post data for an internet access intervention, pre-post survey data were collected from demographically similar nearby communities to serve as a control group. Some of the interested participants in the target community (Turney) were unable to be connected to the network due to technical constraints. This created an additional comparison group in the post-survey. There are two primary findings, (1) changes in using the internet for employment, education, and health could not be directly attributed to the internet intervention, and (2) the internet intervention was associated with quality-of-life benefits related to the ability to use multiple devices at once. Although there were no significant within-subject differences in internet usage behavior for Turney households after the internet intervention, there was evidence that households had fewer issues accessing the internet. Participant feedback indicated that participants increased their existing usage rather than changing their behavior. For underserved communities, it may be more common to see these types of marginal benefits. Second, instead of achieving social impact measures related to employment, education, and health, participants were primarily motivated to get better internet to achieve quality-of-life benefits. Quality-of-life can be an important consideration for small rural towns that are competing with other similar towns for residents. For example, if a young couple is choosing whether to move back to their hometown or the next town over, they are highly likely to consider broadband access in their decision, in a similar way that it impacts the location decisions of new firms (Kim & Orazem, 2017; Krause & Reeves, 2017).

It is challenging to evaluate the impact of broadband access in an underserved community where there are competing technologies to facilitate access and residents already use the internet to meet their most pressing needs. This study had three primary recommendations that can inform future broadband evaluations, (1) identification of appropriate outcome variables, (2) recruitment challenges, and (3) survey timing. In terms of outcome variables, underserved communities may benefit more from quality-of-life measures than social impact measures. Future studies should put increased emphasis on these types of outcomes to better measure the benefits that community members perceive. Also, future studies should aim to quantify how much time participants use the internet for the applications of interest instead of having a binary indication if they use or not the internet for the activities of focus. In terms of recruitment, achieving a high participation rate can be difficult in small rural communities. Future studies should plan to use a combination of recruitment strategies and could benefit from ensuring that the same recruitment methods are used for all groups, if possible. In terms of timing, the extended recruitment period in Turney shifted the timing of data collection, so it was not consistent between groups. Future studies should ensure that education-related behaviors are only measured during the academic school year to avoid outliers associated with the summer months. In addition, this study focused on short-term impacts that occurred in the last 3 months. However, it may take longer for social impacts to emerge. Future studies would benefit from longitudinal data collection to evaluate which types of social impact are observed over time.

The fourth paper in this dissertation describes the discovery and implementation of a reference architecture to represent community-driven wireless broadband projects. The value of the reference architecture is demonstrated via a proof-of-concept solution architecture as well as input from two fit-for-use interviews. This reference architecture may assist community-based organizations in planning, designing, and deploying broadband infrastructure to serve their target community. In particular, this reference architecture aims to keep the community at the center of the process at all times. This has the potential to serve as a valuable communication tool for managing these types of projects, especially for interdisciplinary teams that vary in terms of technical expertise. There are two primary findings, (1) the reference architecture does effectively represent projects, and (2) has high potential to serve as a communication tool to support project management. This framework can be used as a checklist or template for designing a system or reporting on a solution implementation in a standardized way. Second, the fit-for-use interviews suggest that the reference and solution architectures can support efforts to communicate internally as well as externally about the broadband project. Reference architectures contribute to effective communications between diverse stakeholders (Cloutier et al., 2010).

Developing socio-technical reference architectures is a ripe area for future research, particularly in the context of infrastructure projects. Future work should identify additional components to add to the community-driven wireless broadband reference architecture, such as an Operations Structure component. More broadly, there is potential to shift from a static to a dynamic representation. This architecture can be operationalized in a modeling language, such as Systems Modeling Language (SysML), to identify requirements and provide predictive capabilities. In addition, this framework may be able to be extended to other domains. For example, identifying the community profile and structure could support the planning and design of technical solutions in energy, water, transportation, and health (Kramer, Mierzejewski, & Ward, 2000).

Overall, this dissertation highlights information assymetries in the broadband development space that could be addressed with better data and analytical tools. Infrastracture that accounts for the human or social dimension is likely to better meet the needs of the end users and other stakeholders. However, it is challenging to discern the needs of these stakeholders and predict the impact of broadband in a specific community. As a result, communities will need to take a multi-faceted approach to combine various data sources and modeling approaches to make best estimates. Future work should investigate the effectiveness of these tools in improving knowledge, confidence, and impact within community-driven broadband teams.

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