# Building Urban Infrastructure Resilience through Network Governance

**Abstract**: As the scale and intensity of disasters continue to increase, building and enhancing resilience to disasters has become a critical policy and governance issue. Of particular importance to this topic is urban infrastructure resilience because infrastructure systems support the continuity of operations of governments and businesses, and are essential to the economy, health, and public safety. The purpose of this paper is to propose and apply a network governance perspective to examine interdependent infrastructure systems, such as water (wastewater), electric power, transportation, and telecommunication. The paper contributes to a better understanding of the role of governing interdependent infrastructure systems in enhancing urban infrastructure resilience to disasters. The paper also highlights the need to leverage collaborative leadership and organizational capacity to develop robust and connected community networks to enhance urban infrastructure resilience to disasters.

**Keywords**: Urban infrastructure resilience, network governance, Texas Winter Storm

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## Introduction

Disasters overwhelm the response capability of communities. Policymakers, professional practitioners, and researchers have embraced the notion of resilience to enhance their communities' ability to bounce back, adapt, and continue to function in the face of disasters (National Academies of Sciences [NAS], 2019; National Institute for Standards and Technology [NIST], 2016). Resilience is "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (NAS, 2012, p. 1). Resilience as a capacity of a system (e.g., an organization, community, city, or society) enables it to proactively adapt to and recover from shocks that fall outside the range of normal and expected disturbances (Comfort, Boin, & Demchak, 2010).

As the scale and intensity of disasters continue to increase, building and enhancing community resilience to all hazards has become a "national imperative" (NAS, 2012), especially in urban areas. Extreme weather events, which have become more frequent and intense globally, cause substantial disruptions to urban infrastructure systems, along with significant physical and socio-economic costs. For example, in the United States, the top five costliest hurricanes—Katrina, Harvey, Maria, Sandy, and Irma—cumulatively cost more than $500 billion (National Centers for Environmental Information [NCEI], 2020). Moreover, just to maintain the current service level, like in many other countries, U.S. infrastructure systems need significant investments (American Society of Civil Engineers [ASCE], 2017).

According to the United Nations (2018), approximately 55% of the world population lives in urban areas, and the number is projected to increase to 68% by 2050. Unfortunately, urban resilience policies and practices have not kept pace with urban population growth.

Moreover, the environmental consequences of urban growth need to be addressed through planning, policy, and governance (Kennedy, Cuddihy, & Engel-Yan, 2007; Sitco & Massella, 2019). Rapid urbanization and a lack of coherent and commensurate resilience policies and practices will likely exacerbate disaster impacts in urban areas in the future.

Of particular importance to this paper is urban infrastructure resilience to disasters. We define urban infrastructure resilience "as the ability for the connective network of utilities, structures, equipment, and personnel within a coupled human-environmental ecosystem (e.g., urban landscapes) to be adaptive and operational indefinitely" (Shaker et al., 2019, p. 9). This definition was selected among many others due to its broad scope and relevance to the focus of this paper. Urban resilience promotes capacity building of individuals, institutions, communities, and systems to absorb external shocks, sustain, and adapt to build back better based on past experience.

Infrastructure systems, inclusive of lifelines and critical infrastructure, support the continuous operations of governments and businesses, and are essential to the economy, health, social activities, and public safety (Chang, 2016). Infrastructure systems are interdependent, meaning that failure in one infrastructure, such as electric power, can have cascading effects on others like communication (Bigger, Willingham, Krimgold, & Mili, 2009; Chang, 2016; Mitsova et al., 2019). These interdependent infrastructure systems face significant risk of disruptions in a disaster situation due to their vulnerability to malfunction and distress, and their geographically extensive nature (Chang, 2016; Goh, 2021; Paton & Johnson, 2001).

Well-functioning community lifelines such as transportation, power, water, and telecommunications are critical for community well-being in the face of disasters. This lifeline perspective provides an opportunity to apply the network governance perspective in identifying

the integration of key community lifeline stakeholders for planning, policy, and decision making. In this paper, the network governance perspective is specifically applied to urban infrastructure and key stakeholders as critical community lifeline in preparing for, responding to, and recovering from disasters.

The resilience of interdependent urban infrastructure systems is a multidimensional concept that encompasses the social, human, and cultural dimension, financial and economic dimension, natural dimension, and institutional dimension (O'Rourke, 2007). There are myriad studies on urban infrastructure resilience, yet the research on the institutional dimension remains limited (Kapucu, Ge, Martin, & Williams, 2022; Tanner, Mitchell, Polack, & Guenther, 2009). Formal institutions (e.g., laws and regulations) and informal institutions (e.g., routines and norms) define the roles of actors and guide how a diverse range of actors interact with one another in the social-technical infrastructure systems.

Fragmented governance structures hinder the goal of building resilient urban infrastructures; therefore, over the past decade, an increasing number of scholars have highlighted the importance of institutional perspective and suggested the need for the integration of institutional efforts (Huck et al., 2020a). Moreover, how to build the necessary conditions for a network approach to urban infrastructure resilience remains understudied (Huck et al., 2020b). As a result, additional studies are needed on the institutional dimension that will provide important insights and understanding of how the institutional dimension can contribute to the resilience of interdependent urban infrastructures. Hence, this paper focuses on the institutional dimension by investigating the interface between planning, policy, and governance to understand the resilience of urban infrastructure systems including electric power, transportation, water (wastewater), and telecommunication.

The goal of this conceptual paper is to address urban infrastructure resilience to disasters by applying a network governance perspective to understand interdependent infrastructure systems. Network governance refers to coordinating processes, platforms, mechanisms, and structures that rely more on interdependent relationships than traditional hierarchical authority to guide the collective effort of stakeholders in building and enhancing urban infrastructure resilience in response to disasters (Kapucu & Hu, 2020; Waugh & Streib, 2006). The network governance perspective is relevant for addressing complex infrastructure resilience as it requires partnerships among different sectors and levels of government in mobilizing resources and developing innovative solutions (Ansell, Sørensen, & Torfing, 2022; Therrien & Normandin, 2020). This paper addresses how network governance contributes to the resilience of interdependent urban infrastructure systems by enhancing multi-level and multi-sector stakeholder collaboration and mobilizing community resources. In doing so, this paper contributes to a better understanding of interdependent urban infrastructure systems from an institutional perspective.

## A Network Governance Perspective for Urban Infrastructure Resilience

More frequent, and intense disasters and aging infrastructures have made building resilient infrastructure systems and communities a national imperative (NAS, 2012). This imperative highlights the need to build capacity and partnerships across all levels of government, businesses, and nonprofit organizations (NAS, 2012, 2019). Similarly, the National Academy for Public Administration identifies building resilient communities as one of the 12 grand challenges in public administration with specific emphasis on capacity and cross-sectoral collaboration to respond and recover from adverse conditions caused by disasters (2019). This section addresses

the network perspective in promoting urban infrastructure resilience with specific emphasis on network governance structure, collaborative leadership, and network resilience.

**A Multi-Level and Multi-Stakeholder Collaboration Perspective**

Studying urban infrastructure resilience needs a multidimensional perspective, including natural or environmental dimension (sustainability) (Coaffee, 2008), infrastructure dimension (built environment) (McDaniels et al., 2008), financial and economic dimension (powerhouses of modern economy) (Martin & Sunley, 2015), human and cultural dimensions (distinctive set of historic and cultural characteristics) (Campanella, 2006), social dimensions (social capital and sense of community) (Meerow, Pajouhesh, & Miller, 2019), and institutional dimension (politics, policy, and governance) (Hucka, Monstadt, & Driessen, 2020; Kapucu et al., 2022). Among all the dimensions, the institutional dimension has received relatively little attention from researchers (Kapucu et al., 2022).

Despite a growing number of studies developing resilience frameworks, measures, and indicators, disaster resilience research has focused on the individual, organizational, social, infrastructure, and community levels separately (Cutter, 2016; Fisher, Norman, & Peerenboom, 2018; Parker, 2020). Hence, research is needed to understand urban infrastructure resilience from a holistic multi-level and multi-stakeholder collaboration perspective. Our approach in this paper aligns with the whole community approach of the US Federal Emergency Management Agency (FEMA). FEMA recognizes the whole community as "a means by which residents, emergency management practitioners, organizational and community leaders, and government officials can collectively understand and assess the needs of their respective communities and determine the best ways to organize and strengthen their assets, capacities, and interests" (FEMA, 2011, p. 3).

There has been a significant interest in resilience at the global, national, state, and local levels. Policies and plans have been developed in many communities around the world. However, the implementation of many of the plans and policies has relied on individual siloed organizations rather than the collective and collaborative effort of multi-level and cross-sector organizations (Coaffee et al., 2018). Resilience policy implementation should be entrenched in the engagement of stakeholders from all levels of government, businesses, and nonprofit organizations. Nevertheless, there is still a prevalence of siloed perspectives in addressing resilience challenges. Therefore, a flexible, adaptable, holistic, and inclusive network governance perspective can be useful in engendering a collaborative mindset when implementing resilience policies for interdependent urban infrastructure systems in response to disasters (Coaffee et al., 2018; Henstra, 2016).

By applying a network perspective, this paper underscores the importance of collaboration among central/federal, province/state, and local government agencies, as well as businesses, and nonprofit organizations to enhance urban infrastructure resilience to disasters (FEMA, 2011; Lindell, 2019). Resilient urban areas can be considered as regions with enhanced community capacity to recover quickly after external shocks and return to their previous level, or better conditions of employment and economic output without catastrophic loss and damage, reduced productivity, and with little outside assistance (Mileti, 1999; Therrien & Normandin, 2020). Urban resilience for new areas also involves a focus on the way that the governance system targets the needs and well-being of poor and marginalized groups (Tanner et al., 2009).

Urban infrastructure systems have become more interconnected and interdependent and critical infrastructures, such as telecommunications, power, transportation, and water supply (wastewater transport systems) have become elements of a bigger system. Infrastructure systems

may use one another's output and operate together to provide joint services. The interdependence between two systems can cause a decline in the performance of one system due to disruption in the other system. For example, infrastructure components may depend on others within the same system (e.g., a downstream water main depends on its neighboring upstream water main) and across other infrastructure systems (e.g., water/wastewater pumps and traffic signals depend on power supply) leading to interdependencies. Hence, disruption to one infrastructure system may propagate into others and eventually affect various services that are critical for the lifeline and well-being of urban communities.

During and after disasters, various local stakeholders may face major disruptions and experience significant challenges restoring and recovering from disruptions (Bigger, Willingham, Krimgold, & Mili, 2009; O'Rourke, 2007). These stakeholders include local governments, utility operators, businesses, nonprofit or civil society organizations, and residents. They are the critical agents who oversee (i.e., plan, operate, and use) most urban infrastructure systems and services. A critical step toward enhancing urban infrastructure resilience is a better understanding of the interdependencies of actors among different systems. Compounding the technical challenge of infrastructure interdependencies, urban stakeholders may or may not know the dependencies of their own infrastructure system with other systems. They need to take the interdependencies explicitly into account in their policy development, investment planning, and operational decisions (Hasan & Foliente, 2015). Hence, the following section proposes a network governance perspective in building resilience of urban infrastructure as interdependent multi-level and multi-sector networks and systems.

**A Network Governance Perspective for Building Resilient Urban Infrastructure Systems**

A stakeholder-oriented lens of network governance perspective is necessary to enhance the resilience of interdependent urban infrastructure systems. Local government authorities assess the vulnerability of infrastructure systems in their jurisdiction and develop corresponding risk management and adaptation strategies; develop and maintain infrastructure assets (e.g., transport services through roads and bridges; telecommunication services; electric power and water supply); and plan for disaster scenarios and develop disaster mitigation, response, and recovery plans so that risk of disruptions in services can be minimized. Utility companies plan, design, and build new infrastructures and evaluate alternative options for a local community; take risk-mitigating measures to prevent cascading failures and protect assets; and rapidly recover from disruptions in critical services. The network governance perspective provides a holistic approach to identify key actors and their relations and interactions across different interdependent infrastructure systems and discover the structural properties of stakeholder partnerships that are crucial for maintaining overall service delivery during/after a disaster and optimizing investment.

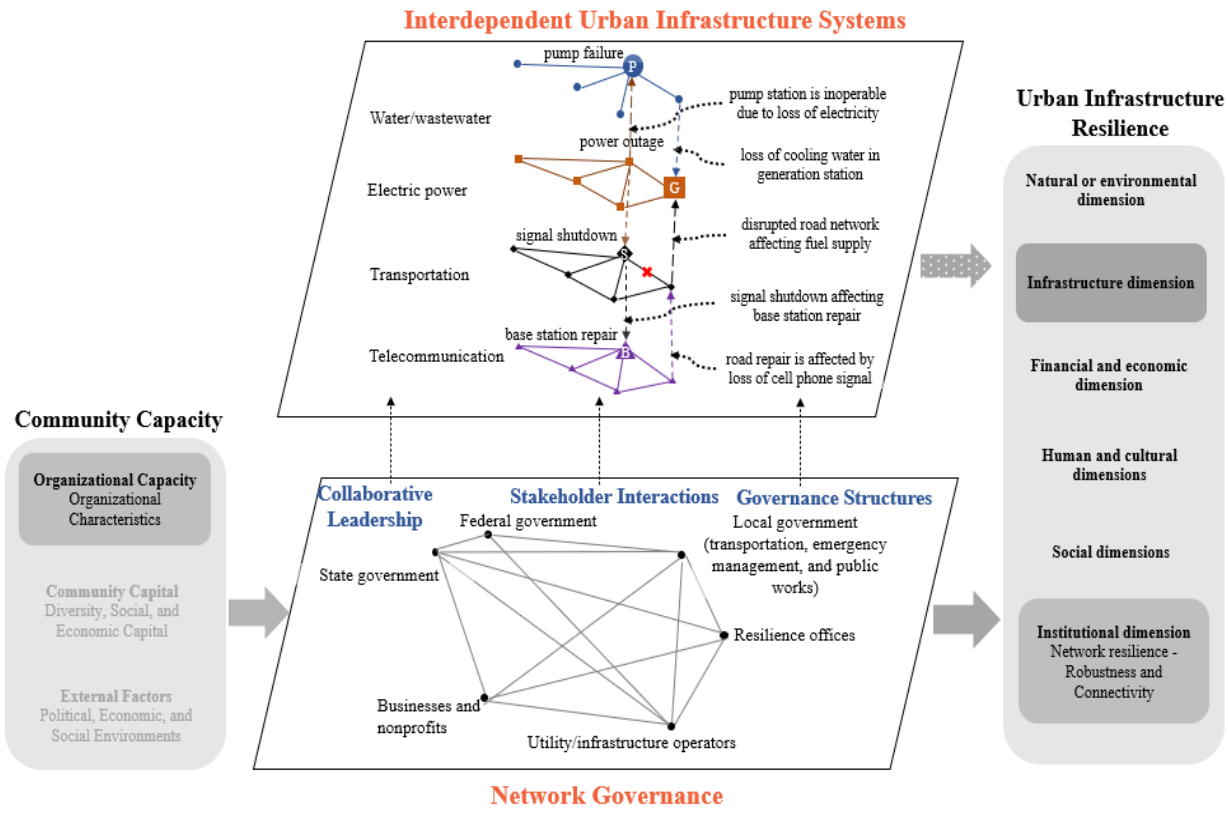


*Figure 1. Network governance and urban infrastructure system's resilience*

As shown in Figure 1, we apply a network perspective to conceptualize urban infrastructure as multi-level and multi-sector networks that are composed of (1) infrastructure facilities and their relations due to resource flow and interdependency; (2) key stakeholder groups, such as government agencies at all levels, businesses, nonprofit organizations, and their interactions that influence the planning and policies on infrastructure investments and maintenance; and (3) interactions between infrastructure systems, consumers or user groups, and planning, policy, and governance actors. Network governance as an institutional dimension of urban resilience provides tools and platforms to better design and implement urban resilience policies and plans.

The interdependencies in urban infrastructure systems demand a holistic and inclusive stakeholder involvement for the successful implementation of policies and plans (Coaffee et al.,

2018). Diverse groups of government agencies, businesses, and nonprofit organizations are involved in building and enhancing urban infrastructure resilience to disasters. The interactions among these organizations in interdependent urban infrastructure systems form complex networks of participants from all three levels of government—federal, state, and local—as well as across various sectors (e.g., government, private, and nonprofit entities). It is within and across the various levels of these networks that synergistic processes occur. These interorganizational relationships inevitably cross boundaries between the community, public, private, and nonprofit institutions, and allow stakeholders to utilize resources effectively during disasters. The paper examines the following key elements of network governance: *collaborative leadership, stakeholder interactions, governance structures, and network resilience*. Collaborative and adaptive forms of network governance promote the capacity of organizations and community stakeholders to adapt to a dynamic environment of disasters (Kapucu, 2006; Tierney, 2012; Ysa, Sierra, & Esteve, 2014).

The complex interdependent urban infrastructure systems make coordination, decision-making, and the division of responsibility essential to systems' effectiveness (Kapucu & Hu, 2020). Network governance facilitates stakeholder engagement and supports a community's capacity to enhance urban infrastructure resilience (Deyle & Butler, 2013). Effective network governance spans individual organizational boundaries and cultivates a unified network of multiple stakeholders (Drabek et al., 1981; Kapucu, 2006; 2012b; Nowell & Steelman, 2013; Robinson, Eller, Gall, & Gerber, 2013). Capacities of individual stakeholders from different sectors and multiple agencies are necessary to prompt appropriate information and resources in achieving network effectiveness. It is essential for stakeholders to embrace shared responsibility and culture to foster continuous learning, collective decision, and action (Comfort, 2007;

Kapucu, Berman, & Wang, 2008) to address the challenges and complexities of network governance. Each stakeholder in the collaborative environment plays an important role in facilitating effective governance for urban infrastructure resilience (NAS, 2012).

Organizational and cross-sector networks within governance structures represent the simultaneous actions and interactions of multiple actors with different knowledge, resource, and functional capabilities. The network perspective holds that an urban infrastructure system is defined by the regular patterns of relations among its actors. Networks thereby offer a holistic approach to the study of actors (stakeholders) in urban infrastructure systems, whereby the structure of the network can influence individual actors' attitudes and encourage or constrain behavior through the allocation of resources and knowledge sharing (Berkman et al., 2000).

Network governance offers a means to overcome the structural challenges of less flexible, more bureaucratic, and control-oriented siloed administrative structures (Ansell & Gash, 2008; Kapucu, 2008; Kapucu & Hu, 2020). Network governance thereby can contribute to a more effective resilience policy implementation and strengthen collective effort outcomes (Provan & Kenis, 2008). Network governance can strengthen urban communities by helping organizations share knowledge, learn from others, and build capacity for collective action needed to enhance urban infrastructure resilience to disasters (Andrew, 2009; Isett et al., 2011; Kapucu, Garayev, & Wang, 2013). Regular and frequent interactions among stakeholders and community members can generate new ideas and solutions. The following section elaborates on the key elements of the network governance perspective and examines urban infrastructure resilience to disasters.

### *Network Governance Structures*

The way networks are governed influences their performance. The nature of tasks may require participating organizations to work interdependently with other organizations, which makes it imperative to have high-level coordination skills at the network level (Bryson, Crosby, & Stone, 2006; Provan & Kenis, 2008). The governance structure within the collaboration will influence the overall effectiveness of the network (Ansell & Gash, 2008, 2017; Popp, Milward, MacKean, Casebeer, & Lindstrom, 2014). Provan and Kenis (2008) summarized three forms of governance structures: "shared governance" in which all network members govern the networks and make collective decisions; "lead organization-governed networks" in which a lead organization in the network coordinates network-level decision-making and essential activities; and "network administrative organization (NAO)" model in which an external organization is in charge of coordinating network-level decisions and activities (Provan & Kenis, 2008, p. 234-236).

The functioning of networks depends on the alignment of a governance structure with the attributes and context of urban infrastructure resilience. For instance, a shared governance form does not function well in a situation where the goal consensus among organizations is low or when the size of the network is large (Provan & Kenis, 2008). In practice, network governance is not static and needs to adapt as the network of organizations grows and evolves. The multilevel nature of urban infrastructure systems demands a hybrid network governance structure. Multiple organizations may take the lead in different functional areas and form a polycentric governance structure. Such a hybrid mode can also blend the shared governance form with lead-organization governance (Hu & Kapucu, 2020). A well-designed governance structure not only encourages the participation of network actors, but also sustains their engagement in network activities.

*Proposition 1: The form of network governance structures will influence the connectedness of multi-level, multi-sector, and interdependent urban infrastructure systems.*

***Organizational Capacity***

A wide range of public, nonprofit, and private organizations embedded within the whole community of urban infrastructure systems contribute to the resilience of the system. Community capacity—the interaction of community capital, external factors, and organizational capacity (Chaskin, 2001)—provides the underlying structure to support network governance of urban infrastructure systems. The term "community," in a broad sense, encompasses "the full range of potential communities—including local neighborhoods, family units, cities, counties, regions, or other entities" (NAS, 2012, p. vii). Similarly, FEMA's whole community approach highlights the diversity of community with variations in place, interest, belief, and circumstance (Edwards, 2013; FEMA, 2011). Communities need to adapt to external factors, including political, environmental, and social factors, and utilize their internal community capital, including diversity, social, political, and economic capital (Kapucu et al., 2022). This paper adopts this broad definition of communities and examines the role of organizational capacity in building and enhancing resilience of urban infrastructure.

Organizational capacity can be defined as the ability of an organization "to achieve its mission effectively and sustain itself over the long term" (Pact, 2010, p. xi). Organizational capacity includes experience, human resources, knowledge, and resources that enable an organization to fulfill its goals. Systems research elucidates the structural and organizational capacity of systems to perform basic and fundamental functions (Alter & Hage, 1993). However, relatively little is known about the influence of organizational capacity on network governance of urban infrastructure systems resilience. Organizational characteristics will contribute to the

overall capacity of an organization, and subsequently, their ability to adapt and remain resilient during extreme events (Carley & Harrald, 1997; Comfort, Boin, & Demchak, 2010; Gillespie & Colignon, 1993). In addition to organizational capacities, networks of stakeholders can create partnership synergy (Varda, 2011) and develop effective collaborative governance strategies that will contribute to and strengthen urban infrastructure resilience.

This paper emphasizes how variations in organizational characteristics and capacities influence their participation and roles in multi-level, multi-sector network governance in building urban infrastructure resilience. Whether organizations have enough human resources, sufficient financial resources, and knowledge influences their engagement with the collaborative effort to build resilient urban infrastructure systems. The effective functioning of network governance depends on the alignment of a governance structure with the attributes and capacities of the network actors.

*Proposition 2: Organizational capacity will influence stakeholders' participation in multi-level, multi-sector, and interdependent urban infrastructure systems.*

***Collaborative Leadership***

Collaborative leadership is especially critical when dealing with complex problems—such as widespread power outages after a hurricane landfall—involving multiple stakeholders and communities (Kapucu & Hu, 2014; Van Wart & Kapucu, 2011; Weick & Sutcliffe, 2007). Collaborative leadership, as a critical factor of network governance, engages in behaviors that facilitate interactions across organizational boundaries, mobilize resources, and coordinate efforts of network members to solve problems (McGuire & Silvia, 2009). Leaders at different levels of government and communities must be firm believers in participatory and inclusive decision-making and need to engage in managerial networking with a wide range of stakeholder

groups. We focus on collaborative leadership as a core element of network governance in this paper because it plays a crucial role in spanning organizational boundaries and integrating resources for effective results (Molenveld, Verhoest, Voets, & Steen, 2019; Ysa et al., 2014). Moreover, collaborative leadership is crucial for integrating and mobilizing resources, building support and consensus, establishing governing rules, and managing potential conflicts among network participants (Van Wart & Kapucu, 2011). To achieve these intended outcomes, leadership competencies are required for the effective facilitation of collaborations to enhance urban infrastructure resilience (Kapucu, 2008; NAS, 2012; Van Wart, & Kapucu, 2011). Leaders in individual organizations need to rely on their networks for knowledge and resources necessary to build strong communities. Network-based decisions and agreements are founded on consensus, owing to participating administrator and professionals as partners (Agranoff, 2006, 2007; Boin, 't Hart, Stern, & Sundelius, 2005; Kapucu & Van Wart, 2008).

This paper emphasizes the role of collaborative leadership in organizational engagement in urban infrastructure resilience networks. Within multi-level, multi-sector urban infrastructure resilience networks, leaders frequently interact, communicate, and coordinate with external partners and diverse groups of stakeholders to make collective decisions. Collaborative leadership will influence the extent to which partner organizations are involved in the governance of multi-level, multi-sector networks. Network governance as a collaborative mechanism necessitates collaborative leadership involving diverse stakeholders from multiple sectors with different resources, knowledge, background, culture, and expertise needed to achieve a higher network performance (Cannon-Bowers & Salas, 2001; Comfort 1999, 2019). *Proposition 3: Collaborative leadership will help organizations span institutional boundaries, mobilize resources, facilitate knowledge sharing, and consequently, contribute to network*

*resilience.*

***Network Resilience***

Network resilience is the capacity of a network to respond to external disturbances and sustain connectedness and functioning despite internal and external disruption (Kapucu & Hu, 2020). Maintaining a certain level of redundancy of nodes and connections is necessary. Furthermore, the diversity of ties and nodes and hybrid governance structures contribute to the resilience of a network (Chester et al., 2020; Ferrari, 2020). Existing research suggests the characteristics of networks such as density of ties, centralization, and subgroup connectivity jointly influence the resilience of networks in ecological systems (Bodin & Crona, 2009). However, few studies have examined what structural characteristics of interorganizational networks can achieve efficiency while maintaining stability in the context of urban infrastructure resilience (Li et al., 2019). Moreover, fewer studies have examined interorganizational networks working within and across different infrastructure systems (Li et al., 2019). Hence, we hope to help fill this gap by examining how networks within urban governance systems can respond to external shocks like disasters and maintain their connectedness and functions, and in doing so, contribute to urban infrastructure resilience (Kapucu & Hu, 2020).

Network resilience can be examined by the capacity to protect individual nodes from being overloaded and the capacity to remain connected when link failures occur in urban infrastructure networks (Dodds, Watts, & Sabel, 2003). This paper examines the inherently interdependent and embedded relationships within and across the networks of infrastructure systems and stakeholder groups that are assumed to contribute to resilience. It is necessary to establish and maintain connectedness within and across groups of stakeholders working in different but interdependent infrastructure systems to ensure timely communication and effective

coordination among organizations, when disruption in individual organizations or in the links (not communicating or coordinating with an infrastructure operator) occurs. In this paper, we assume network resilience is a function of organizational capacity, collaborative leadership, and uninterrupted interactions among involved organizations.

*Proposition 4: Collaborative leadership, organizational capacity, and network governance structures will contribute to the network resilience of urban infrastructure systems, measured by the robustness of ties and connectivity of network actors*.

This study addresses urban infrastructure resilience, particularly the process by which stakeholders engage in knowledge and resource sharing, planning and policy development, governing interdependent infrastructure systems, which are critical for network governance (Aldrich, 2010, 2012; Comfort et al., 2010; Corbacioglu & Kapucu, 2006; Gazley, 2013). The following section illustrates the importance of governance structures, organizational capacity, and collaborative leadership during the Texas Winter Storm of 2021.

## Urban Infrastructure Failure during Texas Winter Storm in 2021

We use the Texas Winter Storm in 2021 as an example to demonstrate the failure of interdependent urban infrastructure systems and limited application of network approaches and leadership failure. Texas has its own independent power grid that is separate from the U.S. eastern and western power grids. Voters in the state determines who is responsible overseeing the power system in the state (Cai, Douglas, Ferman, 2022; Machemer, 2021). The U.S. Energy Information Administration (EIA) (2021) estimates about 50% of Texas is powered by natural gas, 20% by coal, another 20% by wind and solar, and 10% by nuclear energy sources. The case demonstrated how failure in an element of the system caused by extreme weather conditions can

trigger cascading failure of other elements of the system. During February 13-17, 2021, several states were impacted by severe Winter Storm Uri, which was caused by cold air from the North Pole. The arctic blast from Uri spread from the Pacific Northwest to the central U.S. (Machemer, 2021). Winter Storm Uri caused the largest blackouts in US history and interrupted water, heat, and electric services to millions of people (Machemer, 2021). Texas was the most impacted state with the failure of grid operations that left millions of citizens without power and under boil water advisories (Machemer, 2021). Over 150 people were killed either directly or indirectly by the storm (Gabbatiss & McSweeney, 2021). Texas's independent grid system failed due to the impact of extreme cold weather and as a result, could not provide the much-needed power to millions of Texans (Ayres, 2021). The massive electricity generation failure caused a substantial impact on lifelines that rely on electricity like drinking water, food, heating and cooling, and medical services (Busby et al., 2021).

The winter storm caused the collapse of more than 350 generators, led to the blockage of natural gas pipelines by ice, and caused piles of coal to freeze (Machemer, 2021). In addition, frozen wind turbines and solar power panels, and inadequately prepared natural gas equipment for winter were identified as primary reasons for the failure of the interdependent power system. The blackouts cost approximately $200 billion and are considered the costliest disaster in Texas history (Ferman, 2021). Controlled outage was implemented by the Electric Reliability Council of Texas (ERCOT) to prevent statewide complete weeks-long power outage (Willey, 2021). The storm and the subsequent power outages caused substantial food and water shortages, infrastructure damage, such as the destruction of fire hydrants and plumbing in commercial and residential buildings, damage to the environment, such as increased pollution, and negative impacts on COVID-19 response.

The power plant was listed at the bottom of the critical infrastructure list in the state emergency management document (Willey, 2021). The companies accountable apologized and acknowledged their responsibility to provide better services and establish better systems (Willey, 2021). The Texas Division of Emergency Management (TDEM) failed to provide updates, and the Governor of Texas, Greg Abbott and TDEM officials encouraged people to search for resources on social media or Google. The Texas Legislature demanded regulators demand from power companies improve preparation to extreme weather conditions but did not ask Texas Railroad Commission, regulates the gas sector, to increase standards (Cai et al., 2022).

The governor made a disaster declaration on February 12 and mobilized government departments including the national guard for snow removal and assistance to motorists stranded on the highways. The governor also requested a federal emergency declaration the following day (Office of the Texas Governor, 2021). On February 14, 2021, President Biden declared a state of emergency and authorized the Department of Homeland Security and FEMA to deploy resources including generators and blankets and provide disaster assistance throughout Texas (Gabbatiss & McSweeney, 2021; Wermund, 2021; White House, 2021). The statewide impact of the winter storm made it very difficult for local governments to help one another.

Many residents throughout the state lost communication with family and friends. County Emergency Operations Centers (EOCs) checked on people as much as they could and provided supplies, such as water, food, and fuel (Gillespie County, 2021). In addition, EOCs checked shelters to make sure they could provide essential items for the people who preferred to stay in the shelters organized and operated by several counties (Gillespie County, 2021). Because of the power outage, communication, radio use, as well as 911 dispatches were incredibly challenging. Furthermore, critical infrastructures were severely damaged during the winter storm, problems

with utilities and roadways made delivery of essential needs almost impossible, and many of the major stores did not have enough supplies (Gillespie County, 2021).

The Texas winter storm crisis demonstrated the vulnerability of interdependent urban infrastructure to external shocks. It is a major case of catastrophic failure and lack of resilience of the urban infrastructure system when faced with the unexpected. The Texas Winter Storm case illustrates the importance of governance structures, organizational capacity, and collaborative leadership in enhancing network resilience of urban infrastructure systems when tested by a major external shock.

**Network Governance Structures**. Despite the warning of potential winter failure from the U.S. Federal Energy Regulatory Commission on February 1-5, 2011, the State of Texas did not take the necessary steps to develop preparedness plans and policies to address this concern (Federal Energy Regulatory Commission (FERC), 2011). Moreover, the After-Action Report (AAR) from the City of Austin (2021) notes that there were significant gaps between the state government, elected officials, and the response operations carried out by community-based organizations in terms of implementation and coordination during the Texas Winter Storm. In short, it is evident that the governance structure in place when the storm hit did not effectively connect relevant sectors and organizations. The lack of proper governance structure discouraged the participation of several key stakeholder groups. Therefore, one of the recommendations in the AAR is to revise disaster planning documents to include "additional non-profits, the private sector, and other relevant community-based service delivery organizations" (City of Austin, 2021).

**Organizational Capacity**. The Texas Winter Storm underscores the importance of organizational capacity. For example, the AAR notes that there were significant staff and

volunteer shortages that exacerbated the damage caused by the storm. Specifically, the AAR states “city and county departments do not have adequate staffing models for multiple-response operations. Staff and volunteer shortages hindered operations. Support agencies could not provide volunteers due to COVID-19” (City of Austin, 2021). Without organizational capacity, it will be difficult to involve stakeholders from different sectors to help improve urban infrastructure resilience.

**Collaborative Leadership**. The Texas Winter Storm is a good example of the importance of collaborative leadership during emergencies. Below are examples illustrating the lack of collaborative leadership. Tim Boyd, Colorado City mayor posted the following on his social media page according to Brito (2021):

> Only the strong will survive and the weak will [perish.] … No one owes you [or] your family anything; nor is it the local government's responsibility to support you during trying times like this! … Sink or swim it's your choice! The City and County, along with power providers or any other service owes you NOTHING! I'm sick and tired of people looking for a damn handout.

In addition, Senator Ted Cruz travelled to Cancun leaving disaster-impacted people in the state behind (Goldmacher & Fandos, 2021). In short, there was no apparent collaborative effort among Texas leaders at the state, city, and county levels as well as private sector leaders to present a united response strategy to deal with the challenges created by the winter storm. The absence of collaborative leadership in this case made it difficult to mobilize resources, share knowledge, and ultimately contribute to network resilience during the response phase of the Texas Winter Storm. In summary, the Texas Winter Storm case emphasizes the importance of

governance structures, organizational capacity, and collaborative leadership in enhancing the network resilience of urban infrastructure systems.

## Discussion and Conclusion

It is necessary to establish resilient systems that can function under severe threats of hazards, which will help stabilize infrastructure functions, minimize threats to health and public safety, and restore and recover critical infrastructure system functions in a reasonable amount of time. The restoration of the critical infrastructure after severe weather events requires coordination and engagement of core stakeholders. This paper focuses on the role of governance structure, collaborative leadership, and organizational capacity in urban infrastructure resilience networks. Governance structures can contribute to a more effective resilience policy implementation and strengthen collective effort outcomes. A wide range of public, nonprofit, and private sector organizations embedded within the whole community of urban infrastructure systems could have made better decisions despite the infrastructure challenges. Network resilience of participating stakeholders for urban infrastructure systems with a specific focus on electric power, water (wastewater), transportation, and telecommunication have the capacity to respond to external disruptions and sustain connectedness and functioning.

Within multi-level, multi-sector urban infrastructure resilience networks, leaders frequently interact with external partners and diverse groups of stakeholders to make collective decisions. Collaborative leadership will influence the extent to which partner organizations are involved in the governance of multi-level, multi-sector networks.

In the face of impending disasters, it is important that communities build infrastructures with the adaptive capacity to respond to and recover from disasters. Building and enhancing

urban infrastructure resilience require the engagement of stakeholders within a system of embedded relationships in communities. However, systematic theoretical work and empirical research remain limited in studying the interactions, interdependencies, and connectedness among stakeholders in urban areas on infrastructure resilience.

This conceptual paper can contribute to network governance within the field of disaster management by drawing on an institutional approach to the governance of community resources and network theories on governing interdependent urban infrastructure systems. We urge researchers to consider applying the key elements of network governance—organizational capacity, collaborative leadership, governance structures, and network resilience—to interdependent urban infrastructures, such as water (wastewater), electric power, transportation, and telecommunication. In addition, future studies may develop network-level resilience metrics to assess the resourcefulness, interdependency, rapidity, and adaptability of urban infrastructure systems. If we can successfully accomplish these two research goals, we will be able to develop network governance strategies based on partnerships, stakeholder engagement, and inclusive decision making to promote urban infrastructure resilience policies and practices. To conclude, we outline a future research agenda on urban infrastructure resilience by offering some important questions. First, how can the resilience of interdependent urban infrastructure systems be enhanced through multi-level and multi-sector stakeholder collaboration and mobilization of community resources? Second, how can governance structures influence the connectedness of multi-level, multi-sector, interdependent urban infrastructure systems? Third, how can organizational capacity influence stakeholders' participation in multi-level, multi-sector, interdependent urban infrastructure systems? Fourth, how can collaborative leadership help organizations span institutional boundaries, mobilize resources, facilitate knowledge sharing, and

consequently, contribute to network resilience? Fifth, how can collaborative leadership, organizational capacity, and governance structures contribute to the robustness and connectivity of urban infrastructure systems? Answering these questions, empirically, will undoubtedly help to further illuminate and advance our understanding of how to build urban infrastructure resilience through network governance.

This study has some limitations. This study is exploratory and conceptual. As a result, the goal is not to test the propositions. We used a recent disaster in Texas to contextualize the discussion and illustrate the need for network governance in enhancing urban infrastructure resilience. Empirical testing of the propositions will be our future work. We also need to develop more specific measures for several key components of network governance, such as collaborative leadership and governance structures. We selected network governance structure, collaborative leadership, and network resilience as essential elements of network governance based on the review of the existing literature. Further research can expand on these core elements of network governance.

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