

RESEARCH ARTICLE

Infrastructure governance for the Anthropocene

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Transitioning infrastructure governance for accelerating, increasingly uncertain, and increasingly complex environments is paramount for ensuring that critical and basic services are met during times of stability and instability. Yet the bureaucratic structures that dominate infrastructure organizations and their capacity to respond to increasing complexity remain poorly understood. To change infrastructure governance, it is critical to understand current conditions, the barriers to change, and the strategies needed to shift priorities and leadership strategy. The emergence of modern infrastructure bureaucratic and organizational structure is first explored. The need to rethink infrastructure as knowledge enterprises capable of making sense of changing conditions, and not simply as basic service providers, is discussed. Next, transformation of infrastructure governance is presented as both a challenge of organizational change as identity and power and leadership capacity to shift between stable and unstable conditions. Infrastructure bureaucracies should create capabilities to shift between periods of stability and instability, emphasizing flexibility where ad hoc teams are given power to make sense of changing conditions and steer the organization appropriately. Additionally, several critical factors must be addressed within organizational power structures, identities, and processes to facilitate change. Allowing infrastructure governance to persist in its current form is likely increasingly problematic for the future and may result in an increasing inability to maintain relevance.

Keywords: Infrastructure, Anthropocene, Governance, Resilience, Complexity

1. Introduction

Physical infrastructure systems today and the institutions that manage them are facing growing challenges that raise serious questions about their viability in the Anthropocene. Approaches to designing, maintaining, and managing infrastructure systems have remained stubbornly stable for over a century. Both the physical systems and the organizational systems that build and manage them are obdurate, resistant to change (Hommels, 2005). They have been remarkably successful at delivering reliable and affordable critical services—such as power, water, and transportation—and in doing so driving growth and economic stability and improving well-being. These systems may be victims of their own success. They have become so mundane that they appear taken for granted in the developed world and often viewed as the engineer's domain (La Porte, 1996; Coutard, 2002): We might expect that the delivery of reliable and affordable critical services will continue without question, despite operating environments that are

becoming significantly more complex. At the dawn of the Anthropocene, evidence is emerging that we are beginning to experience profound shifts in Earth and human systems (Steffen et al., 2015). Climate is rapidly destabilizing, cybertechnologies are rapidly accelerating, disruptive technologies are changing how we consume services, social and political spectra appear increasingly polarized, and infrastructure are in many ways at the center of these trends (Chester and Allenby, 2019a). Infrastructure designed for the past may be problematic for an accelerating, increasingly uncertain, and increasingly complex future. Yet there remains limited insight into how infrastructure are governed, whether these governance models are appropriate for the future, and how governance processes emphasize technologies that may or may not be appropriate for the future.

Changes in the environments in which infrastructure operate, and in infrastructure themselves, will be troublesome for those who manage the systems and need to ensure their ability to meet public needs into the future. In Simon's (1996) *Sciences of the Artificial*, a distinction is made between *internal* and *external* environments in his design of an intellectual structure to characterize natural and artificial phenomena. The internal system is an organization capable of attaining goals within some range of environments, while the external system determines the conditions for goal attainment. Infrastructure are designed to deliver services within a somewhat narrow range of environmental conditions but at the same time

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contribute to environmental change thereby generating vulnerability (e.g., automobility and air quality, energy and carbon, flood management and unending complexity that can't be controlled). They mediate human–environment interactions in ways and scales that are increasingly difficult to make sense of (Chester et al., 2019). This context appears remarkably different than decades ago when our infrastructure systems were designed. A rapidly changing world appears at odds with infrastructure design principles that emphasize consistency and systems that are instantiated for decades with limited flexibility and agility to transition (Hommels, 2005; Sovacool et al., 2018).

Although there is a growing body of work that examines the challenges associated with agile and flexible infrastructure from a physical design perspective, little work has been done to understand how the structure, functioning, values, rules, norms, and processes of the *institutions that manage infrastructure* keep infrastructure services obdurate or create the conditions for transformative change. Indeed, a large literature describes the forces that created modern infrastructure systems and how these sociotechnical regimes have changed over time (van der Brugge et al., 2005; Geels et al., 2016; Desai and Armanios, 2018). This work has shown that a complex governance system, of multiple state and private actors, scales, arrangements, and modes of governing, is emerging to address the variety of ownership arrangements, financial constraints, and sociopolitical pressures exerted on modern infrastructure development (Leach et al., 2010; Goldthau, 2014; O'Brien and Pike, 2015). But a systemic review of the *bureaucratic structures* that persist and the rules, values, norms, and practices that define their operation at the intraorganizational level is not apparent, yet is critical. In this article, we endeavor to describe the emergence of the divisional bureaucratic organizational structures of many contemporary U.S. infrastructure, how this organizational form emerged, and what it means to change infrastructure governance for the future. When considering change, we evaluate both organizational leadership and identity to understand across hierarchies the conditions of transformation for both stable and unstable environments. We conclude by focusing on the processes of transition toward improving sensemaking of the environment, models of governance that may be more appropriate for an increasingly complex environment, and key factors that support public service organization mission change. We view the whole of the discussion as a treatise on describing how infrastructure governance should transition for the future.

Going forward, we use a lexicon to describe governance concepts that is rooted in governance and sustainability transitions theory (Muñoz-Erickson et al., 2016). *Governance* is a process involving collective action for resource allocation and use across multiple civic and private actors and not just the state (Kooiman, 1993). Government is to governance as structure is to function, and transitions are the processes that lead to fundamental changes in structure, culture, and practices as they relate to a particular goal (Jordan, 2008; Loorbach, 2010; Muñoz-Erickson et al., 2016). Following Ostrom (2008), we discuss *institutions* as

the rules and norms that humans use when interacting within repetitive and structured situations. Governance actions are shaped by institutions. When it comes to organizations and their structures, the term *bureaucracy* describes the formalization of behavior to achieve coordination, including division of labor, specialization, formalization of behavior, hierarchy of authority, chain of command, regulated communication, and standardization of work processes and of skills (Mintzberg, 1979; Ferreira and Serpa, 2019). Whether public or privately owned, an organization is bureaucratic if its behavior is standardized (predictable) and specialized (Mintzberg, 1981).

2. Emergence of the infrastructure divisional bureaucracy

Infrastructure and the institutions that design, manage, and maintain them (as sociotechnical systems) emerge due to a diversity of pressures, and bureaucratic structures are a response to the goals, technologies, and cultural preferences of past conditions. Just as physical infrastructure are resistant to change, so are their social and organizational components. Before analyzing the bureaucratic structures that guide infrastructure today, it is important to recognize these pressures. They include the allocation of financial risk (Brealey et al., 2000), technological emphasis (Kaminsky, 2018), the ability to scale (Edwards et al., 2007), certainty of service delivery (La Porte, 1996), the need to consolidate (Edwards et al., 2007), and the formal and informal rules for operating systems (Ausubel and Herman, 1988). Graham and Marvin (2001) frame infrastructure as networking activities—water, power, transport, communications, and so on—and their governance as the management of flows across scales. There are myriad pressures that have created the manifestations of infrastructure as sociotechnical systems, and recognizing these conditions is critical for shifting the goals and purposes of large engineered systems (Osborne and Brown, 2005; Sovacool et al., 2018). However, understanding the bureaucratic structures and the embedded knowledge and assumptions that drive (and possibly constrain) infrastructure today is a critical step toward ensuring that they transition to meet our future needs.

The scant evidence suggests that at the end of the 20th century, the organizations that manage U.S. infrastructure were often structured as a divisional bureaucracy, where divisions reflect departments with focused expertise (Friedlander, 1995a, 1995b; Friedlander and Initiatives, 1996). Transportation agencies may have divisions specialized on pavement construction and rehabilitation, traffic operations, inspections, and environmental planning (U.S. Department of Transportation, 2017; Arizona Department of Transportation, 2019; Caltrans, 2020; Georgia Department of Transportation, 2020; Phoenix, 2020). A water distribution agency may have divisions focused on system design and construction, production, and distribution (Central Arizona Project-AZ, 2010; Environmental Protection Agency, 2020; Long Beach, 2020; U.S. Geological Survey, 2020). Power providers often structure themselves according to assets or functions, for example, asset

management, field services, and regulatory management (Horan et al., 2018). Across governmental and jurisdictional scales, the divisional bureaucracy is present (and worthy of particular focus) and, in addition to construction, maintenance, and operational functions, also often includes administrative functions such as communications and outreach. This organizational structure appears to have persisted for the entirety of modern infrastructure systems (Chandler, 1977; Friedlander, 1995b; Friedlander and Initiatives, 1996). As a staple organizational structure, the divisional bureaucracy has undoubtedly delivered tremendous value, but as the challenges around infrastructure in a rapidly changing environment grow, serious questions remain as to whether this form of management is able to handle substantive change and deliver the public service values needed into the future. How did the divisional bureaucracy emerge as a dominant management structure of infrastructure organizations?

2.1. History of the divisional bureaucracy in infrastructure

The Industrial Revolution was a key turning point in the scale, scope, and rate of human activity and was associated with immense increases in power and speed enabled by a transition to largely coal-based energy sources (Beniger, 1989). Through the early 1800s, energy use was largely associated with human, animal, and wind power. But the use of coal in the early 1800s, first in ships, and later in manufacturing, contributed to an explosion in the material economy that far outpaced the capacity of the supply and demand landscape (at that time largely small firms) to manage (Beniger, 1989, p. 262). This rapid growth created for the first time in human history a sustained global demand for distribution and control systems including information processing, programming, and telecommunications (Beniger, 1989, p. 185). It led to a “crisis of control,” the need for new technologies, processes, and organizational structures that could manage the growing complexity and speed of change of commerce (Edwards, 2003).

Control mechanisms and information flows advanced rapidly to manage the increase in economic production. The rise of organizational hierarchies and associated bureaucracies in the 19th century was a direct response to information-handling demands. The American economy until then had been defined by small business with limited to no hierarchy that relied on communication through market mechanisms (Beniger, 1989, p. 262). Communication through the market for the first time became too slow, and as wholesalers increased in size, they adopted organizational structures (hierarchies and bureaucracies) that could match the market’s increasing speed. Bureaucracies flourished because they could yield lower costs, increase productivity, and increase profits relative to other market structures (Beniger, 1989).

America’s railroads were at the center of these technology and changing market trends, deploying technological and organizational innovations, that ultimately become a template for large organizations and other infrastructures. Railroads were the first major global

system to experience dramatic control problems as the U.S. manufacturing base exploded and population grew during the mid-1800s. The U.S. railroad system had in the early 1800s consisted of smaller carriers and by the middle of the century was experiencing rapid consolidation. At the end of the 19th century, U.S. railroad systems were the largest infrastructure (and business) organizations in the world, in terms of number of people employed, transactions handled, and capital used. In 1891, the Pennsylvania railroad employed 110,000 people, far more than the U.S. armed forces (39,492) and U.S. post office (95,440), which at the time was the largest government agency in terms of personnel (Chandler, 1977, pp. 204–205). The expanding size of the railroads necessitated pioneering in business administration to handle the complexity of their operations.

The consolidation of the railroads brought with it a need for organizational management across geographic and managerial scales (including financing), and two competing models emerged. The decentralized model saw geographic regions of a railway company self-managing, where top managers of the regions worked together to evaluate, coordinate, and allocate resources across the entire network (Chandler, 1977, pp. 185, 186). The centralized model used departments focused on functional areas such as traffic, transportation, and finance, making decisions across the entire organization and remaining independent. Financiers preferred the centralized model as it created fewer managers and thus administrative costs, had all managers in the same location easing communication, and allowed departments to operate autonomously (Chandler, 1977, p. 185). By the end of the 19th century, virtually all railroad systems were using a centralized system. As the railroads consolidated, their size increased, resulting in the need for additional layers of management (hence the middle manager). The president, vice presidents, and board of directors in these centralized organizations were thus positioned to steer strategic goals. The divisional bureaucracy was born where middle managers controlled operations and top managers allocated resources.

By the early 20th century, the railroads had achieved control over competition. They had consolidated to control large geographic regions and had begun sharing rates with the Interstate Commerce Commission which then handled negotiations between the railroads and shippers. Little competitive pressure meant that there was less need for long-term planning and coordination of existing activities (Chandler, 1977, p. 186). Railroads became the administrative model that other natural monopolies adopted: They were highly visible and even low-level managers carried significant status in their communities (Chandler, 1977, p. 188). Not surprisingly then the railroad was the largest infrastructure in the 19th century and deployed innovations across technologies and organization structure. Organizational innovations included complex administrative structures with multilayered hierarchies and a large degree of functional specialization (Edwards, 2003).

The innovations necessary for the railroad triggered the development of other critical services including

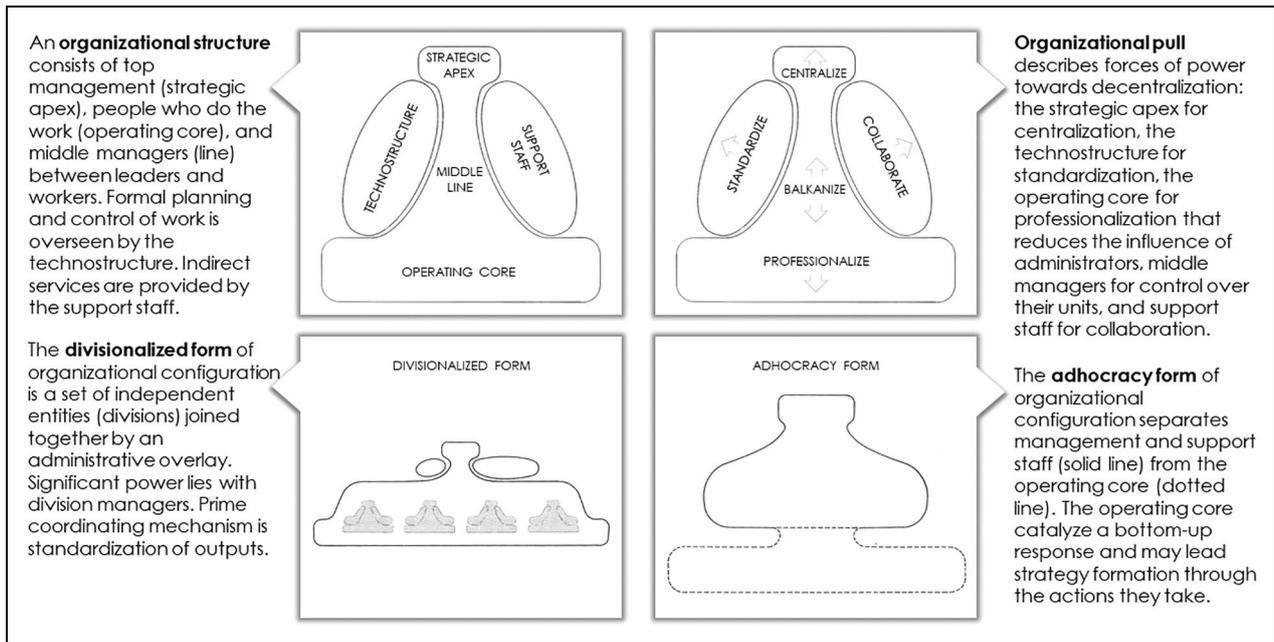


Figure 1. Organizational components, pulls, and forms. Four organizational figures are shown: the top row describing structure and tensions and the bottom row showing the divisionalized and adhocracy structural forms. Vertical (delegating decision making down the chain of authority) and horizontal (shifting of power to nonmanagers) dimensions represent control schema. Adapted from Mintzberg (1979) and reprinted with permission of Pearson Education, Inc., New York City, NY. DOI: <https://doi.org/10.1525/elementa.2020.078.f1>

steamships, urban transit, and communications (namely, the postal service, telegraph, and telephone). Like the railroad, many of these industries operated without competition, and the beginning of the 20th century saw an explosion of public enterprises that were not regulated by market mechanisms, including lighting, power, and heat in cities (Chandler, 1977, p. 204). These utilities were carried out by a single privately owned enterprise that had no competition and worked with localities to provide services. By the late 1800s, railroad managers had become more professional and were systematically disseminating information about their innovative processes and procedures, including how their use resulted in efficiency gains (Chandler, 1977, pp. 117–121). Nascent public enterprises adopted the dominant divisional bureaucracy model, with its standardized processes, of the much larger railroads, creating the institutional foundations and specialized structures that are still in use today.

The hierarchy associated with the divisional bureaucratic form of management itself became a source of permanence, power, and continued growth (Chandler, 1977, p. 8). The enterprises that had existed prior to managerial hierarchies were short-lived. They were based on partnerships between individuals who were easily dissolved, for example, in the event of retirement or death, or if one businessperson simply decided they'd rather work with someone else. The hierarchies that defined divisional bureaucracies were intrinsically persistent. When a manager left, they were easily replaced by someone with appropriate expertise. The organization's mission and goals persisted despite turnover of managers (Chandler, 1977, p. 8).

2.2. Divisional bureaucracies for standardized products

It is helpful to understand the benefits and trade-offs of divisional bureaucracies based on how they are structured. Organizational design can be classified into several general schema to structure the basic components of organizations: strategic apex (top management), operating core (persons responsible for basic work), middle line (intermediate managers between chief executive and workers), technostructure (personnel who design internal systems for planning and controls), and support staff (personnel who provide indirect services; **Figure 1**; Mintzberg, 1981). The divisional organization (one such schema) is less an integrated organization and more independent entities (departments) under a loose administration. Each division is treated as an independent entity with its own goals that get translated down the line into subgoals and standardization of work (bureaucratization of structure). Although the divisional organization emerges to improve adaptability—adding or subtracting divisions in response to new conditions—evidence suggests that the organizational structure discourages risk-taking and innovation (standardized and measurable performance goals work against innovation; Mintzberg, 1981). It creates hierarchical barriers that make it difficult for innovative ideas at the bottom to reach higher levels of strategic management (Wilson, 1989). Next, the division-specific performance goals can work against cross-division problem-solving. The recruiting of employees into a division and building their specialization within the division create cultural fortresses (Wilson, 1989). And finally, divisional management structures rely on

performance-based goals that are measurable, often economic in nature, and are not conducive to social goals which may be relevant to the broader public that relies on the institution's services (Mintzberg, 1981).

Framing infrastructure *centralization* in terms of how the organization delegates power, instead of the configuration of assets and how they interact, becomes a valuable frame for understanding the capability of different infrastructure governance forms. Centralization and decentralization are often discussed in terms of network typology when it comes to infrastructure (Hines et al., 2015). Yet network typology does not sufficiently address power relationships, who controls what, and why that matters as it relates to organization structure. Centralization and decentralization are rooted in power dynamics and the delegation of authority (Mintzberg, 1979). Centralization is the aggregating of power at a single point in the organization, while decentralization is the disbursement of power down the chain of authority (*vertical*) or out from the chain of authority to nonmanagers (*horizontal*). Centralizing power may be necessary for coordination, but for many large organizations, simply bringing all relevant information to a central authority is not feasible. Decentralization allows the organization to respond quickly (by avoiding the transmission of information to the center) and is a stimulus for motivation (providing creative space). Vertical decentralization disperses formal power down a chain, from a strategic apex to the middle managers. Horizontal decentralizations disperse decisional power, so that nonmanagers are granted control over decision making (Mintzberg, 1979). We discuss these relationships as we describe the alternatives to the divisional management structure.

The characteristics that define the divisional management structure that is the core arrangement of infrastructure organizations appear inimical to the emerging challenges of the Anthropocene, that is, growing complexity and uncertainty and cross-disciplinary efforts to address these challenges through agile and flexible approaches. Serious questions remain as to whether our infrastructure institutions are prepared to change to meet these emerging challenges. We do not believe that an entire restructuring of infrastructure institutions is necessarily needed. Instead, an opening up of how we manage infrastructure is needed that considers both stable and unstable conditions, and an examination of why we allow organizations to focus on performance goals that largely reflect those of the last century, that is, the continued and uninterrupted delivery of services using largely centralized and rigid systems, with what appears to be limited capability of adapting to the accelerating challenges and complexity of the Anthropocene. We now turn to examine infrastructure management within this new landscape, and the paths necessary to ensure that public and critical services are met into the future.

3. Rethinking infrastructure as knowledge organizations

If the bureaucratic forms that define infrastructure organizations are insufficient for the future, then what should

we do? Approaching increasingly complex systems and environments necessitates new processes that are different from those that dominate infrastructure today. At the macro it requires embracing acceleration and uncertainty where assumptions change based on developments in society, there are multiple accountabilities and the need to balance this power, value is created not as profit but as social welfare, and there is richness of diversity (in people, structure, activities, culture, and processes) where any particular person cannot fully understand systemic interactions and emergent characteristics (Karp and Helgo, 2008). So what does this mean for institutions and how they're organized? To answer this question, we can look at how successful institutions respond to increasing complexity. In doing so, we can see that fundamentally these institutions create the capacity to generate knowledge about how conditions are changing by shifting power structures to enable those in the organization that are in the best position to sense change and creating capacities to experiment since certainty about the future is diminished and therefore deterministic recommendations become more problematic.

Prior to assessing institutional change, it is important to ask the basic question of what would motivate infrastructure institutions to change. Infrastructure institutions have largely since their inception (generally only 50–100 years ago in the United States) operated in environments of stability where environmental variables (social, political, financial, climate, and technologies) have been relatively stable, and as such, demand has been stable or at least reasonably predictable (Chester and Allenby, 2019b). Both internal and external forces are likely to upend this paradigm (Simon, 1996). Infrastructure institutions will most likely have to change out of necessity as they find themselves increasingly unable to match the accelerating change happening in the environment around them and in the demands they provide.

The infrastructure organization in the Anthropocene will need to reorganize into a *knowledge enterprise* whose complexity matches that of the environment and knowledge accumulates, is shared, and is used at low cost. Such an organization will need to be capable of anticipating wicked problems (problems that are resistant to a clear definition and agreed solution; Head and Alford, 2015) and, in doing so, will shift from knowledge creation and management for control to navigating the service through the complex environment. Infrastructure organizations are already knowledge organizations, with systems that structure the generation, validation, circulation, and use of knowledge (Miller and Muñoz-Erickson, 2018). However, the knowledge systems of current infrastructure organizations are narrow and specialized to match the expectations for technical standards and service delivery. Whereas these knowledge systems focus on managing for the efficient production and delivery of physical assets, in the Anthropocene, infrastructure organizations will need to adapt to produce and share knowledge differently (Boisot, 1998; Schneider, 2002; Uhl-Bien et al., 2007). The *Law of Requisite Complexity* says that to remain effective, a system must possess equal complexity to the environment in

which it must operate (McKelvey and Boisot, 2003; Uhl-Bien et al., 2007). Therefore, to remain effective and relevant, infrastructure organizations need to change their knowledge systems and enable intellectual assets through distributed intelligence rather than relying on upper management, focus on speed, and lead for adaptability, knowledge, and learning, instead of efficiency and control (Uhl-Bien et al., 2007; Uhl-Bien and Arena, 2018). In introducing change toward complexity, organizations will need to distribute information, interests, and power (Head and Alford, 2015). They will need to optimize the organization's capacity for learning, creativity, and adaptability (Uhl-Bien et al., 2007). We now describe what change means and how it can be incentivized.

4. Transforming infrastructure management

The insights from organizations that have embraced change in the context of rapidly changing environments or in the name of Anthropocene challenges do not often address the foundational questions of what change means to an organization. They instead tend to focus on business acumen and steering of employees toward new goals. For example, Lockwood and Papke (2017) describe how design thinking as a set of organizational attributes creates opportunities for innovation. When it comes to infrastructure, there remains a dearth of knowledge around what change means to an organization and why some organizations are able to embrace challenges like sustainability while others are not. Here, we explore what change means to public service organizations focusing on a literature base that describes communication and power structure effects in institutions.

4.1. Organizational change as identity and power

Leading change is about recognizing the nature of human beings and their reactions to changing structures, processes, routines, and outcomes. It is less about the structures and strategies themselves (Diefenbach, 2007). Organization change has been described as the renegotiation of shared meaning about what is valued, believed, and aimed for (Spencer-Matthews, 2001). Change starts with leaders and managers, who create the conditions for communication and renegotiation of roles. Whereas leaders view change as opportunities to renew the organization and sometimes advance their careers, middle managers and the operating core (those who do the basic work, as per Mintzberg, 1981) tend not to seek or welcome change (Karp and Helgø, 2008). Organizational change can happen only when a critical mass of people's own agenda overlap with that of leadership (Karp and Helgø, 2008). As such, organizational change is often described as a socially constructed reality where power relationships are negotiated (Grant et al., 2005). The primary challenge is facilitating a transition where people can associate their new identities and interests in the organization with the goals of leadership, and they do this through communication where they relate to one another and find meaning that is associated with the new goals (Stacey, 2007).

Change is wanted only when people see no other solution to the change (Diefenbach, 2007). Most people don't

openly resist change but instead learn to cope with it on a tactical and operational level, often bypassing it in their daily routines (Diefenbach, 2007; Karp and Helgø, 2008).

From a leadership perspective, change involves negotiating between being and not being in control, as the realignment of identities occurs (Streatfield, 2001). The ways of the organization in the status quo allow for plans, processes, and tools that allow for predictability in governing. But as change happens, interactions between people and the old structures occur in unpredictable ways as new identities are formed and leaders have limited control over this process. Furthermore, public agencies are generally formed around models of predictability to hedge risk, and in doing so, they resist chaos, complexity, and uncertainty (Karp and Helgø, 2008). The primary challenge for the future is restructuring organizations to be welcoming of continued change. Instead of leadership focused on control that seeks to perpetuate the status quo, in complex environments, leadership must instead loosen control and focus resources on forming identities to ensure that change is successful (Streatfield, 2001; Griffin, 2003; Stacey, 2007; Karp and Helgø, 2008). The loosening of control allows chaos to occur and removes barriers to reorganization, allowing for self-organization, self-governing, uncertainty, new ideas, sensemaking, and diversity to flourish, necessary catalysts of change (Karp and Helgø, 2008).

4.2. Leadership for complex adaptive systems

In the pursuit of organizational change in the name of adaptation, traditional approaches have tended to emphasize fixed boundaries, compartmentalized organizational responses, and simplified coordination and communication that have hampered efforts (Simon, 1962; Cilliers, 2001; Uhl-Bien et al., 2007). Infrastructure organizations must emphasize collective thinking and flexibility in viewpoints, toward adaptability that emphasizes the creation and capture of knowledge (Uhl-Bien et al., 2007). In managing knowledge production, managers should focus on enabling emergence and coordinating its context. They do this with three leadership functions: *administrative* (formal managerial roles to plan and coordinate activities), *adaptive* (adaptive, creative, and learning actions that emerge from interactions that drive complexity), and *enabling* (creates conditions for adaptive leadership and manages entanglement—dynamic relationships between formal top-down hierarchy and informal complex adaptive emergent forces—between administrative and adaptive functions). The formal bureaucracy cannot be disentangled from the complexity. At times, the bureaucracy (rationalized structure and coordination) needs to be emphasized (when the environment is stable) and at other times the complexity (when the environment is volatile). Enabling leadership is the management of adaptive and administrative emphasis.

In complex environments, administrative leadership is necessary for periods of stability but must exercise authority with consideration of the organization's need for creativity, learning, and adaptation (Uhl-Bien et al., 2007). Administrative leadership is the management of

bureaucratic function. It is necessary to ensure the structuring of tasks, planning, vision building, resource acquisition, crises management, and organizational strategy (Yukl, 1981; Mumford et al., 2008). As organizations seek to introduce agility in the face of growing complexity, administrative leadership will drive the allocation of resources within the organization and support planning and coordination. As such, how this aspect of the organization supports knowledge building is critical. Institutions that do not relax administrative control during times when strategic realignment is occurring or the environmental conditions are volatile are going to be less capable of adapting to change.

Adaptive leadership emerges in the movement to change priorities and goals and is a dynamic rather than a person (Bradbury and Lichtenstein, 2000; Drath, 2001; Lichtenstein et al., 2006). It emerges from the renegotiation of roles, goals, and ideas and results from asymmetry in authority or preferences. Authority-based asymmetry involves top-down hierarchies that seek change. Preference-based asymmetry describes how the clashing of incompatible ideas, knowledge, or technologies produces new knowledge, creative ideas, learning, or adaptation (Uhl-Bien et al., 2007). This innovation occurs when groups debating a particular approach give up the untenable aspects of their respective positions and focus on tenable aspects, or the creation of new ideas, to identify new approaches or thinking. As such, adaptive leadership is not the result of people but of a process of learning toward the creation of new insights or knowledge (i.e., emergence).

Enabling leadership encompasses the maneuvering of conditions to catalyze change, and middle managers are often in a prime position given their access to resources and their ability to steer production (Jaques, 1989; Osborn and Hunt, 2007; Uhl-Bien et al., 2007). Enabling leadership has two primary functions, to (1) manage the conditions in which adaptive leadership occurs and (2) move innovative knowledge and products of adaptive leadership through the organization (Uhl-Bien et al., 2007). In managing the conditions for adaptive leadership, (1) fostering interactions (facilitating the movement and interplay of information by creating the conditions for self-organizing to occur), (2) fostering interdependency (creating the pressure to act on information, particularly in situations where agents are receiving incompatible information and must adjust to elaborate their information), and (3) creating tension (an imperative to act and elaborate strategy and information, through stimuli such as pressures or challenges that are supported by resources for creativity) are fundamental.

4.3. Organizational strategies

In addition to leadership change, several strategies can be employed to increase the capacity of organizations to work within complex environments. A body of research characterizes how public service organizations should approach wicked problems (Head and Alford, 2015). We draw from this work to describe the competencies needed by public service organizations in navigating wicked problems and increasingly complex environments.

Thinking that results in greater room for discovering alternative ways of solving problems is needed to elucidate the *variables*, *options*, and *linkages* at the heart of complexity and how solutions are advanced (Head and Alford, 2015). First, wicked problems are not generally amenable to solutions driven by regulation or appeals to scientific knowledge (Schon and Rein, 1995). Instead, they are often grounded in different value perspectives that frame how different parties understand the issue and its solutions. By identifying how these different framings differ, organizations can start to facilitate a dialogue that recognizes the different value perspectives, describe how the implications of these different value perspectives, and address conflicting views (Head and Alford, 2015). Second, by deploying systems thinking, organizations will begin to recognize the inputs, processes, and outputs that are defining the complexity and that solutions will be context dependent, overcoming some of the command-and-control bureaucratic structures that limit these explorative opportunities (Senge, 1990; Chapman, 2004; Seddon, 2008). Third, analysis can learn from complexity theory which recognizes the interdependencies, feedback loops, emergent features, and surprises that produce chaos and contradictory results (Berkes et al., 2008). Complexity theory can help organizations identify trends in what appears to be noise and move away from conventional approaches that focus on identifying the more effective solution (Head and Alford, 2015).

Whereas divisional bureaucratic structures limit an organization's ability to sense and respond to complex environments, *collaboration* is needed to develop a shared understanding, agree on purpose, and establish mutual trust (Huxham and Vangen, 2005). Where there are multiple parties with different knowledge, interests, and values, collaborative relationships can show blind spots in an organization's knowledge system and enhance understanding. It can increase the likelihood that the nature of the problem and its causes are identified, and solutions are found and agreed to by helping diverse parties reach an understanding. Collaborative approaches also help implement solutions as parties are more likely to agree on next steps, and they enable share contributions, coordinated actions, and mutual adjustments as solutions are implemented (Head and Alford, 2015).

The leadership styles previously described tend to focus on organizational agility for power sharing and should be supported by *collaborative leadership* for shared power (Crosby and Bryson, 2005). Collaborative leadership is about eliciting cooperation from partners through invitation to the dialogue, framing of the issues, orchestrating of the agenda, recognizing expertise, facilitating win-win negotiation processes, identifying entrepreneurial opportunities, and engaging in diplomacy (Head and Alford, 2015).

Leadership and the capacities to work within and develop solutions for complexity will require *organizational structures and processes* to change. First, as discussed, the traditional divisional bureaucracy tends to silo expertise constraining an organization's ability to collaborate, share ideas, and sense changes in the

environment. To alleviate these divisional constraints, assigning staff to a home division but creating opportunities for them to be reposted to strategic projects improves organizational agility to respond to wicked and complex problems (Head and Alford, 2015). Crosscutting committees can also be valuable if imbued with decision-making authority. Second, the financial structures and incentives associated with divisional bureaucracies emphasize products and services but not usually how well the organization is responding to complex challenges. Budgets and financials should consider how to support outcomes, outputs, and processes associated with an organization's knowledge system and its ability to sense and respond to changes in its environment. There should also be opportunities for the pooling of budgets, where incentives are provided for multiple divisions within an organization or multiple organizations to work together to address multifaceted problems (Head and Alford, 2015). Similar to financial structuring, performance assessment or knowledge system monitoring should be updated to reflect how well the organization is tackling complexity (Dooren et al., 2015). Finally, organizations should shift how they hire, retain, and promote their staff with consideration given to the knowledge, experience, and skills necessary to work in a collaborative environment when addressing complexity (Alford and O'Flynn, 2012).

These leadership and process changes have a commonality of supporting the capacity of the organization to sense and respond to changing conditions at faster rates. As infrastructure organizations are increasingly required to navigate the growing complexity, they will need to transition to accommodate these structural and process differences. How effectively they transition will likely determine their capacity to deliver services in accelerating and uncertain environments and ultimately their relevance. Next, we reimagine an infrastructure governance model that is capable of transitioning to thrive in the Anthropocene.

5. Transitioning infrastructure governance

Transitioning infrastructure governance is an effort that will require sustained commitment to taking down forces that lock-in the systems including management, financing, education, and technologies. It will require a recognition that how we currently manage infrastructure and the services it produces is under threat and a willingness to test what could work without having clear evidence of precisely how to structure governance. Each of these is inimical to the current ways of governing infrastructure, and as such, any transition represents a wicked complex process that will require new approaches that most infrastructure managers are not trained for. Following, we first describe what management form infrastructure organizations should consider transitioning to. Next, drawing from literature on how to change public service organizations, we summarize key factors necessary to support the successful transition of infrastructure governance. We then describe the steps necessary to improve the sensemaking capabilities of infrastructure systems, for increasingly complex environments.

Where the divisional bureaucratic form is pervasive, infrastructure organizations should create the flexibility where *adhocracy* structures can dominate during times of instability. Adhocracy is a structural configuration of management that emphasizes the fusing of experts from different disciplines as ad hoc teams to tackle new and complex problems (Mintzberg, 1979). Whether the divisional bureaucratic structure should remain at all is an open question. Uhl-Bien et al. (2007) contend that the reality is that complete transitions away from the current structure are unlikely and that they may still be needed during periods of stability. However, adaptive leadership for unstable conditions and enabling leadership to shift between stability and instability are critical competencies for public institutions increasingly confronting new and more complex demands and challenges (Uhl-Bien et al., 2007). What is clear is that the divisional bureaucratic form is ill-suited for conditions of high complexity and instability. An adhocracy emphasizes a highly organic structure with little rationalization and formalization of behavior (Figure 1). It involves a grouping of specialists in functional units but with the capacity to deploy them to market-based teams as needs arise, a reliance on a liaison to communicate and coordinate across ad hoc teams, and selective decentralization of teams and their strategic locating across the organization (Mintzberg, 1979). The adhocracy structure works against the organization relying on any form of standardization for coordination. It not only imbues experts with the authority to study external conditions and drive decisions but also emphasizes the building of new knowledge and skills. Mutual adjustment becomes the prime coordination mechanism, unlike a divisional bureaucracy where coordination is left to a few managers. Managers do exist in the adhocracy, but instead of focusing on standardized procedures and goals, they will lead small groups and help coordinate across groups by liaising and negotiating (Mintzberg, 1979). Mintzberg's adhocracy model may have been describing Simon's (2002) *near-decomposability* feature of systems, that is, subunits that have autonomy but maintain connections and coordinate activities (Teece, 2007). Near-decomposability describes how subunits at the lowest levels in a system find equilibrium solutions faster than higher levels, due to rates of interaction and therefore greater ability to change (Simon, 2002; Teece, 2007). To shift from a divisionalized form to an adhocracy, the power structures and identities within organizations must be shifted.

Motivating change is less about convincing the organization of a better future but more about a bad or dangerous present (Diefenbach, 2007). Nevertheless, the organizational and leadership strategies we have described enable the sensemaking necessary to recognize that a new vision is needed prior, or at least desired, prior to a crisis and avoiding disaster conditions if possible. Changing the identities of individuals in the organization through a shared vision requires sustained and sufficient efforts. In reviewing the factors relevant to public service organization change, several commonalities exist (Armenakis and Bedeian, 1999; Fernandez and Rainey, 2006). Summarizing the work by Fernandez and Rainey (2006),

we describe key aspects of these factors in the context of infrastructure organizations.

- Leaders must ensure that change is needed by convincing individuals of the need for change. This involves crafting a compelling vision that is easy to communicate, that members of the organization find appealing, and that provides a direction for change. Windows of opportunity such as natural disasters can be excellent times to introduce new visions (Judson, 1991; Kotter, 1995; Nadler, 1997; Abramson and Lawrence, 2001; Carnall, 2007).
- The vision must be transformed into a course of action with goals, plans, and new expectations and rules for achieving it. Plans serve as road maps that provide direction to a preferred end state, identify barriers, and recommend options for overcoming the barriers.
- Internal and widespread support for change must be garnered to overcome resistance. A crisis or shock often results in reduced resistance as individuals view change as inevitable. The shock can be real or manufactured (Thompson and Fulla, 2001; Laurent, 2003). To overcome change resistance, several strategies exist including threats, criticism, persuasion, rewards, compromises, guarantees against personal loss, psychological support, building loyalty, and recognition of the value of past practices (Judson, 1991).
- Upper management support for change is necessary. Coalitions can be important for steering resources and support to organizational members.
- External support from political overseers and external stakeholders is needed to ensure that change resources are appropriated to the organization and reduce barriers.
- Change is expensive, and underfunding can lead to weak implementation including stress on individuals and neglect of the core organizational functions. Appropriate and sustained funding is required for change activities including strategy development, communications, training, new processes and practices, restructuring, and testing innovations.
- If the aforementioned factors are not institutionalized, then significant risk exists that the organization will revert to past behaviors. Change leaders must modify formal structures, procedures, and practices, employ

rights, deploy innovation through trial projects, track progress through data collection, and coach employees through learning by doing (Armenakis and Bedeian, 1999).

- Transformation of large organizations requires congruence in subsystems and understanding of the interactions of these subsystems. Change in only a fraction of the subsystems can lead to failed transformation. Focusing on high-impact decision-making subsystems may be an effective way to prioritize (Amis et al., 2004).

These eight factors provide useful guidance for infrastructure managers as they plan change. They point to the preconditions, opportunities for disruption, and sustained actions and resources necessary for transformation. However, change without visions or goals is often misdirected, and improved sensemaking is increasingly highlighted as the critical competency for the Anthropocene.

Sensemaking is the process of giving meaning to how the environment is changing and of changing technologies, governance, and education at a fast enough pace to remain viable (Weick, 1995; Miller and Muñoz-Erickson, 2018). Sensemaking is the primary activity of knowledge organizations. Although infrastructure organizations have been designed around goals of delivering services (often physical and characterized by public and not market value), they are likely to struggle to continue doing so under assumptions that service demand and conditions of delivery will remain predictable. As such, they'll need to innovate how they architect knowledge. Knowledge organizations must be reflexive by observing, assessing, evaluating, reflecting on, and reforming their knowledge systems, that is, how they make knowledge about their own systems and the environments they operate in (Miller and Muñoz-Erickson, 2018). They must establish a perspective of the organization and its environment and question whether their knowledge systems are adequate. To do this, three key strategies are needed (Miller and Muñoz-Erickson, 2018). First, infrastructure organizations must realign their knowledge and decision making. The alignment of knowledge and action is called coproduction and involves developing a decision framework and then focusing on the knowledge necessary to implement the framework and monitoring the outcomes. Following the organizational change rules described by Fernandez and Rainey (2006), knowledge creation should occur among diverse stakeholders (producers and users) so as to avoid lock-in driven by a single stakeholder (e.g., the knowledge producer) assuming they know everything needed to act. Next, following the coproduction process, knowledge systems innovation is needed (including monitoring, stress testing, and upgrading) to ensure that processes are changing and functioning as required. Finally, a professional capacity for knowledge systems management must be built, including training the organization's workforce to create, analyze, and innovate knowledge systems and

design. As per the adhocracy model of governance, the organization must ensure that there are people strategically located throughout who can reflect on the knowledge systems, how they behave and work, how they are organized, and how they generate, validate, communicate, and apply knowledge to critical decisions (Miller and Muñoz-Erickson, 2018).

6. Conclusion

For an infrastructure organization embracing the reality of the Anthropocene, this would mean a more flexible, adaptive, and reflexive mode of operation. Infrastructure organizations would analyze and explore current and future trends to not only understand threats to physical operations but also to gain information that might require organization changes. This would entail sensemaking activities across the organization that require an interdisciplinary approach that would enable staff and administration to analyze opportunities and risks across complex social, ecological, and technological domains at various spatial and temporal scales. This would be augmented by an embrace of a more collaborative governance model—working with other infrastructure organizations as well as other governmental, industry, and community stakeholders. Knowledge systems design, then, is fundamental to infrastructure design in the Anthropocene. This would include boundary agents or units within and across infrastructure organizations to ensure crosscutting risks and concepts, such as resilience, are integrated. Now, climate or resilience expertise is often in a separate part of a bureau or in a different department altogether. More adaptive knowledge systems would break down those institutional barriers to integrate expertise on specific risks and across social, ecological, and technological (infrastructural) domains. This knowledge integration would also be connected with design, implementation, and maintenance across infrastructure types. For example, management of green infrastructure by, for example, a parks department could enhance service delivery from stormwater bureaus as well as deliver thermal regulation benefits. Better coordination between infrastructure organizations as well as with a broader set of stakeholders would also support collaboration in how and what kind of services are delivered as whole (as opposed to siloing management and understanding).

Shifting from rigid governance models to those that emphasize agility and flexibility will not be without trade-offs. The rigidity that is present has indeed created tremendous value and well-being for societies over the past century. The inertia inherent to the rigidity has likely helped projects to get built and to persist despite political and funding cycles that operate on much shorter time-scales, allowed investors to risk capital and base their investment on the presumption of infrastructure permanence, and sent signals that there is a commitment to established development that new services should be built on. The foundational concern, however, is that when a system is unable to change appropriately or at the rate that its environment is changing, then it will lose viability. This could take many forms including the decentralization of

power where new players control aspects of the system that previously were controlled by a single agency or at the extreme where the agency or technologies are replaced. We argue that the tensions between legacy models that emphasize and perpetuate rigidity and new models that allow for flexibility and agility in the face of instability must be reconciled. If they are not, then the basic and critical systems that we rely on appear increasingly likely to be disrupted and irrelevant.

It is difficult to identify examples of major proactive shifts in infrastructure governance motivated by a recognition that environments and demands are likely to become unstable. There are many examples of agencies that have embraced sustainability or resilience (Feiock et al., 2014; Martin et al., 2018), for example, but these efforts tend to focus on adding new considerations on top of existing priorities and the structures that have persisted. If indeed there are few to no cases where foundational transformation of infrastructure agencies for complexity exists, then this is quite telling. Despite growing evidence of accelerating, increasingly uncertain, and increasingly complex environments, infrastructure organizations do not appear to have the capabilities to recognize forthcoming change and/or meaningfully change governance processes to proactively respond. Radical change isn't needed overnight, and infrastructure services will remain relevant for some time. However, the increasing disconnect between what our infrastructure are governed and designed to do and what we'll need them to do in the future can be expected to become increasingly apparent. And where existing services are unable to keep up with increasing complexity, new alternatives will emerge, adding more complexity to the delivery of basic and critical services. It is critical that agencies today invest in building the capacities for sensemaking and begin assessing how their organizations should be structured for the next century instead of the last.

Data accessibility statement

There are no data to access.

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