The Centrality of Restoration Resilience Across Interconnected Critical Infrastructures for Emergency Management: A Framework and Key Implications

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Note to the Reader

This final report is an amalgam of three documents, which we present here as a single document for the convenience of practitioners, policymakers, researchers, and the general public interested in maximizing the resilience of critical life infrastructures in major disasters.

The first document, which we use here as an executive summary, is a policy brief intended also as a stand-alone document (which is why it has a different title).

The second document, which constitutes Part I here, was an interim report of the overall project.

The third document, which constitutes Part II here, covered the last part of the research project.

In addition to the Table of Contents, we provide a brief index to help readers find specific items (e.g., examples of emergent interdependencies for specific infrastructures, such as electricity transmission or road transportation).

The views expressed in this paper are those of the authors only, and do not necessarily reflect the views of the Oregon Research Institute or of the U.S. National Science Foundation.

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Executive Summary

POLICY BRIEF

Reducing Interconnected Vulnerabilities in the Restoration Resilience of Pacific Northwest Lifeline Infrastructures for Major Disasters, Most Notably the Magnitude 9 Cascadia Subduction Zone Earthquake

This policy brief addresses a major inter-infrastructural vulnerability and associated weaknesses we have observed in current Cascadia Subduction Zone (CSZ) emergency planning and the preparation for restoration response to a magnitude 9.0 earthquake. Our findings are based on U.S. National Science Foundation-funded interviews with first-responder emergency management personnel and with frontline and control center infrastructure managers and operators in Oregon and Washington State.

This research focuses on the capacity for inter-infrastructure resilience in the restoration of critical lifeline infrastructure service in the aftermath of M9 events. Lifeline infrastructures of interest are critical ones providing real-time power (electricity and natural gas), water (potable supply, and wastewater disposal and treatment), telecommunications and road transportation. Our findings apply to responses in other major disasters, including wide-ranging wildfires, regional ice storms and watershed flooding.

The research

1. Our specific research centered on the capacity of personnel on the emergency response frontlines and in control rooms and maintenance departments in the four lifeline infrastructures to respond both to the shifted interconnectivities of these infrastructures during major emergencies and to the uncertainty posed by the shifts that challenge real-time response and restoration of services.

   Of particular concern are those interconnections unobserved or even unimagined beforehand. These only reveal themselves when a natural disaster results in interconnected infrastructure failures, and in the emergent interconnections thereafter required to respond quickly in the restoration of critical services. What had been "latent" interconnectivity now becomes "manifest" and must be dealt with in real time.

2. The vulnerability we are most concerned with is the need to support and enhance the ability of frontline personnel to address these real-time challenges in advance of M9 CSZ events or other major disasters.

3. We offer specific policy and programmatic suggestions for how current vulnerabilities in post-event restoration resilience can be avoided in the lifeline infrastructures.

4. Our research point of departure is that shifting interconnections between and among critical infrastructures have different configurations and that these differences matter for effective disaster preparedness, response and restoration.

   For example, two or more seemingly unrelated infrastructures can suddenly become mutually dependent as specific problems present themselves, thus posing major challenges to be prepared for in immediate emergency response and initial service restoration. Box 1 provides examples from our previous and current research.

Box 1 Examples of interconnectivities shifting from latent to manifest in disasters

- A road atop a levee depends on the levee for its existence. But a levee leak can suddenly lead to active functional reciprocal interdependence in fixing the leak. The road becomes vital as the only landside repair route to the levee for transport of repair crews and fill material, while levee leaking can cut off access, hindering repairs.
- A major road and an airport next to each other take on shared functionality when the airport and the road become links for onward transport of emergency supplies. If either one is too damaged to use as intended, then onward supply transport ceases for both of them.
- Firefighters and electricity infrastructure become more interconnected when the former set their firebreaks under accessible rights-of-way for electricity transmission lines, creating conflict between backfires needed by the firefighters and the risk of particulates from backfire smoke shorting out the electrical flow along the transmission lines, disrupting power supplies for firefighters and others.
- Restoring electricity is essential for other critical infrastructures to restore their services, yet electric service restoration depends on working telecoms and/or transportation access to lines and related equipment.

Key findings

5. Many interviewees have experience with shifting interconnectivities like those in Box 1. This deep experience with interconnectivity has several notable features.

   Foremost, our interviews with first-responder emergency staff and with frontline and control center infrastructure managers and operators in the two states indicate that a clarity can and often does emerge in their perceptions of the urgency, functional needs and specific requirements for service restoration in a disaster.

   Particularly noteworthy is the collaborative capacity of personnel in emergency management and lifeline infrastructure operations to achieve a shared clarity about, and situational awareness of, the overlapping dependencies between infrastructures whose shifts pose challenges for immediate emergency response and rapid restoration.

6. However, our interviewees indicate that some higher-level officials and planners may not have anticipated such shifts nor fully appreciate the granularity or accuracy of this clarity at lower operational and maintenance levels.

Within the official national and state emergency management systems, improvisational actions taken at lower levels among control operators and maintenance personnel may be seen as a drift away from accountability or an infringement of higher responsibility to set priorities in light of their "bigger picture." Yet ingenuity in the form of on-the-fly improvisations and workarounds has been essential to frontline effectiveness.

7. Given the uncertainties and surprises in major events—including lower-level personnel unable to reach incident command staff—we see both clarity and ingenuity as key resources for emergency response and service restoration by first-responders from emergency management and frontline infrastructure staff in the field and control rooms.

Key implications and recommendations

8. We argue that providing for and supporting these first-responders and frontline staff require different approaches to contingency planning for major disasters before, during and after the emergency. It is extremely challenging but vital for the planning and regulatory agenda to include identifying and allowing for the managing of unforeseen latent inter-infrastructural interconnections and vulnerabilities *before* a CSZ earthquake happens.

9. More specifically, greater facilitation of inter-infrastructural communication, coordination and problem-solving ingenuity in restoration efforts will occur through joint contingency planning efforts, including cross-infrastructure table-tops, shared improvisation exercises, and best utilization of county/city hazard mitigation plans.

Important planning recommendations across infrastructure organizations appear in Box 2.

Box 2 Key recommendations for enhanced contingency planning

- Provide contingent resources, including spare parts distributed over geographic areas, as well as greater interoperability among infrastructures in regard to critical parts and software.
- Expand the job bandwidths of managerial and operational levels in key interconnected infrastructures.
- Real-time operations and maintenance personnel need to be given more time to devote to preparing for these types of large-scale emergencies.
- Improve further the vertical and lateral communications between and among the lifeline infrastructures so infrastructure staff can better use different communication technologies and pathways before the disaster, not just during it.

The need for more time to prepare is especially important and not just for frontline staff in water, roads, electricity and telecoms. Calls by our interviewees for more administrative support to manage and coordinate their local emergency preparedness should not be treated as just another routine complaint or a small deal when compared to other organizational, or city and county, priorities.

10. We also offer programmatic recommendations for state governments in Box 3.

Box 3 Key programmatic recommendations for states

- Create a Governor's Commission devoted to the promotion of inter-infrastructural resilience for the restoration of connected lifeline services.

  Upgrading this resilience will require joint planning and investment in personnel, equipment and facilities. This would include working with existing initiatives and programs, including but not limited to regular simulation exercises, whose participants continue to learn the importance of interconnected infrastructures both in preventing failures and in restoring services after major disasters.

- Identify specific opportunities currently overlooked within existing state programs, budgets and guidelines to facilitate shared clarity and joint ingenuity in cross-infrastructure responses for both normal operations and emergencies, including but not limited to budget and staff reallocations.

- Create a special state program for two-week readiness training (i.e., self-sufficient two weeks after the event) for major private and public sector entities. Program specifics would be adapted to local conditions as one size will not fit all.

- Consider combined tax incentives and regulatory requirements for privately-owned infrastructures to invest in interinfrastructural emergency planning, interoperability for collaborative service restoration, joint simulations, and development of robust systems for joint communications and data sharing.

- Consider tax incentives for certified training of households (or other private sector entities) trained in two week readiness, including potential reliance on Portland State University's professional certificate program in emergency management and community resilience.

We advise taking up these planning and programmatic opportunities in consultation with the many public/private groups who already understand the complexities of interconnected lifeline infrastructures. Without such consultation, the response and resilience capacities available to cope with a future M9 earthquake and its aftermaths may well fall short of what is needed.

(The authors of the policy brief are Emery Roe, Paul R. Schulman and Branden B. Johnson. Dated May 2025.)

Report Structure, Acknowledgments and Methods

Introduction

This report is divided into two parts. Part I, the longest, is based on the first round of interviews and originally drafted in September, 2022. Part II consolidates and updates Part I findings from the second round of interviews (originally drafted April 2024). Both Parts I and II have been edited for clarity and brevity.

The preceding Executive Summary follows directly from Part II which builds on the framework of Part I.

Acknowledgments

We thank the National Science Foundation for its grants 2121528 to Decision Research and 2411614 to Oregon Research Institute (September 1, 2021 - August 31, 2025), which funded interviews for and analyses in Parts I and II. We also thank Branden B. Johnson and Youngjun Choe for their input in proposing this collaborative research as well as for assistance in developing the interview protocol. Branden B. Johnson is co-author of the Executive Summary as well. (The part of the collaborative research headed by Prof. Choe, University of Washington, produced a guide to how practitioners and researchers can quickly summarize the content of multiple lengthy reports, using Cascadia subduction zone earthquake preparedness and emergency response documents as an example; see Lessing *et al.,* 2025).

We are most grateful to our 47 interviewees, a number of whom were interviewed more than once (listed alphabetically): Allen Alston, John Anasis, Aaron Beattie, Bret Bienerth, Eric Brandon, Mike Britch, Scott Burwash, William Chapman, Lesia Dickson, Darren Donley, Mark Douglas, Heather Earnheart, Scott Eastman, Teresa Elliott, Thomas Erickson, Rebecca Geisen, Daniel Goodrich, Lisa Gorsuch, Mike Harryman, John Himmel, Jay Jewess, Leon Kempner, Elizabeth (Eli) King, Lori Koho, Ty Kovatch, Christina LeClerc, William MacBean, Gage Marek, Matt Marheine, Beth McGinnis, James Merten, Bill Messner, Soheil Nasr, John Nguyen, Jeff Page, Nishant Parulekar, Jonna Papaefthimiou, Anne Rosinski, Chris Silkie, Joe Skeens, Kim Swan, Anthony Venditti, Yumei Wang, Chris Wanner, Chantal Wikstrom, James Wong, and Nora Yotsov.

Methods

The primary research mechanism was in-depth interviews with frontline and control center operations personnel involved with private and public infrastructure at the local and regional levels, and local, state, regional and federal emergency response personnel. The infrastructures concerned were: water supplies (including wastewater), electricity, roads, and telecommunications. The 47 respondents in Oregon and Washington state were interviewed remotely, with follow-on interviews undertaken for clarification, expansion, and responses to the draft policy brief.

The interview protocol was semi-structured to ensure that pertinent topics were probed but that new topics could be followed up at the same time. Round 1 interview questions included how interconnected infrastructure preparedness, initial restoration, and longer term recovery fit into current and prospective CSZ planning within the infrastructures of interest, including local, state and federal emergency management. Round 1 raised important questions about the resilience of interconnected infrastructures to identify latent interconnectivities before and restore more quickly after they had become manifest in a disaster, particularly with respect to a moment magnitude scale 9 earthquake offshore in the Cascadia Subduction Zone. Clarification and extension of these issues were the focus of the fewer Round 2 interviews.

An interim report was prepared in September 2022 based on Round 1 interviews, which in turn served as the basis of our *Safety Science* article (Roe & Schulman, 2023). That article laid out a framework of key variables to study with respect to interconnected critical infrastructures affected by a major disaster. Round 2 interviews, which focused on the interinfrastructural issue of restoration resilience specifically, updated the framework, the results of which were drafted in April 2024 and serve as the basis of Part II below. The update in turn led to the drafting of a Policy Brief for wider distribution (May 2025), which also was shared with interviewees for their comments on its content and suggestions for its dissemination. That brief is reproduced as this report's Executive Summary and this longer report is another step in broad dissemination of study results.

Part I Results: A new framework for immediate emergency response and initial service restoration

(September 2022)

Introduction and preliminaries

Aim.

The objective of this research is to identify and describe the major features of a proposed framework and its value-added to understanding immediate emergency response and the early stages of recovery from catastrophe, in this case a Cascadia subduction zone (CSZ) earthquake of magnitude 9.0 (hereafter, M9). The framework seeks to extend what is already known and underway in Oregon and Washington State. To that end, we interpret through the framework what career emergency management staff and infrastructure operators are doing for a M9 earthquake event in four critical ("lifeline") infrastructures that are widely recognized to be very interconnected: water (both potable and wastewater); electricity; roads, and telecommunications. In this, we confine our examples to those backbone infrastructures for which we have undertaken interviews: water, electricity, and roads.

Our research aims to add value to emergency management practice and theory in two ways. We take as our point of departure a body of research on large critical infrastructures vulnerable to systemwide failure and periodic service disruptions that, in our view, has not been sufficiently tapped for the purposes of advancing emergency response and management (Roe and Schulman 2016, 2018). We add to this literature interviews from a wide group of infrastructure practitioners: real-time operators and emergency managers for the backbone infrastructures of interest in Oregon and Washington. Their unique knowledge bases have not been sufficiently tapped, also in our view, for advancing emergency management.

Synopsis of argument and proposed framework.

While a broadening concern for infrastructure interconnectivities has been evident, much of current attention remains on specific infrastructure components: Our interviewees were more likely to discuss that bridges will collapse than they were to identify specific backbone interconnectivities due to a bridge collapse. The argument and framework below are intended to help move the discussion further from components to system interconnectivities.

We are interested in how infrastructure staff and organizational networks, particularly but not exclusively in the infrastructures' real-time operations and related emergency response units, manage their connections with other infrastructures. The principal management elements of interest are: the types of interconnectivity configurations among network elements, their shifts in disruption and failure states, the improvisations around control variables (those actionable features of an infrastructure—e.g. frequency and voltage for a electricity transmission grid or releases from dams for water supply systems—used to adjust the condition or state of the infrastructure) in immediate emergency response and management, and last but not least, the generation of options across infrastructures for overall effectiveness in coping with sharply altered infrastructure stages of operation.

Interconnectivities present two important issues for understanding the consequences and management of a major subduction zone earthquake for critical infrastructures. One is the substantial vulnerability of critical infrastructures to the failure of other infrastructures, due not just to obvious interconnections, but also surprising latent ones that can cause a cascade of failures across infrastructures in a major quake. The other is that such interconnectivities pose both the requirement *and* the opportunity for joint inter-infrastructure resilience to arise, and even improvise options, for the rapid mutual *restoration* of service across infrastructures.

Now the details. Prior to undertaking the exploratory research, we identified four elements that our previous work on large interconnected infrastructures indicated were critical to emergency management: (1) the different *types of interconnectivity* that can exist between and among the backbone infrastructures for real-time electricity, water, telecoms and roads; (2) the *points or phases at which the types of interconnectivity shift* during infrastructure failure, immediate response and initial recovery; (3) the importance in immediate response of *jointly undertaken improvisations around system control variables relied upon by more than one of the backbone infrastructures*—all of which are in turn managed to (4) a *performance standard that includes the effective generation and use of "requisite variety"* (that is, effectiveness in emergency response and management in generating options to match real-time task demands and real-time resources).

In what follows, examples and implications are drawn and contrasted with current emergency management activities as described in our interviews. A major upshot is that both initial emergency response and strategy for service restoration have to address infrastructure interconnections in ways rarely documented or fully appreciated by policymakers.

Roadmap.

Section I presents two fairly recent and major wake-up calls in Oregon and Washington State about the central impact of interconnectivities between and among backbone infrastructures for first-phase emergency management (specifically immediate response with initial service restoration among backbone infrastructures). The wake-ups are: the last decade of (at times back to back) wildfires, floods, and storms (ice, wind) and the Covid-19 pandemic.

Section II presents the key challenge and special properties posed by a Cascadia M9 earthquake to present-day emergency management in the two states (based on our interviews). Reasons are given for why the M9 earthquake is uniquely outside core competencies of even the best infrastructure and emergency managers. We argue a different approach is needed to address the unique features more effectively. This discussion sets the stage for applying our proposed framework in the subsequent sections.

Section III presents a detailed description of the framework with initial extensions for emergency management in Oregon and Washington State before, during and after an M9 earthquake. Section IV shows how our framework helps in clarifying the challenges under different conditions of failure, response and recovery. Section V illustrates the framework's utility in clarifying key topics in emergency management related to: communications; learning; staff and resource scarcities; networks of contacts and professional relationships; interconnectivities creating scale effects; and pre-disaster mitigations.

Sections VI and VII take up two inter-related topics core to the value-added of the framework. Section VI gives much more detail on its implications for emergency management performance standards. Building on the role of requisite variety in effective performance, Section VII turns to rethinking the central role of emergency management coordination in planning, response, initial service restoration, and ultimately, longer-term recovery after an M9 earthquake. We conclude Part I with a summary of other implications for further exploration ahead, including that of new strategies for statewide resilience.

Section I. Two wake-up calls about critical interconnected infrastructures in emergencies

1. More recent fires, flooding and storms in Oregon and Washington State.

We start with roughly the last decade of emergency events around which a number of responders have amassed skills and experience in both states.

Exceptions can always happen, but ice storms, fires and floods have generally speaking been predictable with respect to times of onsets as well as with wind force and precipitation estimates. First have been the advances in weather forecasting and storm mapping. “Some of these [fires and floods] you can predict,” a former chief engineer of a major city infrastructure told us. “Floods are an annual experience sometimes more severe than others,” added a state emergency manager for state highways and roads. “In a normal year,” a city’s water construction and maintenance manager detailed, “we have 150 to 200 main breaks. . .spread out over the course of the year”.

Patterns of impact are also known. Ice storms affect road transportation more than other events, according to a statewide emergency manager. A senior engineer in a major power transmission company added, “We see failures on a regular basis. . .I would say we lose 1, 2, 3, maybe 4 towers a year due to wind, ice, trees. . .We see lots of those [kinds of] events”. Emergency management planners can reasonably expect to provide public warnings beforehand and many emergency protocols to be in effect. Emergency responders can also reasonably expect their own buildings and facilities to remain intact with emergency power and some telecommunications during seasonal ice storms, flooding and wildfires.

Exceptional cases do happen, however, and more of them are occurring in the view of interviewees. Their frequency has been its own wake-up for the states’ emergency managers. “2020 was of course nothing like they’d seen before [when it came to wildfires],” said one state-level manager. A single 2017 winter event of freeze-thaw-freeze majorly affected Portland’s above- and below-ground infrastructure, roads and water. Two back-to-back floods in one day were reported for a Washington State city in 2019, affecting multiple infrastructures. An Oregon interviewee spoke of 2019 witnessing flooding, drought and snow “all in the same space”.

Yet even these exceptional events do not pose the conditions confronting emergency planners and responders when the M9 earthquake “unzips,” in the phrase of a state official. Yes, one senior emergency official underscored how busy their agency had been recently with two or three emergency declarations a year. Some interviewees also had experience in response and recovery for major disasters not seen in the Pacific Northeast, namely, Katrina. But that experience also pales before an M9 set of events (details in Section II).

What, though, about experience with actual earthquakes in Oregon and Washington State? Few recent earthquakes have happened and they are most notable for not being on the scale of the M9. One interviewee mentioned being in a water and wastewater treatment facility during the 2001 Nisqually earthquake, where “our infrastructure did very well during the quake”. “Knock on wood, we haven’t had any earthquakes with any damaging events in my time,” said a state emergency manager for roads. Earthquake location matters, however, and so do their wake-up calls: A utilities engineer said for their city, a “SWIF [Southern Whidbey Island Fault] event. . .is probably more critical to us, is more important than an M9, it is more devastating [as the fault is comparatively shallow]”.

2. Covid-19 pandemic.

The pandemic was a very major wake-up call to the infrastructures about their interconnectivities. “COVID had catastrophic effects on everybody, including critical infrastructures,” said a state emergency preparedness manager with long experience, adding the response was and had to be “unparalleled”. “We have wind events, we have fire events, we have power events, then the biggest event of all, COVID,” said a senior city public works official. The uniform opinion of interviewees is that no one predicted its very real impacts and interruptions for the wide swath of local, state and federal emergency managers and infrastructure operators.

What were the impacts? First and foremost: those related to the pandemic’s interconnectivities. In the view of a very experienced emergency management expert, “the one thing that the pandemic is bringing out is a higher definition of how these things are interconnected and they’re not totally visible”. Covid-19 response made clearer that backbone infrastructures, especially electricity, are “extremely dated and fragile” in the view of experienced interviewees (e.g. in Oregon). Covid-19 responses also put a brake on infrastructure and emergency management initiatives already in the pipeline (e.g., preventative maintenance), according to multiple respondents.

The pandemic, combined at the same time with the other emergencies already mentioned, led to difficult trade-offs. The heat dome emergency required a treatment plant’s staff not to work outside, but in so doing created Covid-19 distancing issues inside. The intersection of lockdowns and winter ice storms increased restoration times of some electrical crews, reported a state director of emergency management for energy. A vaccination mandate on city staff added uncertainty over personnel available for line services. Who gets to work at home and who gets to work in the plant also created issues. “We struggled with working with contractors and vendors” over the vaccine mandate, said a state emergency manager for roads.

“The scarcity of people and things was global,” concluded one interviewee. Roads staff shortages in the aftermath of a vaccine mandate were mentioned by a state emergency manager for transportation as making it harder to undertake operations. Covid-19 meant many staff had to work virtually via internet from home during the 2020 Labor Day fires, which entailed communication difficulties between and among staff. Having to work from home is especially important by way of implications for response to an M9 earthquake. The expectation among emergency managers is that much of the emergency response and initial—even if temporary—service restoration will necessarily have to be *on-site* in contrast to off-site Covid-19 work. Said one interviewee: "COVID is so unique and out of the box that we've developed rules and processes that we're only going to use during COVID because they don't make sense in any other disaster".

In other words, readers need to understand what makes M9 a challenge beyond any experience for infrastructure operators and emergency managers in Oregon and Washington State.

Section II. Unique features of a magnitude 9 earthquake for backbone infrastructures and emergency management in Oregon and Washington State

For emergency management to cover such a vast area as that necessitated by the M9 earthquake would be "unique" in the US experience, said a senior engineer with long experience in emergency management. "We've never seen a Cascadia type of event," a senior engineer with extended background in a major transmission company told us, adding he still could not get his hands around this kind of event.

A senior state emergency manager, also with substantial experience in M9 planning, sought to compare the M9 earthquake to then recent time- and resource-consuming emergencies discussed in Section I: ". . .and we know how tough those events were and, of course, that's *nothing* [compared to what] we would endure and have to respond to with a Cascadia event". An emergency manager for roads in another state said much the same: Highway restoration priorities in current emergencies, like snow and ice storms, would have to shift significantly with the M9 earthquake to, i.e., reaching communities completely cut off and threatened or shifting to search and rescue functions only.

"If I'm still alive" were the words in reply to our question about what one water district operations manager would do once the M9 hit. Try to imagine, another interviewee put it, something like Puerto Rico after its 2020 earthquake stretched across west Oregon and Washington State. "Realistically I think you have to assume," said a long-time infrastructure engineer, "that from the west side of the Cascades from southern Oregon all the way up to Vancouver BC they're all going to be in [the M9] together". Then imagine, pressed other interviewees, the M9 earthquake happening during a normal winter or when high winds are coming or in the wet season with the usual flooding or at night and then add in local factors like flaming toxic sludge from Portland's central energy hub or the three major faults already running under Seattle and Tacoma. . . .

Specifics for the M9 scenario.

There are however scenarios of more specific concern to emergency and infrastructure managers in the two states. Here is one, whose elements we also heard from other interviewees:

> A lot of my contemporaries and planners on the emergency side have all said that the devastation is going to be so great that the ability to get resources in to help out survivors is going to be so limited that this thing is going to be so protracted that there is not going to be enough preparation in the homes of people—the individual communities are not prepared enough to last long enough and there's going to be a lot of subsequent deaths after day-7 of the event. There's not going to be enough response ability to come in because infrastructure is so broken. There's no roads, no bridges, no airports, no shipping ports, no communication, no electricity, no freshwater, all that stuff. It's going to be one of those biblical proportions kinds of disaster.
>
> (A federal emergency manager working in the two states.)

This is not hyperbole to interviewees. An M9 Cascadia earthquake (when combined with magnitude 8.0 aftershocks and huge tsunami and possible volcano-related impacts) will be unimaginably catastrophic *precisely in light of* prior experience and training with lesser emergencies such as those discussed in the preceding section.

The tsunami will be "unbelievably devastating," said a long-time state emergency manager, referring to new data: "There's nothing going to survive a 60' wall of water". We know the earthquake will merit a Presidential Disaster Declaration, said another and "pretty obvious that the geography of the coast is going to completely change" said a third. But a constellation of interrelated factors makes much of the rest unknowable or uncontrollable beforehand. This remains the case, it deserves underscoring, even when interviewees have had international experience in very major disasters elsewhere.

What are first-order impacts of an M9 for emergency managers and infrastructure operators? Foremost, even though hourly official "Playbooks" for the event exist, one should put aside any illusion that elected state and federal officials and politicians will have a comprehensive overview of the M9 events and its consequences.

"I don't know that they understand, I don't know how they could understand all the technical issues that might arise. . . .I don't know how they would [even] find me," said the manager of one water treatment plant. That the assumptions guiding really-existing emergency management will diverge from those of state and federal politicians and the public—e.g., their beliefs that backbone infrastructures of water and electricity can be restored immediately—should go without saying.

"To be frank, the state [emergency management support functions] would not be readily available immediately after an M9," said one state-level emergency manager. Even when there, these infrastructure managers and staff, as well as for their part, emergency management responders, would be unable to control, let alone manage. "Bottomline: I can't control the bridges," said an emergency manager in a major utility. M9 will devastate vast regions simultaneously unlike seasonal events that are regional in impact. In the first 96 hours that first week, a state emergency manager went on to explain, efforts would be constrained "to accounting for personnel, triaging and trying to assess what resources [people and material] are actually still available. . . .That is the baseline assumption we are working off".

As such, the challenge in immediate response and initial service restoration is one of having to manage—better yet, cope—in the face of unprecedented failures, disasters and their consequences. Even emergency management experience with prior sudden flooding or recent fire events can't be expected to be a foundation for a reliable estimation of the range of consequences nor for their tasks in responding to those floods and fires that do result from a M9 earthquake.[1]

This means a M9 earthquake will be an *unfolding* catastrophe in major part *because* of the severe limitations it imposes for relying on the prior experienced-based skills and capabilities in emergency management. Many interviewees reiterated they have no idea who or how many of their staff will be able to resume work immediately afterwards. "The first 72 hours and you're still trying to figure out who's alive out there and those who can communicate," said a state emergency manager.

In other words, referring to "the M9 event" is misleading if it's taken to imply one event and not thousands unfolding unpredictably. One major implication, to telegraph ahead, is that it's better to assume infrastructure failure cascades are part of the *unfolding nature* of the M9 earthquake, where rapid and joint improvisations *necessarily* play an important role in addressing those ostensibly instantaneous and uncontrollable cascades.

Accordingly, we refer to the M9 earthquake from this point on as "the M9 events." Several interviewees indeed called into question an exercise or tabletop organized around a one-event M9. From our framework's perspective, if a one-event M9 exercise is undertaken (because of, say, budgetary constraints), the efforts should incorporate a focus on interconnectivities, their shifts and potentially overlapping control variables as discussed below. For example, conventional blackstart exercises to simulate re-energizing line by line after the electricity transmission grid islands assume no lingering asset destruction in the precipitating disaster. This is implausible given the M9 scenarios of the interviewees.

If an M9 scenario is this awful, why plan?

Given these many uncertainties, isn't anyone's educated guess as good as the next? The catastrophe of unfolding M9 events is compounded by the fact that any detailed-beforehand M9 scenario will have low predictive validity (i.e., the more specified a scenario of consequences and interconnectivities, the more likely actual events on the ground will diverge from it). Consequently, the sensible beforehand prediction is that all formal predictions are likely to have serious errors in estimates of complexity and the uncertainty ranges. "I absolutely expect to be consistently surprised and consistently faced with two crappy decisions and having to be in the position of choosing the one least bad for prioritization of what's next," a city water manager told us.

[1] An experienced high-level manager of a variety of infrastructures in California in describing the full complexity of their interconnections, without even thinking of a M9 earthquake, commented: "These infrastructures are more interconnected than we can even imagine." (Roe and Schulman 2016).

“Why are we even planning? It’s going to be that bad,” one interviewee reported county officials asking. I don’t even know where to start once I go down that rabbit hole, to paraphrase the response of another. It can feel like an avalanche you’re just not going to get ahead of, reflected a state senior emergency management official.

Given so much uncertainty that comes with the M9 earthquake, it is no surprise emergency managers rely on their pre-disaster plans and processes as a starting point. The importance of activating the ICS structure has already been mentioned. This means that instead of concluding you can’t really be prepared for something as unimaginable as the M9 events, what concerns most of the emergency managers we interviewed is the lack of further preparedness in respect to what can still be prevented regardless. Some fires are clearly preventable, e.g., through prior vegetation management. So too if pre-disaster efforts such as mitigations, two-week ready supply programs of essential materials including food and water, and other preparedness planning can help reduce the pressure for immediate response or reduce the longer-term recovery period through the reduction of damage that would have otherwise been incurred in the absence of such measures, these too should not be neglected.

The insight here is that, for those interviewed, the real-time unpredictability and unexpected contingencies ahead in the M9 events carry their own information about interconnected infrastructure systems in failure and that information can be useful for managing or coping ahead (see Schulman 2021). This is especially true for those real-time professionals whose core competencies revolve around systemwide failures: They are likely to know beforehand something about how the system in failure will affect other interconnected infrastructures. As the chief feature of a M9 earthquake will be its shocks and surprises, the framework sketched below alerts us to focus attention on emergency managers and responders already on the look-out for surprises in shifting interconnectivities and joint control variables of the infrastructures.

Interviewees stressed the need to focus on infrastructure components and facilities they *know* will fail in the M9 events, whether or not the knowledge has been formalized into an agency’s risk register and risk assessments. That there are no guarantees pre-disaster efforts will actually mitigate is beside the point for experienced emergency managers who have witnessed or been directly involved in disasters elsewhere. They have seen how better pre-disaster efforts would have made a difference there. That is their job. One core competency of emergency managers is to identify pre-disaster opportunities—including new options and strategies for increased requisite variety to improve real-time disaster response, and not just in their own infrastructures. Seismically strengthening a water infrastructure, as one interviewee confirmed, would better inform emergency planning and projects for the road and wastewater infrastructures adjacent to the water lines.

In short and for the purposes of the framework below, uncertainty isn't defined as the lack of information; it instead can be a form of information about known unknowns, such as where infrastructures might shift their interconnectivities, from one-directional to mutual in M9 events and how this might possibly affect a newly reconnected backbone network. This, we believe, can be a major cognitive foundation for effective jointly undertaken, shared improvisation and real-time coordination of immediate response and service restoration discussed below.

Concluding points about an M9 scenario in Oregon and Washington State emergency management.

We fear there's been much mischief in thinking that gaining disaster knowledge and experience is really about better estimating risk—that is, probabilities and/or the consequences with respect to "low probability high consequences events."

"Operating blind" with the loss of telemetry, cellphones and power is how one infrastructure operator described experiencing an ice storm. It's that "operating," then and prospectively ahead under even worse circumstances, that we seek to better understand and clarify. "I don't know that we answer until we're in the event in a lot of cases," echoed a city infrastructure manager for water. So too is "coming to those answers" a process we want to know more about and explore here. What to do then in terms of more specific planning for, mitigating against, responding to and recovering from the M9 events? We now turn by way of an answer to a proposed approach and initial examples of its usefulness.

Section III. Proposed framework, with extensions to emergency management in Oregon and Washington State before, during and after an unfolding M9 earthquake

Several interviewees described major Labor Day 2020 wildfires when a well-known electricity transmission provider in the two states had lines out, one of which affected a strategically important substation and its service areas. This incident exemplifies the significance and difficulty in coordinating inter-infrastructural interconnections and shared control variables in major infrastructure emergencies. One interviewee described having had to contact, as a matter of extreme urgency, the relevant electric utility and firefighters about the criticality of that substation and urge them to put focused attention on saving it. It was and is a backbone component—a "linchpin" in the words of another interviewee—not only for systemwide transmission electricity, but also for regional fiber optic telecoms, in addition to serving two large urban areas dependent on those critical services. This jointly undertaken and coordinated activity, as well as others on the fly, proved effective in saving the substation and preventing the knock-on consequences of wide failure.

Such incidents make more visible and highlight the elements of our proposed framework for better addressing the M9 events: (1) infrastructural interconnections and their shift-points during immediate emergency response, (2) at the same time, attention to joint improvisations around system control variables shared by key backbone infrastructures, and (3) all measured against a performance standard for emergency management beyond the understandably general and subjective one: "we did the best we could with what we had".

We describe each feature in detail, starting with requisite variety and control variables and then moving on to interconnectivity configurations and shifts. For each, we draw out initial implications and examples of how each helps rethink emergency management as currently understood (leaving for Sections IV and V the larger topics of scale, scarcities, and coordination, among others).

The chief takeaway in this Section III is that the backbone infrastructures are inherently socio-technical systems. While physical interconnections—e.g., Washington State has two supply chains for petroleum products, one physically for its west and the other for its east—are instrumental for effective infrastructure operations, management factors are inextricably intertwined with the physical, and vice versa. These notably embrace the private sector. “Even though they have it in a contract doesn’t mean they’re going to be able to deliver it,” said a plant manager about supply chain shortages that worked against their preventive maintenance activities.

Let us now turn to elaborating at greater length specific elements in the framework.

1. Requisite variety.

The gist of requisite variety is familiar to experienced infrastructure operators and emergency managers: the need to increase real-time options, strategies and resources so as to better match the requirements of unpredictable or uncontrollable conditions. This is the strategy of requisite variety.

As discussed in the relevant literature (Ashby, 1958; Weick, 1995), requisite variety is the principle that it takes some complexity to manage complexity. If a problem has many variables and can assume a diversity of different conditions or states (such as shifting interconnectivity among infrastructures), it takes a variety of management options to address this complexity (such as uncontrollable changes in system inputs) and to transform them into a smaller range of managed states. If there are variations in problem inputs, then there must be enough process variety available to managers to cope with the input variance in order to produce managed outputs. Having a diversity of resource and strategic options or being able to invent them is a way to match and manage problem complexity with a requisite variety of response capabilities. In this way, “what are the things that worked that you didn’t anticipate?” becomes a key performance question, as one experienced emergency manager put it.

How does the principle of requisite variety apply to the M9 earthquake and events? The answer requires us to rethink some commonplaces about emergency management. For instance, establishing and maintaining personal/professional relationships before an emergency is almost universally mentioned by interviewees. “I never want to meet someone for the first time in an emergency” is one example. But more is going on than increasing the number of different contacts. When it comes to assembling and managing for requisite variety during emergency response, networked relationships can enable system-wide pattern recognition for speeding up understanding and revising strategy to deal with shifted interconnectivities under M9 conditions. For example, wastewater treatment requires chemicals, and several interviewees describe how a shortage of one, chlorine, had knock-on effects, including necessitating new contacts and opening up unexpected real-time options.

We have more to say in the following section by way of reinterpreting the importance of contacts and relationships. Suffice it here from our framework’s perspective, relationships (contacts, partnerships, colleagues) are first and foremost *interconnections* between and among people, positions and professions, where engaging these linkages is key to realizing the shifts in interconnected task demands and resource capabilities (see Almklov and Antonsen 2025).

Requisite variety and positive redundancy, it should be noted, are coupled. It is common in the high reliability literature to see the importance of positive redundancy for handling temporary disruptions in normal operations, e.g., the ability of bringing online a new generator when one suddenly fails during normal operations.[2] That positive redundancy also remains key when the standard is one of requisite variety in emergency response. This is true, however, not only for the preservation of options, but also now for other reasons: Even if the generator doesn't go off-line, having another one better enables new options to be assembled just-in-time.

For example, the ice storm that took out water and communications on one side of a major interstate did not do the same for the city on the opposite side of the interstate. That city was in turn interconnected with a third city, which was then able to provide emergency water supplies to the ice-battered city. Having alternatives is no guarantee, however, of requisite variety. A smaller utility had 80% of its physical infrastructure destroyed by recent fire events, we were told. A major fire threatened the watershed of a city and raised very real concerns in the water department about longer-run impacts on supply. A water treatment plant manager reported an ice storm that brought down all four electrical substations supplying the plant's operation; the ability to obtain water with other treatment plants, even if the latter were willing to, wasn't possible because the larger electrical intertie was also without power. While there are spare transformers, they are not enough for the large transmission grid as a whole, should the M9 events occur.

To telegraph ahead, such questions of scale with respect to requisite variety and positive redundancy become wider questions about interconnectivity configurations, their shifts around systemwide control variables, and durations involved (see Section V's discussion of scale-related interconnectivities) . We also have much more to say about the importance of requisite variety and its role in effective emergency management, which is the subject of Section VI and further addressed in Section VII's focus on emergency coordination. Here, however, let's continue with our discussion of the framework's major elements, moving now from requisite variety to the central role of system control variables.

2. System control variables.

We define control variables as actionable real-time features of an infrastructure that can be manipulated to alter the overall state of that infrastructure, such as voltage and frequency controls for an electrical grid or water valves, pipes and pumps to control real-time water flows from dams or other reservoirs.

Control variables are specific to each infrastructure, and their use can overlap in normal operations as when water is released from a dam or reservoir to provide hydropower generation for the operation of the electricity grid. Control variables can overlap far more

[2] Also mentioned with respect to the importance of positive redundancy in normal operations of large infrastructures was designing and building to a "n-1 contingency." That is, systemwide services would be maintained even with the loss of one essential component. Think here, as several of our water and power interviewees did, of having spares always available, such as separate container storage "for the Big One," as one phrased it.

consequentially with interconnectivity shifts in service disruptions and outright infrastructure failure, and thereafter in the requirements for emergency response and initial service restoration. Think here of the very same water flows as control variables for irrigated agriculture and water treatment plants, all along the same large river.

Another case in point is the automatic shutoff valve. It is key in earthquake response precisely because it can adjust or otherwise halt water flows as a control variable and in so doing changes the interconnections of those depending on water in the rest of the system, e.g., the effect of shutting off water for, say, firefighting during the emergency. So too the *loss* of a control variable is incredibly important, e.g. a stuck drawbridge changes the configuration of road transportation across a river and vessel travel within the river and interconnects to other critical infrastructures, like control room operators getting to their respective utilities.[3]

Shut-offs are more than a matter of technologies, reminding us that these are socio-technical systems. The public safety power shut-off (PSPS) was mentioned as a major management tool utilities can use to prevent line failure-induced wildfires during extreme weather events. They are important for state level emergency management because power is so interconnected with other backbone services. A senior state emergency manager told us that telecommunications providers need to know if there's going to be PSPS, so that they can prepare for loss of telecommunications and placement of mobile units to compensate. A utility emergency manager wondered if the PSPS approach should be anything but a short-term measure: There has to be a better solution, pressed the manager.

For a better understanding of the interconnections around control variables and their role in achieving requisite variety, we now offer a lengthier discussion of types of interconnections and then move to shifts in these configurations with respect to immediate response and to initial service restoration. In discussing the shifts we focus on the importance of inter-infrastructural improvisations in rendering the shifts effective. We draw out implications of these features for emergency management as we understand it in Oregon and Washington with respect to the M9 events.

3. Types of interconnectivity and salient configurations.

For initial schematic purposes, think of interconnectivity as uni-directional or bi-directional. In the former, an infrastructure has a one-way causal connection to another either primary or dependent. There can be a sequential dependency of downstream infrastructures running along a chain with each having both a dependency on its predecessor and a primary relation to a dependent downstream user, as an electricity provider has to a telecom and the telecom in turn has to a dependent water provider that requires the telecom for its control room's Supervised Control and Data Acquisition (SCADA) system.

In a bi-directional relationship, the influence and dependency connection is reciprocal, as when a road along a levee depends on the support and strength of the underlying levee, but the levee depends on the road for access of materials and repair crews to repair levee boils and breaches

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[3] "I live a couple of bridges away," said a plant manager. Other interviewees also made a point about the bridges between where they live and work.

(Roe *et al* 2016). It is common in ordinary language to conflate interconnectivity with interdependence, but we reserve the latter term for reciprocal, bi-directional connections. "Interconnectivity" is thus a broader category here.

This interconnectivity can be within the same infrastructures or between and among different ones. A water association manager described how a study that made visible the regional (physical) interconnections between the association water providers proved to be useful for developing strategy for moving water among themselves in times of mutual need.[4] The rest of this report, however, focuses on the interconnections between and among the different backbone infrastructures. We first look at differences in interconnections in terms of whether they are latent or manifest. Then different types of interconnectivity configurations are identified and discussed for the purposes of our framework.

(i) Latent and manifest interconnectivity. Inter-infrastructural interconnectivity includes not only *manifest* interconnections (e.g., infrastructure x's output is infrastructure y's input), but just as important the *latent* interconnections that become manifest when system normal conditions shift into disrupted or outright failed operations. For example, a city water system would have to depend on electricity being in place were it to fallback to groundwater once its current gravity-fed system failed. So too if liquid and natural gas systems fail means having electricity become a more important backup.

Indeed and for our purposes significantly so, some interconnectivities and their configurations are only "revealed at the time of the incident," stressed one long-time expert. For instance, during normal times electricity customers are the last stop in a sequential chain of linear dependencies running from transmission grid managers to distributors. But that changes in periods of high load and/or scarce generation reserves when a grid management agency and distribution utilities have to appeal to customers directly to reduce their energy consumption in order to avoid rolling blackouts. Also, generators that are normally independent contributors to a pool of energy supplied to the transmission grid may now become reciprocally interdependent on one another to keep running at peak generation so as to maintain grid balance of load and generation. They are, in effect, all held hostage to the least reliable generator among them.

Detecting and managing latency is an important element in our framework and requires the recognition of potential shifts in infrastructure interconnectivity under conditions of disruption or failure. An M9 earthquake is expected to cause all kinds of ruptures and leaks in water and sewer lines beneath roads. A leak could with time undermine the road bed and lead to road's collapse above. What was a near independency between the underground lines and the road now becomes a significant dependency between roads and losses of below-ground line integrity. In fact the frequent layered co-location of water, sewer and gas lines has led to a lower-level infrastructure having to wait for the one above it to shut off its pipeline in order to be able to access its own to repair.

[4] More formally and to telegraph ahead, the water association as a focal organization facilitated reciprocal and pooled interdependencies among individual providers who were not interconnected in this way during their respective normal operations (more on these different types of interconnectivity below).

Here too managing latency isn't only a matter of the "technical" side of these large socio-technical systems. Most familiar are those tabletop exercises that include identifying latent technical interconnections between infrastructures that might well become manifest, depending on the type of emergency being exercised. Less familiar, new managerial challenges can arise in coordinating responses across infrastructures to address emergent mutual restoration requirements. Allocating more administrative staff to emergency planning and management units, committees, task forces, and working groups can be a means of seeking to manage ahead for key latent-to-manifest interconnectivities. Calls by interviewees for more administrative support may look like a routine complaint or a small-deal when compared to other priority urgencies. But from our framework perspective, it is a very big deal in attempting to move the planning and mitigation agenda to latent inter-infrastructural interconnections *before* a disaster happens.

It is important to make clear that, based on our 47 interviews to date, only a few respondents in each backbone infrastructures see, let alone act, on these latent-to-manifest interconnectivities. A wastewater administrator and manager told us that in an emergency, one effort is to cordon off and isolate the control room from too many phone calls or communications, given the intensity of the demands on operator attention at that time. This seems more than reasonable, but: What if some of those cordoned-off calls involved time-sensitive requests arising from what had been latent but were now manifest implications for wastewater operations in the emergency? There appears to be a gap in inter-infrastructural strategy regarding the potential cognitive load that latency can impose on infrastructures, which have been operating separately because of their own intensive task demands. We return below to the importance of latent-to-manifest interconnectivity for M9 immediate response and service restoration.

(ii) Different configurations of interconnectivity. In addition to latent and manifest, interconnections also differ in terms of the configurations they take on across the cycle of infrastructure operations from normal, through disrupted, into failed, then under immediate emergency response including initial service restoration, thereafter into infrastructure recovery and onto a new normal (if at all) for operations. Consider an example up to failure and response, e.g.:

- Vessels come into a port and shipments are off-loaded there onto truck and rail for onward transport (sequential interconnectivity with serial dependencies).
- If there is a major service disruption, the port may take a more active role in coordinating which vessels have priority, how shipments are off-loaded and stored temporarily, and the modes of transporting onward (mediated interconnectivity by the port as a focal infrastructure).[5]
- If the disaster is more extensive, the vessels may have to coordinate from ship pilot to ship pilot, without the assistance of port authorities or others (reciprocal interdependence)

[5] Waterway re-openings were also mentioned as in need of a focal organization to help guide priorities for which vessels in the back-up queue were to pass through before others.

· The Incident Command Structure set up immediately after the disaster may make coordinating the waterways for emergency uses one of its first priorities (pooled interconnectivity centered around the focal ICS or a vessel traffic control unit).

It is a challenge to keep in mind these different interconnectivity configurations, let alone their latency and shifts from one to another. A city asset planner and manager told us a continuing problem was how to map infrastructure interconnections so that decisionmakers could better visualize how facilities in poor condition had potential knock-on consequences, along with response and recovery investment implications across the infrastructures. Several interviewees already make use of multi-layer maps of infrastructure placements, including potential (i.e., latent or manifest) hotspots and chokepoints.

4. Shifts in interconnectivity across infrastructures and shared control variables.

Based in the preceding distinctions, immediate emergency response/initial service restoration, along with the longer-term recovery to a new normal (if any), can be disaggregated into three rough types of interconnectivity shifts with associated control variables:

(i) shifts from latent to manifest interconnections;
(ii) shifts in different kinds of configurations related specifically around control variables; and
(iii) shifts in inter-infrastructural/inter-organizational relationships during actual failure, immediate response and across longer term recovery.

Note these three are "relations"—interconnections more than properties—a point we keep coming back to in this report. Let's now turn to each bulleted (I, ii, and iii) shift.

(i) Return first to shifts from **latent to manifest interconnections** during failure and immediate response, e.g., the road that is used exclusively for transportation pre-disaster shifts to serving also as a fire break in wildfire response. Underlying these shifts is the importance of *single resources having multiple uses*. Telecoms and electricity may share the same utility poles. Different electricity providers can share the same transmission tower. Ferries become an extension of the highway system. Crews on the distribution side help with repairs on the transmission side of a water system, where the separate units "have a very interconnected role," said the manager of the distribution system. Crews on the wastewater side and potable water side are cross-trained to help the other out.

Emerging uses or creating new uses for existing resources are an important part of being a backbone infrastructure: "If [resources] are only there for the emergency, you're not really using them effectively the rest of the time," said a former senior water engineer. When the meter wasn't working, the water treatment plant staff reverted to using a tape measure to gauge reservoir depth. Park and recreation facilities serve as temporary city shelters when needed. The facility housing the water department is the back-up facility for the roads department, should the latter lose access to its own older, less seismically sound office block. Assets permitting, the water department will clear important roads, even if the roads department can't.

Formally, what had been a latent resource use becomes manifest for that resource in emergency times. The improvisations we discuss below are an exemplary case of making use of what is hand, even if not originally intended for such. Exemplary, though, shouldn't be taken to mean exceptional: Personnel in roads and water departments may be better at improvisation in an emergency because they also work together routinely at other times. (For example, during normal operations of both, road crews pave over sites where water repairs have been undertaken.) Also, the city units for transportation, water and wastewater are "very interconnected in how we interact on a daily basis as well as in crises," said one of the unit managers. Should it need saying, this cooperation during normal times may also be done for cost-effective or budgetary reasons.

(ii) There are also **shifts in types of interconnectivity around shared control variables**. This is an extremely important element in the framework and below we spell out key points.

Although a backbone infrastructure in normal operations differs dramatically when in failure, sequential or serial interconnectivity at the infrastructure systemwide level doesn't disappear, nor would it the M9 events. Interconnectivity configurations, however, would most assuredly change. Restoration of the electric transmission grid would start with the 500kV lines, then the 230kV, then the 115kV. An emergency manager for an electric utility said that M9 outages would initially be treated like any other outage, following a multi-step process to bringing back the system. We were also told by a statewide emergency manager that response to a major ice storm consisted of first closing the affected state roads, followed by power companies coming in to move the downed lines, and then crews coming in to remove the fallen trees. The manager added: The first priority is to get I-5 open; then try to help out where they can in clearing non-state roads, like to a hospital or water treatment plant.

A senior emergency manager in a major electricity transmission company spoke of the company's Covid-19 response sequentially: "Slowly over time. . .we figured out who the critical wraparound service—those capabilities are. It may have been 400 people at first that were coming in physically, but then as we got better and understood what COVID was doing, then we allowed a little bit more critical IT folks, critical supply chain logistics folks to come in to help sustain the mission essential function personnel. That ballooned out to about 800 folks or so, and we sustained that 800 folks since then." Immediate response and initial service restoration involve such sequences.

Some shifts in sequential interconnectivity have been misunderstood by outsiders. One of the first things to happen when power, telecoms and water components fail, is to revert to manual operations, where possible. "They try to do it manually," said one infrastructure manager about staff operations during immediate response. Such a shift from automated (electronic, digital) operations to manual, hands-on operations triggered by an infrastructure emergency is sometimes seen in the literature as a reversion to an older practice or technology. From our framework's perspective, the shifts in interconnectivities from (more) automated to (more) manual operations reflect and recognize that the same system control variables remain important—that doesn't change in failure—and can only remain so through special efforts like improvisations undertaken during emergency response. Even when "shifting to manual operations" looks like the way they used to do things, doing so doesn't have the same role in an emergency affecting interconnected infrastructures.

An earthquake can shift sequential interconnectivity to reciprocal interdependence with respect to backbone infrastructures. The quake ruptures the utility corridor where wastewater pipes are at the bottom of the trench with potable water above it, and fiber optic above that, or natural gas nearest to the road, thereby rendering it interactively volatile. (One interviewee mentioned that some utility corridors are adding new infrastructure layers and latent interconnectivities, e.g. the addition of bioswales to better trench stormwater above layers just mentioned.)

Emergency response and initial service restoration often bring mediated interconnectivity into the mix of shifting reciprocal and sequential interconnections. How this happens is particularly important in thinking ahead about M9. Most of those we interviewed—but not all—were part of already small organizational units; in fact the individual may be the unit. "I'm a one-stop person," said an experienced manager of a water providers group and echoing what was said by others we interviewed. "In my organization, I'm it," emphasized a state emergency preparedness manager. "Up until recently I was an office of one," a state emergency director told us. It is fair to recognize that a single "one-shop" person, while functionally providing mediating interconnections, also becomes a fragile interconnection that could disappear under an M9 earthquake.

In formal terms, the focal organization in making and undertaking interconnectivities is often the focal professional, with his or her duties and responsibilities. These professionals are central to realizing the shift from interconnectivity configurations that existed pre-emergency to a mediated interconnectivity in whose configuration they play an instrumental role. While in need of more staff and larger budgets, being a unit of one or few persons under emergency management mandates puts a premium on maintaining and updating contacts as a way of both augmenting your own resources and making the best use of your time as an emergency manager. A not-inconsiderable benefit is when your contacts include members of infrastructures that are difficult to reach by your other network members (the lack of rail and telecommunications contacts being most mentioned to date).

Sometimes the focal professional derives clear authority from his or her position. Said one emergency manager in the state's department for roads, "[Our department] is the only agency in the state that has the authority to close [state] roads". Not infrequently, these professionals take on responsibilities beyond their formal duties. Their helping to bring in back-up generators to where they were needed—e.g., coordinating generator placements at gas stations whose power was out but which were needed for nearby responders—is, in our framework, professionals undertaking a focal mediating role. This may involve also coordinating field managers of crews, road closures, fuel trucks, private-sector hotel rooms and meals for first responders. . . so as to ensure a requisite variety match then and there for the time being.

The mediation configurations differ, as one might expect when the performance challenge is ensuring requisite variety. One focal professional mentioned sitting in on meetings with front-line responders to help smooth over conflicts and tempers. A comparatively better staffed emergency management unit was described by its manager as having a mediating role with respect to state-owned roads, rail and maritime. There was also that earlier-mentioned instance where one water district, it being a "hub," provided water to another by being interconnected to a third, where not only was water a shared control variable but also electricity by virtue of the generators that unit provided as well to the distressed city.

Being a focal organization can also be in part a matter of explicit organizational design: One state's department of transportation, for example, is responsible for ferries and aviation in addition to state-own roads and rail. More directly, many see the government Incident Command System, once activated, as having the big picture and "thus" serving as the single command and control mechanism in emergency response. While none of the interviewees to date mention it as a problem, the ICS could be an obstacle to fully realizing the horizontal micro-coordination and improvisation dynamic we have been stressing as a key to the generation of requisite variety in M9 response options and efforts (more below).

To summarize the preceding discussion on system control variables: Shifts in latency and in types of interconnectivity around control variables depend upon the event (its demands) and staff and equipment available (resource capabilities). Context always matters. The fact that a major road and the airport are adjacent to each other takes on added functionality when the airport becomes a staging area for onward transportation of emergency supplies. The backbone infrastructure of a city water system was selected to be close-by to hospitals. The fact that the emergency managers had been activated for Covid-19 made it easier to piggyback activation for the later wildfire response.

Clearly, overlapping or shared control variables are a major factor in shifting interconnectivities, and certainly will be in M9. The overlap of different control variables can be very problematic in managing shifted interconnectivity even if they are separate and different control variables. Firefighters setting their firebreaks under more accessible rights-of-way, which are the same rights-of-way for electricity transmission lines, create conflict between backfires needed by the firefighters and the voltage and flow paths along the transmission lines. When major wildfires occur near power lines, field crews from a major electric transmission provider are dispatched to coordinate with firefighters over line and safety issues, e.g., shut the line down if backfires were needed in the right-of-way.

Another example of overlap is when a stretch of a major freeway is closed so a power company can repair a major transmission line that crosses that highway. Road closures can be extremely important with respect to shifting interconnections among overlapping control variables, not least being getting fuel and generation to first responders protecting key assets during a fire. As for shared control variables, because they share the same waterway, clearing a waterway and opening the port happen together post-disaster.

(iii) Last but not least, there are also **shifts in inter-infrastructural/inter-organizational relationships during actual failure, immediate response and across longer term recovery** that necessarily involve new political players and stakeholders and, with them, changing imperatives (clearer in immediate response but less clear or agreed-upon during longer recovery). Hand-shake agreements—in our framework, examples of reciprocal interdependencies—between managers or operators to help each other out in case of an emergency remain instrumental at the time of writing. But "a hand-shake is good for six months or so" after the disaster, an experienced emergency manager phrased it.

New manifest and latent interconnections, and their different configurations, emerge during recovery, as the complexity of recovery increases. These include, e.g., getting rid of an infrastructure's legacy technologies and facilities or adding new environmental protections with "never-happen-again" regulations. Do we rebuild the facility, replace it with something better, or move to a better site—all these involve building codes, permitting processes, shifted personnel, and often political disputes—in short different interconnectivities and less unanimity and clarity of objectives than in immediate emergency response. It's easy to see why interviewees say about recovery, "All of this takes time." From our framework's perspective, however, it's better to say that the shifting and emerging interconnectivities can extend out in duration and scale, including new latent-to-manifest interconnectivities and conflicts that lead invariably to "it took much more time and money than anyone thought."

To sum up the preceding three subsections, the reader should now be better able to appreciate why understanding shifted interconnectivities due to a major emergency or catastrophe requires not only better understanding of the latent interconnectivities that have become manifest in disaster response. It also requires greater recognition of the broad dependencies that have built up and evolved around critical infrastructures in terms of interconnectivities and dependencies, be they positive, negative or alternating between.

For example, the M9 rupture of commute interconnections between infrastructure workers living in areas well away from their headquarters, control centers and field offices cannot be subsumed narrowly under "a road infrastructure catastrophe." Large socio-technical systems, like roads, have evolved over time, one feature of which has been their evolution of commuter schedules (x weeks on, n days off) and remuneration packages that made pre-disaster commutes more or less worth it. An integrated approach to policy and management with respect to the M9 earthquake, however, must ask: Are the arrangements still worth it? How are the latent and manifest vulnerabilities posed by new arrangements, post-disaster, more manageable? Answers would require careful attention to vulnerabilities arising out of designing new infrastructures *as well as* arising out of infrastructures actually recovered previously.

5. Joint improvisations around overlapping or shared control variables.

Improvisations, jointly undertaken by infrastructure operators and emergency responders, take on their premium and criticality within the dynamic M9 context of shifted types of interconnections where emergent latencies and control variables in normal operations are still important but now often in very different ways for immediate response and initial service restoration.

Improvisational behavior is mentioned repeatedly in the emergency management literature (see also Boin *et al* 2016; Frykmer *et al* 2018). Our research findings add value by stressing the importance here of an extremely important subsample of joint improvisations (see also Guerrero *et al* 2023). An impromptu berm is built around a substation or a fire break bulldozed around a communications tower, both of which are critical. Why? Because of the collocation of critical components that supported, in the case of the high-valued tower, state police, forest service and transportation. These inter-infrastructural improvisations on the spot end "saving the asset," which in our terminology was preventing failure in critical services interconnected through a shared substation or tower. Other examples of what we are calling joint improvisations during emergencies were also mentioned in our interviews, the point being in the words of one county emergency planner and emergency coordinator: "There's a lot of improv that has to happen here".

The key feature of joint improvisions involving emergency responders and infrastructure operators is that they come in unpredictable forms contingent on then-specific demands and then-existing capabilities, but they are each and all for what are then essential needs. One state coordinator involved in communications management during emergencies told us about convening an online group of competing companies and infrastructure providers:

> During a winter storm we had a utility or provider say we've got fiber cuts in this area, we don't have the fiber to replace it in that area, our resources are in this other area—that allowed us to look at the group and say now is the time for some teamwork: Can anyone else solve that problem and be a good team member? And we've seen a lot of that sort of problem-solving manifest among the agencies with very little input from us. Another example might be a cellular carrier who is a competitor of another carrier going "Hey, we're going to fill our generator, can we top off your fuel tank while we're up there?. . .But I don't think [those kinds of cooperation] would occur if we didn't coordinate it and get everybody on the same call and provide a platform for them to kind of air those sorts of things.

To characterize these one-off improvisations, like topping off a fuel tank, as incidental or side work or what mates just do for each other, is to miss entirely the point that they are essential for professionals undertaking effective emergency response. (More on this in sections that follow.) Indeed, from our framework's perspective, not foregrounding the role of improvisations (and improvisational skills) can lead to confusion about "building in resilience" and its role in emergency management.

Since, if our interviews are any guide, improvisation will continue to play such a central role in emergency management practice, it is not possible to answer the seemingly reasonable question, How much pre-disaster mitigation is needed? When is "resilient-enough" enough?," asked an interviewee. Maybe we don't have to fix every road before the earthquake, to paraphrase another. While understandable sentiments, no amount of money or political-will beforehand would be enough to dislodge the central and strategic role of improvisation in the unfolding M9 events.

It is, of course, countered that the absence of expense beforehand guarantees things will be even more expensive afterwards. More than one interviewee underscored that major disaster response, restoration and recovery requirements were so great as to necessitate the involvement of all manner of interconnected partners—state, federal, city, county, private, out-of-state and more—and each with its special interests and expertise. Yet the fact that these working partnerships don't exist with the same immediate-response logic, clarity and urgency before the disaster or for the longer-term recovery that follows is far more important for emergency management on the ground than differences in dollars and cents for this or that mitigation beforehand. *When it comes to immediate response under M9 conditions, there is no workaround for improvisation*.

With these framework elements and implications in mind, turn now to how they enable us to reinterpret many recurring topics raised in our interviews and in the literature. Section IV deals with the complicated subject of distinguishing failure, response and recovery and how our framework helps clarify matters. Section V illustrates how the framework clarifies other major topics in emergency management related to: communications; learning; staff and resource scarcities; networks of contacts and professional relationships; interconnectivities inducing scale effects; and pre-disaster mitigations. Sections VI and VII take up the all-important subjects of emergency management performance standards and emergency coordination, respectively.

Section IV. Failure, immediate response and longer recovery from Framework perspective

The state government literature reviewed for this research typically assumes recovery follows response, where the former builds on the latter. Some interviewees (all insiders), however, make it a point to say recovery begins with response, if not earlier. Our framework allows for a more nuanced set of terms, because of its specific focus on different types of interconnectivity configurations as they shift around different but at times overlapping or shared system control variables and in light of impromptu improvisations.

The shifts in how things are interconnected enable us to distinguish between immediate response (e.g., search and rescue) and attempts at initial service restoration of backbone services (e.g., placement of mobile cell phone towers), both of which happen more or less just after the disaster. Sometimes interviewees seem to mean by "recovery" that service restoration occurs hand-in-hand with response. In other cases, interviewees seem to be alluding to the fact that thinking about longer-term recovery, especially in terms of undertaking damage assessments and requests for federal reimbursement, occurs during initial response and service restoration. There are other times, where service restoration takes place because the destroyed assets have been immediately repaired or replaced with newer versions already available. Where so, the improved repairs and upgrades begin to look like part of longer-term recovery strategies from the infrastructure's systemwide perspective.

That said, there is no getting around having to think about recovery in immediate response and initial service restoration, if not well before. Restoring electric power and re-building new lines or generation may have to go on simultaneously. "A lot of response for water systems is related to recovery," a drinking water subject matter specialist told us. "For us, recovery begins at the same time response begins, at least at the state level," said a state logistics officer. Clearly, thinking about recovery is going on in pre-disaster planning. Asked when recovery starts, a state emergency manager responsible for roads, said: "It starts now. We are already working on recovery".

From our framework's vantage point, however, long-term recovery does differ from immediate response and initial service restoration (with or without asset upgrades) in at least one crucial respect: New or different stakeholders become involved with respect to the goals and aims of that recovery. The key indicator is when recovery efforts lose the logic, clarity and urgency that characterize immediate response and initial service restoration. To put it from the other direction, longer-term recovery is more political and conflictual than what preceded it by way of first response and initial restoration.

In the rest of this subsection, we will illustrate how the framework helps in better understanding the distinctiveness of immediate response and service restoration, along with the different kinds of initial recovery activities mentioned by interviewees. The more political and conflicted longer-term recovery is something our interviewees typically said was outside their wheelhouse or above their pay grade. Let us now turn to the interview details.

With the interconnected failure of backbone infrastructures comes the logic, clarity and urgency in immediate response identified at the end of the preceding Section III. Part of this is that the roles and actions of emergency responders and managers are already defined in many playbooks and action plans for emergency management. It's the disaster itself, however, that gives emergency response its logic, clarity and urgency when it comes to restoring backbone services, even if temporally (e.g., through placement of mobile generators or the like). The improvisation option is necessary as the playbook or action plan is overtaken by events. Yet, at the same time as immediate response and initial service restoration are underway, so too are meeting the administrative requirements for reimbursement and other funding requests that follow from FEMA involvement at the time of writing. Again, the composition of key stakeholders must be expected to change in relation to shifting goals and actions in this period from response and restoration to longer-term recovery.

But when it comes to expectations, the first, and arguably biggest, change to anticipate are the shifts in interconnectivity between response-as-planned and response-as-undertaken. Experienced emergency managers and responders recognize the heavy implications that follow for actual emergency management as distinct from what is described in official playbooks, preparedness plans and documentation for business continuity, delegation of authority and orders of succession in emergencies. A senior state emergency official recounted how at an earlier Cascadia event exercise he didn't hear anybody first say, "Hold on, let me check the playbook and see what it tells me what I'm supposed to do".

This does not mean the planned timelines and interactions between and among backbone infrastructures are unimportant for emergency response: "I do think about timelines," a district emergency management planner told us. "We all know that you can only survive without water for three days". Water treatment chemicals have a shelf life, and one recent shortage was described by a city utilities engineer as "pretty scary". There are timelines specifically for the technical side of infrastructures. "If we lose a transformer and we don't have a spare, it could take anywhere from a year to two years to replace," said a senior engineer in a major power transmission company. With the M9 events, the time-urgent priorities for infrastructure capacity and assistance would shift to saving lives given the short window of efficacy for that, said more than one interviewee.

But no plan survives contact with the enemy. First and as already noted, failure events will be ongoing throughout the M9 response. Consider the example where an initially small fracture in the water-main (or for that matter, the adjacent wastewater line) doesn't become evident until the leak causes a sinkhole, taking out the section of a road above and around. (If it were a catastrophic break in a transmission water-main, it would be seen more readily because of the high water pressure.) What in hindsight is a late response by a water utility becomes part and parcel of an unfolding failure sequence that is now inter-infrastructural by virtue of the stretch of road being knocked out. "The incident within the incident" is how a senior state emergency official put the unfolding and is very relevant to the effectiveness of the site- or system-specific emergency management.

The character and duration of unfolding failure are, in other words, reciprocally interconnected to immediate response. What had been latent interconnectivity between the road above and the water-main below becomes manifestly interconnected after the disaster, but in ways that do not fit a neatly "first-there-is-failure" and "then-there-is-response."

At this point we need to be clearer about what "unfolding" does *not* mean with respect to the emergencies discussed, including M9 events. From the perspective of the framework, "cascading failure across infrastructures" should be disaggregated into different interconnectivity configurations and their respective control variables before drawing out emergency management implications. Cascades may be more granular with respect to duration and open to management than assumed in formal modeling and planning processes. Certainly, interviewees described major emergencies in terms of punctuated sequential interconnectivity rather than as single huge rush of disasters.

The notion of punctuated duration shines light on another distinction that is more important for our framework: Disaster response actually begins in the backbone infrastructures. It begins before the formal activation of the emergency management infrastructure with its Incident Command System (ICS), such as incident management teams (IMTs) and emergency operations centers (EOCs). "When the M9 hits," said a city water distribution manager, "my group, we're going to be the first in. . .We're the first responders for the water system. I may even have to call someone who lives nearby and tell them to drive up to our major water tank and close the shut-off valve."

We believe a major point of departure in better understanding emergency management is recognizing that infrastructure control room operators and staff would be the first to know there's been an earthquake *with-respect-to their interconnected systems* and, as such, are first responders. Why is this important? Because backbone infrastructures and their organizations are invariably described as over-siloed or stove-piped during their normal operations.

From our framework's perspective, this intra-infrastructure shift from normal operations into failed operations triggers the emergency's first-response around interconnectivities that had been latent up to that point *and precedes* formal inter-infrastructural coordination mechanisms, most notably the ICS. Nor is it just that disaster response begins before formal activation of the ICS; *it's also that inter-infrastructural coordination and improvisation begin beforehand*. We were told that statewide emergency managers would be reaching out to one another with respect to an incident before any formal activation of the state EOC. "We cannot work in isolation," summed up this state senior preparedness manager about their shifting interconnectivities before ICS activation.

Inter-infrastructural coordination beforehand also includes public or business continuity programs (COOP, continuity of operations for public agencies, business continuity for private sector): "Don't forget COOP" an interviewee asserted. "In a continuity of operations plan, we have to know where the buck stops," added a senior emergency management official. From the perspective of our framework's focus on interconnectivity, COOP programs move center-stage because they are a key means of keeping immediate response, service restoration and initially recovered assets interlinked and stabilized for the purposes of decisionmaking ahead. There are no guarantees, however, even in M9 scenarios.

Yet while thinking about longer-term recovery may well be parallel and ongoing to response, there are distinct temporal shifts between the beginning of immediate response and the end of initial service restoration that deserve mention. These include: emergency declarations that trigger release of response funds; first responders leaving the site; disbanding of ICS site centers and incident management teams (a month or so after one fire emergency) along with production of after-action reports; or something more specific like the end of feeding programs or the reactivation of suspended environmental regulations. A key indicator that response and/or initial restoration are winding down is shifting the sequential interconnectivity from, say, two conference calls a day, to one a day, then none as we were told.

From the pre-disaster direction, a county emergency planner and coordinator told us that they had started recovery planning too early as emergency response and restoration continued longer than expected. They assumed, by way of an example, that worker Covid-19 vaccinations and staffing changes would proceed without much difficulty. Indeed, when it comes to speculating about recovery from an M9 earthquake, an experienced interviewee advised us to go back to February 2020 and imagine speculating then about what recovery would look like for Covid-19 by 2022.

So too are response and restoration distinguished from longer-term recovery in terms of their on-the-ground interconnectivity configurations and control variables as distinct from what is written by way of published timelines and plans. Response and restoration transition into longer-term recovery as shifting interconnections over a shared control variable—real-time water pressure, in the case of firefighting and restoring water supplies—stabilize (back) into more routine configurations or around a "new normal." Staying with water flow as a control variable under different interconnectivity configurations in emergency response, what had been water from irrigation wells during normal times could be converted to water flows for firefighting, or used to test for leaks in pipes that had bled out, or to treat by way of providing drinking water. In an emergency, can we put non-treated water in the drinking system so as to maintain pressure for the other water uses, to paraphrase a water district emergency planner?

Finally, return to that longer-term recovery about which interviewees have had little to say. From our framework's perspective, it's not an option to preserve the clarity of urgent response and restoration into those longer-term recovery processes. Nor do the demands of immediate response ensure an easier longer-term. As one emergency manager stressed, "How to talk about recovery in the present tense is something I'd love to figure out," we were told.

What our framework seeks to underscore is that new or emerging interconnections—particularly, making manifest the political relationships that had been more submerged during failure-and-immediate response—will be one of the most notable features of longer term recovery after the M9 events. And it will be *longer*: If at the time of writing (late 2022) former services are still not fully restored after the 2020 fires, imagine how much longer the staggered sectoral recovery will be after the M9 events. Managing the money and resources coming into the two states for response and recovery—an "overwhelming" problem in the words of two interviewees who had worked on other disasters like Katrina—is recognized also to be a management issue that extends the transition length between on the one hand response and restoration and on the other longer-term recovery for the M9 events.

To recap, the value-added of our framework's focus on interconnections, their configuration and shifts, especially around shared control variables and joint improvisations, isn't just to focus on the interconnections between, say, water and fire departments in a catastrophe. It's also to draw out the implications for both immediate response and initial service restoration when water pressure is a key real-time control variable for water supply and for firefighting. The framework directs analysts to focus their attention on the shifting spatial and temporal interconnections as the water system is restored, line-by-line, and fires are fought improvisation-by-improvisation, while other infrastructures operate or come back online.

It is this absence of the increased granularity necessary for analyzing and acting in immediate response and initial service restoration that best characterizes longer-term recovery and separates it from the former. Considerable implications for emergency management follow, to which we now turn.

Section V. Framework applications to key topics in emergency management: communications

1. Communications.

Much has been written in the literature on the importance of communication in emergency management, and certainly our interviewees don't dissent from the consensus on that importance. Our aim here is to add value by highlighting how the framework reinterprets some of the same findings.

In the first place the framework helps identify what we believe to be an underacknowledged positive of tabletops and pre-disaster exercises. Even in normal operations, some outages take a great deal of time to plan for and execute, requiring much communication and coordination between and among different units beforehand and during. Tabletops and pre-disaster exercises can foreshorten considerably that duration and coordination. In addition, tabletops bring into play new and potentially useful players for improvisations through changes or additions in city, county, state and federal partners. Against a back-drop where planning and coordinating for routine service disruptions take much time and effort by way of communication, tabletops and related exercises can shorten or deepen communications associated with task schedules and execution. They are also a means of developing personal contacts across infrastructures that according to many emergency case studies can facilitate more effective planning and coordination in real time of improvisational restoration efforts.

In the second place, gaps in communications arise because the interconnections between and among real-time task demands and resource capabilities shift spatially and temporally as disaster events unfold. What is going on here involves a principle underscored by our framework: Communication forms and flows follow the interconnections when the configuration of interconnections and control variables change. It isn't only that communications between and among emergency responders and infrastructure operations establish a follow-on interconnectivity; as their prior interconnectivities change and shift, so do communications change in form and content.

That is why diversity in mechanisms for communications under dynamic conditions—land lines, cellphones, satellite phones, CB radio, Starlink and more--is so important and why interoperability among communications systems, as important as it is, cannot substitute for needed requisite variety in disaster communication. Official cellphone capabilities dropped in one area as a result of an ice storm event, while personal internet hotspots remained available for key personnel during the same event.

2. Learning.

Emergency managers readily concede the importance of on-the-job learning as a factor in their emergency performance. "Every day you learn something new. It's one of things I enjoy about emergency management," repeated a senior official in the state agency for emergency management. "There's always something to learn," said a county emergency planner and coordinator. "I learn something every day," a state emergency manager told us. A water treatment plant manager had "a crash course" in learning about water rights during a heat dome emergency.

Our framework suggests to phrase the point from the opposite direction: Effective emergency managers, including those who have many good things to say about pre-disaster planning and education, are not able to un-learn and un-experience cases where even the best plans did not mitigate the disaster as it unfolded. Yet the longer the period that has passed in learning from the last disaster, the greater are two challenges for emergency management ahead: Not only may the people concerned have become more complacent and new priorities take over, but the newer emergency personnel may not have that learning, experience and contacts that come with earlier multi-emergency operations and facing new challenges each time. Note the same reservations apply to tabletops and pre-disaster exercises, i.e., the longer ago they were, the less helpful they are likely to be for what's ahead.

This multiple deficit—longer away from first-hand experience, new things to worry about, and turnover in emergency staff—can make planning beforehand understandably difficult for governance structures to use as a guide to eventual recovery after the M9 events—especially when it entails imposing formal power ahead of what happens on the ground.

3. Staff and resource scarcities.

Staff shortages are mentioned by interviewees as a major driver in their emergency management: "Worker shortages are the greatest impediment to all kinds of response and recovery," a city emergency manager said. One state emergency manager mentioned people throwing around a number like 40% of the departmental staff in the western part of the state would not be able to come to work because of a Cascadia event. Whoever gets there will be the ones we're left to work with, a city water distribution manager told us in terms of M9 immediate response.

Our framework suggests it's helpful to break down staff and other resource scarcities into more detail from the get-go. Any scarcity is first to be understood as the interconnection between demands made on resources and resources available to meet those demands. This puts staff shortages at the heart of the interconnections between the task demands and resource capabilities in response and initial service restoration.

"Look around. Most of these people won't be here" was the concern an infrastructure supervisor expressed about their unit in the event of M9. In such ways, a need for more granular and diverse interconnections is highlighted for effective emergency management. For example, what matters may not be so much that the worker is physically there, but the loss of his or her skills and experience relative to the task demands faced then and there. But the network of co-worker skills and experience with respect to the task demands may compensate. It may also matter what the abilities of those who are not co-workers are when it comes to meeting sudden or unique task demands. Work as typically done may not matter as much as the ability to make improvisations.

These follow-on networked interconnections in matching tasks and resources during immediate response and initial recovery are core to our framework, leading to our next topic.

4. Networks of contacts and relationships.

It follows from the preceding that: Change the contact networks and you may well change the interconnections and resources available for the requisite variety match. Much more, however, needs to be said about these networks and the interconnectivities of interest, from our framework's perspective on immediate response and initial restoration.

No one professional or organization can have all pertinent contacts, because (1) no disaster—and most certainly a M9 earthquake—is limited to interconnections already known or manifested only, and accordingly (2) no requisite variety can be defined beforehand in such a way as to macro-design organizational structures and management mechanisms. It's no surprise then why improvisations in the M9 events *must* not only be expected but also are center-staged in emergency management around shifting but interconnected contacts and organizations.

Understandably then, one's network contacts could well be drawn from any level in a hierarchical organization—and from inside or outside the formal structures of emergency management. The extent and composition of contacts assembled over time help explain how a planner, regulator or executive can also be a key, even mediating player in immediate emergency response. We interviewed a regulator who had as part of their job description also serving as a coordinator and liaison for emergency preparedness in their subject area. A planner at the state level, in other words, might be an active participant in joint improvisations over overlapping or shared control variables at the local level.

The priority put on personal relationships by interviewees is reinforced by the fact that much of the critical infrastructure in the two states is privately owned or managed. One interviewee expressed surprise when first learning that the government didn't own mobile cell towers and other communications infrastructure, but relied on private communications providers, who would place towers where requested. The issue here isn't private (or voluntary) *versus* public (or government). It isn't so much that from time to time there are those who show up in an emergency who are in it for profit or other advantage. In more exact terms, a disaster solidifies the fact that stakeholders are interconnected in ways they were not before.

This means that person-to-person networks in emergency management become all the more a resource capability as compared to when proprietary or security concerns act as routine inhibitors to one-on-one interactions. In framework terms, activating the real-time reciprocal connections made across public and private entities that interact more formally before a disaster now become crucial and more instrumental during a disaster.

5. Interconnectivity-induced scale effects.

An unfortunate feature of discussions of large-scale phenomena, like infrastructures and disasters, is that separate scales of activities are typically identified first and then linkages sketched in and examples given. For instance, the levels micro, macro and the meso in between are presumed and then filled in, e.g., as different factors or patterns emerging at the meso level that were not visible at the micro level. The ICS hierarchy with its city, country, and state levels exhausting resources before seeking funds/resources from the next higher level is a perfect example.

Our proposed framework, however, suggests there are times when that characterization needs to be turned inside-out. One such occasion is emergency response and initial restoration, where not only control variable interconnectivities make different system scales visible but also where shifts in those interconnectivities lead to shifts in scale. This happens when an infrastructure's control variable is adjusted by its central control room for specific localized responses within that system. A city water manager told us that recent improvements in the system meant that they could close down portions of it, segment by segment, and thereby isolate "what the scale of their problem" was. Another city's water manager had to shift its water supply temporarily to well water in order to reduce its water demand from a large supplier that had now to service another city that had lost its alternate water pipeline. For these times and purposes, scale effects, like communications, also follow from interconnectivities.

Why is this important for emergency management with respect to the M9 events? A key follow-on of M9 events will be the shifts in infrastructure interconnectivity never seen before and with that, the never-seen-before match-ups for requisite variety. "Basically, we're going to go from a bureau that treats wastewater to figuring out just how to get it away from people. . . and we're not going to know how to do that until we know what's working and what's not working," said an environmental services official. This means that joint improvisations involving shared or overlapping control variables become incredibly important precisely when the improvisations establish interconnectivities that *both identify and shift* the scale(s) of the emergency response problem. In fact, inter-infrastructural improvisations may be the best indicator that shifted interconnectivities are in effect and so too are adjustments in the scale of the tasks and resources being confronted by one or more of the backbone infrastructures.

When questioned about their take on the M9 events, interviewees also talked about other interconnectivity-related scale effects. First, given the likely numbers of displaced, hungry, or otherwise distressed people in the M9 catastrophe, emergency managers and infrastructure operators must expect fear and confusion—but how widespread is the issue—to cause significant behavioral surprises well beyond the core competencies of emergency managers and infrastructure operators. Second and from our framework's perspective, a centerpiece of immediate damage assessments just after the M9 earthquake includes determining what still remains interconnected (and at what scale) even in the midst of the devastation. This is a major point we return to at several points below. Suffice it to say, we believe infrastructure operators, both in control centers and as field staff, are especially key to that determination. If they are not there, the assessments default to emergency staff more familiar with devastation than they may be with backbone interconnectivity.

6. Pre-disaster mitigations.

The perspective of preserving and enlarging requisite variety can also be applied to thinking about pre-disaster mitigations in relation to infrastructure risks, uncertainties and unknown-unknowns in and following from M9 eventualities.

First, the requisite variety perspective encourages thinking (already undertaken and promoted by some interviewees) about system-wide perspectives on failure instead of a primary focus on vulnerable infrastructural elements and their mitigation, such as hardening of this bridge or that stretch of pipeline.

One interviewee gave us the example: If after an incident a utility wanted to build something and get reimbursed, it had to have documented that beforehand in an official county hazard mitigation plan. That is, you get funds to build back what was lost, not to build back to something better. This makes earlier and broader interconnected pre-disaster mitigation plans very important practically, and not just from the framework perspective.

Second, mitigation can be analyzed not only from the perspective of preventing failure in an infrastructure, but also in terms of limiting the consequences of a failure not prevented. Here, the term "limiting" highlights the interconnectivity configurations, shifts and control variables that are associated with "the consequences of failure." For example, can we better identify beforehand mitigations that might enhance rather than undermine options for inter-infrastructural problem-solving and joint improvisations (both key to requisite variety)? Preserving some fallback capability in the face of failure, e.g., through the strategic placement of positive redundancies in key equipment and parts—think of COWs (a Cell on Wheels that backs up telecommunication capabilities) being collocated adjacent to system chokepoints—can create and preserve more options than a comprehensive design for failure prevention that inadvertently leaves little with which to work.

Other emergency management topics could be discussed, but let's stop and turn now to the far larger and more important issue for adding value via our framework to what is already known: How does our framework and the points just made improve the effectiveness of emergency coordination not just in Oregon and Washington State but elsewhere as well? What is required for effective coordination as the disaster unfolds? Answers entail first discussing in greater detail requisite variety as a performance standard (Section VI) and thereafter the related but wider issue of what makes for *effective* emergency coordination (Section VII).

Section VI. Performance standard for immediate response and initial restoration (with a comment on standards for longer-term recovery)

"What does success look like?" a senior state emergency manager asked, and answered from his experience: "Success in every disaster is that you didn't have to get improvisational immediately. You can rely on prior relationships and set up a framework for improvisation and creativity." Why? Because contingencies that can't be planned for require improvisation. "I was lucky," reported a statewide emergency manager involved in an ice storm that happened during the Covid-19 lockdown as "my neighborhood was only out of power for six hours. . ."

Contingency—happenstance, accident, chance, coincidence—will matter even more for the M9: "What side of the river will I be on?" replied an infrastructure operator to our question of what would be a performance standard in the M9 events. Being at work, holding water in the main reservoirs, and getting some of the wells up and running would be a success, the interviewee added. Opening a road from point A to point B, that's a success, to paraphrase a state emergency manager for highways. "Doing the best with what we have" was the frequent response. "Being here and do as best as we can, would be considered a win," put one infrastructure operator. But how can we know that the "best" was done? The best with respect to what?

Our framework seeks to take that "best" and formalize it differently for the purposes of establishing a standard for effective performance in immediate emergency response and initial restoration. That standard will, moreover, be key to identifying effective emergency coordination in the following Section VII.

From our framework's perspective, "doing their best" has very specific meaning by way of being a performance standard for immediate response and initial service restoration: When responders find or create a match between task environment demands and response capabilities in real time, then response and initial restoration can be said to have been performed effectively, at least then and there. This is the earlier requisite variety standard.

More formally: Effective performance can be understood as the contingent correspondence of task environment demands and the response capabilities (resources, skills, options, strategies) to meet those demands. The term, "contingent," conveys the sense that the conjunction of capabilities and demands can be fortuitous and is by no means assured through pre-disaster mitigations, formal preparedness plans, and other agency arrangements, like mutual aid agreements.

Seeking requisite variety in matching unpredictable/uncontrollable task demands with highly contingent resource capabilities is, we argue, a strategy and performance standard appropriate for both immediate emergency response and initial service restoration. This is because skills in assembling options under highly volatile conditions remain central to enabling shared improvisations and the role of such improvisations thereafter in improving conditions leading to more acceptable response outputs.

The fact that there can be no guarantee the shared infrastructural improvisations—these impromptu but major interconnections—will be effective means there is a premium placed on people whose skills at improvisation increase with experience. As just underscored, newer infrastructure employees and emergency staff may well not (yet) have the requisite skills: "A lot of our folks don't have that skill set to be able to look at a pressure reading somewhere and determine the level of water [left in an above-ground reservoir]."

In other words, this priority given to ensuring requisite variety in emergency situations means not only having prior experience with emergencies, but also being adept at emergency on-the-fly improvisation. As an emergency planner and coordinator put it, "I think what makes a good emergency manager is you feel uncomfortable being off-balance. . .That's one of the reasons I was drawn to the field. When nobody has the answer that's when I feel most capable in my job". "Disaster response—we find a way" put another long-experienced emergency manager of that challenge.

Activation of the ICS, to repeat, helps provide some structure to trying to meet the challenge. What achieving requisite variety provides is time-, duration- and site-specific organization that can add up to longer stability. As one state coordinator put it: "My responsibility on the response side leading into recovery is stabilization, [which means] this is not going to get any worse. We've restored a foundational level of service, whether that is permanent or temporary. . .". This ensuring that response capabilities match task environment demands requires managing—over the different durations—the different backbone configurations of interconnectivity between and among demands and capabilities and the shift-points (including latent to manifest) from one configuration to another.

We conclude this section on the requisite variety performance standard by discussing three topics that deserve special underscoring in light of the preceding:

1. The role of managing control variables and improvisations for the purposes of immediate response and initial restoration.

These variables become an important means of managing interconnectivity configurations and their shifts so as to maintain a changing match of capabilities to task demands. An example was to restore to a community, cut off during a disaster, "enough network connectivity to run things like point-of-sale terminals and sell goods and services necessary to sustainment of people". Improvisations jointly undertaken by two or more infrastructures around their shared or overlapping control variables become themselves a primary mode of operation. “On the fly, we reconfigured our telemetry [with hand-held generators they were able to obtain],” a water treatment manager added about another of their many improvisations during an ice storm. A landslide that took out a major road for a community necessitated the cooperation of multiple state and local partners to improvise by upgrading an old forest road—roads, being the control variable—as an alternative.

More important, “you can’t put those things in advance in a plan because it’s not going to make any sense,” said a senior official in a state agency for emergency management speaking about these kinds of joint improvisations just discussed. Latent interconnectivity invisible before the disaster and prior to the on-the-fly improvisations is not something that can be specified beforehand and in advance, at least for the major contingent requisite variety matches around already dynamic system control variables in immediate response and initial restoration of backbone services during the M9 events.

This open-endedness with respect to on-the-ground jointly-undertaken improvisations also takes place against the constraining backdrop that the infrastructures involved have their own dynamic priorities, tasks and responsibilities in the emergency. What a performance standard for joint improvisations does, however, underscore is that interconnectivities necessitate entertaining response options that extend beyond the priorities or commercial interests of a single infrastructure. In emergencies, infrastructural interconnectivities can well be a public good, and it is this public-good aspect, not each infrastructure on its own, that resists pricing and privatization.

2. Effectiveness includes requisite variety in organizational capabilities.

Oregon and Washington State have a diversity of different organizational and network formats to better address the requisite variety requirements of real-time matches between contingent task demands and then-available resources.

Here is a sample of a few different formats interviewees mentioned in no order: the Clark Regional Emergency Services Agency as a special district (and other district types, like special purpose districts); a Regional Disaster Preparedness Organization with members from multiple jurisdictions and with special committees and subcommittees; the Pacific Northwest Economic Region, a longstanding multi-state statutory entity that takes a regional economic perspective on inter-infrastructural emergencies; an intergovernmental and water coordinator funded by a consortium but located in a utility; a multi-country water suppliers forum; a citywide disaster policy council; federal defense staff embedded in a state and other emergency management units when liaising over a catastrophic event; a multi-agency coordinating group at the state level, whose members change with type of incident; an infrastructure working group and a critical infrastructure branch at the Oregon state level; the Western Region Mutual Assistance Group dealing with electricity; a disaster resilience action group across city agencies; a watershed-based water providers group; a senior policy group in a large electricity transmission provider; special state task forces, e.g., to “restore power and roadways at the same time” as one state emergency put it; a water utility with a dedicated account manager in the electric utility; and a Statewide Interoperability Coordinator as well as a State Resilience Officer for the state of Oregon, among others.

Such diversity in organizational formats is what we would expect when requisite variety is key to immediate response and initial service restoration—and even more so for the M9 events. We would expect to find many more, real-time functioning formats, not just by location but also by type of sub-event. We counsel against any dismissal of such variety as "unnecessary organization duplication" or in need of "organizational consolidation and integration." The worst thing to do is to "impose prior order" on the real-time need for requisite variety. There is no problem of "having excess capacity" if the real-time requisite match is to be made to help stabilize emergency response and initial service restoration.

A principal feature shared by having diverse organizational and network formats is they enable participants to wear different hats for different occasions. "You have people wearing multiple hats at the same time," in the words of a senior state emergency manager. The department head who is also a member of the city's emergency management working group is able to speak with his or her citywide hat on in ways not open to them as a department head only. The statewide emergency manager having responsibilities for firefighting is also the liaison on such issues in the state's emergency coordination center; other statewide managers shift to being boots on the ground with respect to their function.

More formally and to revert to formal terminology, the single resource—in this case, the professional—provides multiple services as demands change, which in turn is crucial for meeting real-time matches in requisite variety. There are downsides, of course, to wearing multiple hats when it comes to emergency management. One interviewee noted a possible reluctance of city officials to have a new full-time emergency manager position because there were occasions when city officials considered that function to be part of their duties and responsibilities. Another interviewee, however, thought it was a good thing that a wide range of departmental staff had emergency management duties, even if it took up a small percentage of their time.

3. Performance standard(s) with respect to longer-term recovery?

So far, Section VI has been about standards for response and restoration. We'd be remiss, if we did not briefly draw out the chief implication about standards for recovery that follow from the preceding comments.

When it comes to longer-term recovery, the question of performance effectiveness is more complicated to address and assess. Much of this should already be familiar. One state emergency manager underscored that long-term recovery involves the political and societal side, not just the critical infrastructures as socio-technical systems during emergency response. Those earlier-mentioned additional stakeholders and political trade-offs move center-stage, along with an expanded set of community values and policy goals. What this means is that, as one experienced interviewee put it, standards for recovery are "difficult because every community is different and their priorities are different".

In other words, the more differentiated and multi-dimensional nature of longer-term recovery argues against real-time requisite variety as a performance standard in the way it is for immediate response and initial service restoration. Standards for longer-term recovery are necessarily more ambiguous and controversial, and would necessarily be so for the M9 eventualities in Oregon and Washington State.

With that, we are now in a position to rethink and better improve, we believe, that fulcrum in disaster management: emergency coordination.

Section VII. Framework application: rethinking emergency coordination for the M9 events

Much has been written about coordination in emergency response and recovery. So too our interviewees underscore its criticality for and in the M9 events. *What does this coordination mean from the perspective of our framework and the unique features of a M9 earthquake?*

Our answer has several parts, but first to summarize our point upfront: Emergency management coordination is not only the familiar big-picture coordination and priority-setting at the level of operations up and down the Incident Command System. It is also the less familiar, unplanned or unexpected micro-coordination—more like "coordination effort at the tactical level" one interviewee called it—around shared control variables and joint improvisations instrumental to meeting the needs of the here-and-now in a disaster. It includes the invention of options for effective immediate response and initial service restoration.

The two types of coordination—large-picture and micro—are not mutually exclusive, as a number of interviewees believe much of the second can follow ICS priorities, including partner commitments to fund and supply. We reinterpret both sorts of coordination from the perspective of the framework proposed in Section III and in light of the special topics expanded upon in Section V. Three sets of reinterpretations and their implications are emphasized here. In doing so, we'll be extending our earlier discussion on the central role of interconnectivity in determining communication patterns.

1. First, micro-coordination for emergency response is conducted under the performance standard for requisite variety.

This coordination in other words achieves the correspondence that reflects meeting the requisite variety match: again, the extent to which the skills, resources and other response capabilities invent/improvise/reveal options to match the then-and-there task demands. A chief focus of this coordination is, again, the joint improvisations by emergency responders and infrastructure operators and maintenance personnel to deal with shifted interconnectivity configurations after an M9 event, centered around managing shared or overlapping control variables in real time.

None of this is guaranteed. In the first place, professional emergency managers on one side and skilled managers, operators and maintenance personnel in the infrastructures on the other do not typically interface except in emergencies and even then under different organizational mandates. Getting the plant up and running—"to get the main grid up, period"—is the most important consideration for electrical infrastructure operators. "We're a utility. . . we're trying to get power up or are we getting distracted" was another comment by an electrical infrastructure manager.

“One of the issues I have,” added a plant manager about some emergency management professionals he interfaced with, is “that is all they [emergency managers] do, is disaster preparedness. . .[They start expecting] that is all you’re doing too. I got day-to-day stuff I’m still dealing with. . .I don’t know if I have the bandwidth to take on disaster preparedness at the speed that the people who do it all the time do it. . .We just don’t have the bandwidth to do it. . . .I know I’m not on top of it. And I’m pretty sure the other similar level managers aren’t prepared any more than we are”. Summed up another infrastructure operator, “we don’t have the dedicated time available”.

This is not to say, however, that infrastructure operators, plant crews and utility field staff are not concerned about or involved in emergency management inspections, training, exercises and tabletops; examples of significant concern and involvement were given to us by interviewees. Further, any differences in perceived mandates between infrastructure operators and emergency managers cannot be assumed to be differences over the priority and challenge of saving lives, including search and rescue, in the first hours or days of the M9 events. Indeed, one departmental emergency manager said the “whole goal of the way we are set up is so that the plant manager can do what the plant manager needs to do. . .The rest of us here are to support those people”.

Several substantial implications about and for emergency coordination follow. In formal terms, emergency coordination is what bridges, on one hand, pre-existing planning *processes* for emergency response (in both the emergency management agencies and the other critical infrastructures) and, on the other hand, the changing facts on the ground as the disaster (fog of war) unfolds. Variants of “trust the process more than the plan” were repeated in interviews. “Plans are extremely important, right, they make a difference, but the process of planning is far more valuable than the document itself,” a senior state emergency official stressed.

What is going on, from our framework’s perspective, in this talk about process being more important than a plan is this: Enhancing the requisite variety of options requires people who see problems in terms of processes and requirements to also see resource capabilities beyond their pre-existing job descriptions, localized priorities and documented plans. At the same time, they assume responsibility with others for meshing the requirements with the capabilities, including through joint improvisations to meet the logic of interconnectivity that requires mutual efforts to achieve what must be shared restorations. For our interviewees, processes are just as real and empirical as bridges and pipes to be retrofitted.

It’s also clear, moreover, that documented plans do matter for emergency managers, and on occasion importantly so. One water operations supervisor told us how it really helped having documentation from a previous scenario exercise for what to do when an emergency procedure had to be undertaken for the first time. Another emergency manager at the state level told us of a case where a previous “what-if” scenario exercise helped establish a protocol to be followed when a bridge did eventually collapse, though here too unexpected contingencies came into play. Again, experienced emergency managers can’t unlearn the exception that could later prove the rule. The regularity of planned exercises can also be helpful: “Before the wildfire season, we do what we call a refresh of our plan for this fire season but also do a walk-through, so everybody knows their roles and responsibilities during the wildfire and can respond and activate quickly. . .[I]t builds muscle memory," said a senior emergency manager in a major electricity transmission company.

"I can't say enough good things about planning and how important it is," a state emergency manager told us, "but you realize the gaps in plans when you're dealing with such catastrophic events that we've dealt with in the past 18 months to two years...There's a lot that needs to be decided on the fly because it hasn't been planned for or it's not going to work, the plan didn't consider all the factors because every emergency is different".

From our framework's perspective, part of what is going on here in distinguishing the value of a plan or document from the value of (in)formal planning processes is this: We are back to issues of the scale of the catastrophe, and the different scales induced by interconnectivities, configuration shifts, and control variables. These differences must be taken into account for better emergency coordination. By way of example, a city water manager argued there had to be a plug-and-play document in place to show how to shut-down the water system with the advent of a M9 earthquake, so as to isolate sections from each other and keep positive pressure. *Obviously*, unpredicted contingencies come in between plan and implementation, but the point was the importance of a pre-existing protocol designed in such it way that following it allows a better understanding and coordination among operators of the current system states during the shut-down process and later for initial service restoration.

2. Second, who coordinates and how they communicate are especially instrumental in emergency coordination.

Even though not the prevailing attitude now, engineers have designed infrastructures, still used today, on the premise, we were told, of: "We don't design systems for events that are unlikely to happen". Another interviewee saw a "public safety-heavy" emergency management in their area. It drew from retired military, firefighters and police, which, while that had many benefits, made them "terrible long-range planners" in the interviewee's experience.

This difference in professional orientation is critical when considering the latent-to-manifest interconnectivities between and among infrastructures : "If your specialty is putting out fires, then you're not [equally as] good at long-range planning. . . It's not their strength". A county emergency planner and coordinator expanded on how older orientations brought with them earlier sets of preferences with respect to the specific interconnectivity focus: "We can't rely on the civil defense era style of planning in which you had to have every possible scenario documented and then you end up with a thousand page plan no one reads through". "Emergency management is an old game," the interviewee added; "We still see a lot of the old guard in this. . .working against innovation even if it's not intentional on their part".

"You can always tell who has had a first-responder experience" and, in that interviewee's opinion, "the good fortune to be a first responder" was helpful. From our framework's perspective, those who have experience across the full cycle of infrastructure operations—from normal through disrupted and failed and into recovery and establishment of a new normal (if there is to be one)—are better positioned to assess the different interconnectivity configurations, shifts and control variable challenges for improvisation that are at the core of understanding emergency management micro-coordination during initial response and service restoration. Moreover, they are more likely to have the confidence in their ability to make improvisations and handle an improvisational mode of joint coordination.

It is necessary to reiterate that, as shared improvisation is a core competency in immediate response and backbone service restoration, effective emergency coordination, as redefined here, requires not only the participation of emergency responders and others in the Incident Command System, but also, just as important, participation from those in the control rooms and the wraparound support staff in the backbone infrastructures—electricity, water, telecoms and roads. We were told by an operations planner at a major electricity company that they now had a real-time engineer team working with dispatchers, undertaking real time analysis and study of outages likely to happen in the next day.

Last, no discussion of emergency coordination would even approach being somewhat complete without addressing its horizontal and vertical dimensions. Our framework suggests the best way to do that is by focusing on how communications in immediate response and initial service restoration follow shifting interconnectivities.

When it comes to those working in the field fighting the fires, closing the water valves, and clearing the obstructed roads, **horizontal communications and actions** that are jointly time-critical are patently essential for the success of coordinated responses. An ice storm that shutdown electricity to four water treatment plants required use of back-up generators, but only two were available. This placed priority on continuous diesel supplies, 24/7, for the two, and in the words of the interviewee, "a lot of our [provider group] members were going to gas stations, filling up with whatever they could find" for that round-the-clock generation.

We've already touched on the importance of **vertical communications and actions,** which from our framework's perspective are best understood as organized around the sequential interconnectivities up and down the ICS chain of command in Oregon and Washington State. What is striking across all interviews to date is how detailed and similar are descriptions about the ICS structure in terms of moving up a hierarchy from incident site to the county (if not city first), then to the state and if necessary to the feds, as resources are depleted at each previous level. A good part of their reliance on the ICS structure is that it has been activated in the past for different events at the city, county and departmental levels in the two states. (We were told of a department, city and county, each having its version of an emergency operations center, where, by way of example, the department can activate its EOC even if the city and county have not done so with regard to theirs.)

Just as significant are **horizontal *and* vertical together**, e.g., running concurrently and in parallel. A number of state-level interviewees described coordinating across multiple emergency support functions (ESFs) during the same event. One case was with respect to the 2020 Labor Day fires in Oregon. Another, this time in Washington State, was of statewide emergency managers for different but interconnected functions communicating with each other as the events unfolded, in this case with respect to roads and telecoms after an ice storm.

Other examples of the combined horizontal and vertical dimensions in emergency coordination were given. ESF personnel at the top of the states' emergency management hierarchies have been active in coordinating up from the field to the county, across the state and to the Feds. "We'll connect the appropriate people together," said the state roads emergency manager also on behalf of their counterpart in telecommunications at the state level. Here too we see actions that are *jointly time-critical* for horizontal effectiveness in a structure of vertical coordination.

In other words, it should not be assumed that the decision point is choosing horizontal *versus* vertical communications and actions when it comes to emergency coordination. It may be in fact that, as some interviewees suggested, the Incident Command System is a vertical structure that can enable and facilitate horizontal communications entailed in management coordination.

Cautions are in order, however. There are circumstances where a larger resource and problem picture is held by a centralized emergency operations center or where local actions may create scale problems unforeseen by those in close lateral contact with one another. Yet in our earlier California research, we came across cases where lateral communications and coordination were discouraged in favor of the formal ICS oversight even though lateral communications were necessary because of real-time infrastructure-to-infrastructure interconnectivities.

For example, private utility companies (electricity, water, telecoms) have in some emergencies contacted the state's respective ESF preparedness managers directly, who in turn may contact other ESF managers directly. In some cases, the "bigger picture" help by top-level ICS officials may be a fuzzy one compared with the urgency and clarity seen by participants at the operational level trying to achieve interconnected infrastructure service restorations.

3. Third, shifting configurations of communications must be taken into account and understood when assessing effective emergency coordination.

From our framework perspective, the types of vertical and horizontal communication in emergency coordination are better understood in terms of shifts from one-directional instructions and commands in sequential dependencies to continuing cross-talk and negotiated agreement in pooled and reciprocal configurations. The shifts—while reflecting real-time adaptive responses to the unforeseen among now closely and differently connected infrastructures—are nevertheless patterned, albeit variously.

To repeat, from our framework's perspective, patterns of communication follow from the shifting interconnectivity configurations among control variables. A number of our interviewees stressed the significance of pre-disaster and disaster notifications about emergency events. To that end, the manager of a water providers group was in the process of establishing a notification protocol letting members know simultaneously and immediately about an incident created by others in or affecting their watershed. Here it would seem communication mode leads to interconnected water providers. From our framework's perspective, however, it would be better to say that, because the members of the providers group are interconnected both by water infrastructure and by the common watershed, notification of incidents there had to be communicated promptly and to the point ("everyone had the same information at the same time," in the words of the interviewee). In fact, if or where there is no notification under such interconnectivities, the effectiveness of emergency response would be hampered in marshaling a requisite variety match of then-and-there resources (which in the face of an emergency could now include previously under-recognized provider assets) to then-and-there task demands.

This means any temptation to impose vertical-dominant communications is to be resisted when shifting interconnectivities demand horizontally rich communication. No amount of vertical communications can substitute for achieving a high-enough bandwidth of information necessary for close real-time micro-coordination of infrastructures at points of reciprocal interdependence. The direct line phone connections to the control room of a major electricity utility from a water utility or wastewater treatment plant are examples of "pilot-to-pilot" coordination and interdependencies. This shift in the communication configurations from vertical-sequential to include now reciprocal-horizontal is itself a valuable indicator that priorities in communication are changing (i.e., reconfiguring).

By this point in Section VII, the reader hopefully better understands the need to rethink some of the usual complaints about "lack of coordination." When hearing someone say, as we did, that Washington State Emergency Management Division (EMD) and the Oregon Department of Emergency Management (OEM) don't align very well with one another and have not coordinated very much, our framework suggests focusing specifically on examples of the joint involvement of the two states in coordinating around shared or overlapping control variables and associated risks (i.e., an obvious example being waterflows of the Columbia River on the border of the two states). It's their experience in these cases, or lack thereof, that is the starting point with respect to assessing better coordination.

This means that track records established in past emergency coordination are an imperfect mirror to reflect the challenges ahead in M9 events. There are no guarantees that effective improvisational coordination will be achieved, even by those with established track records in emergency management and infrastructure management having jointly undertaken workarounds for "the biggest fire, or flood, or ice storm, or evacuation. . . the state has ever seen so far".

Some examples are instructive. With respect to responding to recent winter storms, a district emergency planner conceded, "We get them but we don't get them often enough to be good at them". "We haven't had a really major emergency that cuts through all the lifeline [infrastructures] at the same time," a city public works engineer with long experience told us. To paraphrase a senior operations planner with long experience at a major company for electricity transmission: Fortunately in our system we haven't really had any incidents in the Northwest that have been major interruptions of services to our customers up here. A city environmental services staff person said, "I don't know how often we have been tested as a system" by a huge emergency. A water treatment plant operator, with years' experience, hadn't had "any [real] emergencies except for the last year with an ice storm that took out our power". Much the same thing was said by a different plant manager for another treatment plant: In the manager's experience "as far as the distribution and collection system goes, we haven't had anything that has taken us off-line. . ."

In short, both the fact of no emergency coordination track record combined with careers inevitably falling short of comparable M9 coordination experience must be of central concern to preparedness and mitigation processes. Table-top and other emergency simulations are a method of addressing experience gaps, especially if they now include inter-infrastructure disaster and response scenarios, as well as inter-state coordination exercises.

Part I concluding remarks

The findings presented above are based on first-round interviews, with provisional implications drawn and first-order speculations offered. Some confirm what is already known to emergency practitioners generally, namely: failure, response and recovery are interconnected in complicated ways from the get-go. Some findings suggest more priority and attention be given to what others take for granted, such as continuity of operations plans, business continuity plans, and the processes for devolution and orders of succession in case of an emergency.

Part II Results: The core issue of restoration resilience

(April 2024)

Introduction and preliminaries

Our second-round interviews provide a detailed examination of and focus for analyzing specific vulnerabilities and missed opportunities in emergency management. We focus primarily, but not exclusively, on inter-infrastructural interactions during major emergencies, particularly in the context of the Pacific Northwest (Oregon and Washington State) and forthcoming moment magnitude 9 (M9) seismic events. The insights are aimed to add value to emergency response and service restoration strategies by identifying *and* preparing for specific vulnerabilities.

This update focuses on known mitigable errors in emergency anticipation and preparation and the special vulnerabilities these errors pose, when not avoided earlier, to later on response and restoration when the emergency occurs. This issue of avoiding missed opportunities to correct beforehand for already-understood vulnerabilities arose from our first-round interviews and Part I findings.[6]

Despite the uncertainties inherent in disasters, there are known vulnerabilities that can be mitigated in advance. Discussing preventable vulnerabilities contrasts sharply with the unpredictable nature of M9 events. As we saw in Part I, our first-round interviewees told us that real-time surprises and unknowns are widespread in major flooding, wildfire, road and other transportation failures, levee breaches, and transmission line collapses, among others. But, as infrastructure staff and emergency managers also tell us and as illustrated in Part I, there can be an urgency, clarity and logic about what to do by way of just-in-time interventions.

In the latter cases, what needs to be done becomes evident to front-line infrastructure and emergency professionals when not so to those in operations centers or distant official positions. One example from many: "It's the nuclear power plant in central Washington. That's our one and only priority for restoration, so that would be our focus," an experienced manager of Bonneville Power Administration's (BPA's) restoration plan put it by way of illustrating a clear and present danger even in the midst of massive uncertainty.

To better understand the vulnerabilities and mitigable errors, we start with the four variables of major importance to emergency management in Part I for unfolding M9 events:

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[6] Some interviewees prefer "missed opportunities" as the term for what's to be avoided. "It's almost like it's not that they did something wrong necessarily, but it's a missed opportunity," one interviewee put it. It would be a major missed opportunity, in the view of another interviewee, for wastewater infrastructures not to reassess their emergency plans after the water supply infrastructure seismically upgraded its own lines adjacent to those of wastewater. The interviewee called them, "mitigatible errors." A different interviewee was more explicit about the priority need to "develop those plans that anticipate errors" known beforehand.

(1) the different types of interconnectivity that exist between and among backbone infrastructures for real-time electricity, water, telecoms and roads;[7]
(2) the points or phases at which types of interconnectivity can shift during infrastructure failure, thereby shifting immediate response and initial service restoration;
(3) the importance to effective immediate response of jointly undertaken improvisations around system control variables relied upon by more than one of the backbone infrastructures (e.g., electricity transmission lines upon which telecoms depend as well as the telecoms upon which electricity would depend)—all of which are managed to
(4) a performance standard that includes the production and use of "requisite variety" (that is, effectiveness in response in generating options to match real-time task demands of the emergency with real-time capabilities to respond to the demands).

Our second-round research interviews focus on the inter-infrastructural vulnerabilities that arise with respect to known mitigable errors involving the four variables. There are opportunities not to be missed in correcting for known vulnerabilities. We do so because anticipating and preparing for these vulnerabilities are recognized by first- and second-round interviewees to be instrumental effective emergency response and service restoration.

Our goal is to enhance the Part I framework so as to improve what we call restoration resilience, i.e., the capacity to adapt and respond effectively to the dynamic challenges of major emergencies, recognizing that while not all vulnerabilities can be preempted or opportunities taken advantage of, a strategic focus on known interconnectivities and specific errors can significantly improve response, initial restoration and related resilience.

Summary of Part II conclusions

The second-round interviews, in addition to Part I findings, enable us to draw two interrelated conclusions about the special vulnerabilities of interest in our second-round research:

- Inter-infrastructural vulnerabilities emerge from shifting interconnectivities between infrastructures during emergencies, challenging existing response plans and preparedness levels; and
- These vulnerabilities can reduce the capacity to match emergency response demands with available response capabilities, emphasizing the need for emergency management to anticipate and prepare for these shifts.

In more formal terms,

(1) Inter-infrastructural vulnerabilities arise because the potential interconnectivities between and among infrastructures, when shifting from latent to manifest, can invalidate existing response planning and preparedness. The emergency changes or multiplies the range of contacts, communications and negotiations required to produce new and unforeseen options to respond. In this way, infrastructures can be under-prepared and ill-resourced to match their capabilities to the demands of the now-manifested shifting interconnectivities in the emergency.

[7] A number of first- and second-round interviewees confirmed the importance of these four infrastructures in emergency response and initial service restoration.

(2) What were latent but are now manifest vulnerabilities are cases that can reduce the requisite variety to match now-existing demands for response with now-existing capabilities to respond. The vulnerabilities of special interest in the M9 events are those shifts in interconnectivities that increase response demands, reduce response capabilities, or—most worryingly—do both.

In other words, understanding how the interconnectivities between critical infrastructures like electricity, water, telecoms, and roads shift during major disasters helps in refining and directing emergency response and restoration strategies beforehand as well as during the emergencies.

Below we unpack what first- and second-round interviewees mean when it comes to the two-fold conclusion. Thereafter, we draw out what we take to be their major implications for emergency response and initial service restoration with regard to M9 events in Oregon and Washington State. We conclude by outlining how our calls for greater specificity in M9 scenario planning resolve a major methodological issue identified in Part I: The more detailed and specified the disaster scenario, the lower its predictive validity, i.e., the lower the chances that particular scenario will actually happen as detailed.

Specifics and example of inter-infrastructural vulnerabilities and errors of missed opportunity in major emergencies identified by interviewees.

The major point here is that infrastructure professionals expect the need for cross-infrastructure coordination and improvisation but that failing to prepare for this constitutes significant missed opportunities that can be avoided in advance by local, state and federal entities.

Specifics.

As we saw in Part I, interviewees make it clear that latent interconnectivity that is invisible before the disaster and prior to the on-the-fly improvisations necessary afterwards is not something that can be adequately specified beforehand. Yet water, energy, telecoms and road infrastructures can and do "expect the unexpected," not least being surprises associated with shifted interconnectivity between and among infrastructures leading up to, during, and after emergencies.

When it comes to major emergencies, experienced professionals we interviewed can and do expect the need for more extended lateral communications with additional infrastructures as well as the need for flexibility to engage in communicating, negotiating and coordinating joint improvisational restoration options during and after that disaster. Also as part of the need for shared team situation awareness and a common operating picture, they see the advantage of having focal persons or units in official positions to mediate the formal and informal flows of real-time information along with requests they have.[8] They also prefer to see provision—

[8] Examples from first-round interviews of state-level professionals undertaking a focal mediating role include their helping to bring in back-up generators to where they were needed—e.g., coordinating generator placements at gas stations whose power was out but which were needed for nearby responders. Other forms of focal mediation include coordinating field managers of crews, road closures, fuel trucks, private-sector hotel rooms and meals for first responders (see, for example, Radke *et al* 2018).

sequestered and pooled in advance—of foundational technical resources such as tools, transport, and critical spare parts that can make options possible when the disaster hits.

These vulnerabilities are known and this means it is important for infrastructures, both single and jointly, to prepare prior to an emergency the groundwork in positions, contacts, communications capability and contingent resources to support those special restoration processes that are necessary under conditions of inter-infrastructural connectivity shifts. To fail to do so constitutes a mitigable error by creating a latent but eventually manifest vulnerability undermining effective emergency response and restoration performance.

Many discussions of infrastructure "vulnerabilities" focus on physical components, like corrosion in gas pipelines. Sometimes, physical properties considered vulnerabilities are focused on precisely because they follow from the strengths of the system: "So we do have a fairly robust [internal communications] system. The vulnerability is that we are responsible for that system. No one else is going to go fix it, so we have to rely on our internal resources to then have access to the sites to fix any problems that arise," a BPA interviewee told us. The vulnerabilities of interest in Part II, though, are significant weaknesses. These begin when the interconnected infrastructures fail to anticipate the need for special capacities—in telecommunications, for instance—with respect to the demands arising from shifting or shifted interconnectivities.

How does this work? First when activated by an event, different interconnectivity configurations—particularly mediated, reciprocal and pooled configurations discussed in Part I—create challenges to inter-infrastructural coordination, but also offer resources and new options to compensate for the vulnerabilities inherent in any over-reliance on technology and hierarchical command and control in emergency response and service restoration. Sequential dependencies up and down chains of command are of course important (e.g., declarations of emergency to release funds). But they do not and cannot offer sufficient options in micro-coordination for requisite variety to match the shifting demands and capabilities imposed by the shocks, surprises and contingencies of a major catastrophe.[9]

It is also a mitigable error not to recognize the vulnerabilities that come with shifts to these other interconnectivity configurations. Coping with and responding jointly to interconnectivity shifts for service restoration without (1) prior contacts, (2) repositories and pools of back-up material, equipment and facilities, and (3) the availability of robust communication channels and focal units (required because of the new reciprocal, pooled and mediated configurations) must then take place against the constraining limits that the infrastructures involved necessarily focus also on their own priorities, sequences of tasks, and duties, as in: "First get the plant up

[9] This micro-coordination requires a different type of communication from the command and directive instructions given along a hierarchical chain-of-command. It requires give-and-take negotiation and agreement among people in different organizations and institutions. That in turn requires trust among the participants in the truthfulness and personal reliability of one another, a reason why prior contact and experience with one another can be important. Negotiation and improvisation must also rest on the expectation of the authority of each participant to speak on behalf of their infrastructure and turn agreements into specific action. In formal terms, this micro-coordination is not only relational, it is transactional.

and running!" (But they may be unable to get the plant up and running without helping to restore other infrastructures.)

It's not news that robust communications are pivotal in establishing and ensuring situational awareness and a common operating picture in major emergencies. For us, though, communications are robust when they enable and enact the shifts in interconnectivity configurations so as to match real-time capabilities to dynamic emergency demands. The willingness and ability to revert to and use different communication technologies in order to shift from and to configurations of sequential, reciprocal, mediated and pooled interconnectivities is, we believe, key but under-acknowledged in immediate response and initial restoration when it comes to the demands for improvisational behavior on the fly.

The importance we found in both rounds of interviews for the role of shared improvisations underscores this requirement for *inter-infrastructural* anticipation and preparation beforehand. Such indeed follows from the Part I performance standard of better ensuring that requisite variety exists in matching response demands with response capabilities. It's worth repeating that this prior, jointly-undertaken preparation extends beyond the priorities or commercial interests of a single infrastructure. Managing ahead for shifting infrastructure interconnectivity is a public good in interconnected service restoration of critical infrastructures during and after a disaster. This status must be recognized as such by policymakers, emergency management officials, and senior executives in the backbone infrastructures.

Before turning to an example of what can and is being be done to reduce the interconnectivity vulnerabilities of interest, the reader needs to reminded about just how central inter-infrastructural connections are to effective emergency response and initial service restoration. We quote at length from the second-round interviews a federal emergency manager whose national and international experience includes working in one of the Pacific Northwest states during a major event there:

> But as, you know, as they start bringing systems up and we run into this, everybody gets pretty excited, right? They're like, "Oh, water plant's up and running. It's great. You know, we're out of the bottled-water business." Or, you know, people have water to their taps now. And then,. . it's off again. And so we plan those things, we really never plan a kind of a hard cut off of any of it. We continue until we're sure everything is stable. And that kind of the world I live in is the world of stabilization. . .It might not be a long term solution, but they work. And that'll then allow all of those other systems that are tied to it—so water, wastewater or interconnected power with all of that. It allows you time when you once get it stable, time [for] people that really know what they're doing to go and figure out if there are any other problems with the systems, figure out where the gaps are going to be. . .
>
> [For] example, anytime they're putting the grid back together, power will come up in an area. And at some point, they're gonna have to take that back offline in order to do something somewhere else. And so, it's not necessarily stable at that point. So if we are providing food and water, we may still have to provide food and water because there's going to be a time where it might be a couple of days that the power's gonna go back down.

> So, you know, there's that interconnectivity. It seems like that is the world we live in. It all, everything we do, every piece of it impacts something else. . .

Here stabilization is directly and explicitly tied to inter-infrastructural shifts in connectivity. But how can this challenge of stabilization during immediate response and initial service restoration be better addressed in advance?

An example of what is done proactively by way of reducing vulnerabilities.

One second-round interviewee gave the example of a major opportunity that was not missed when, after a flooding event, the local hazard mitigation plan was altered to reflect replacement of the existing but undersized culvert by a new bridge.[10] As an interviewee described it:

> So in the case of the county, they're well positioned because they already had this plan, like we see this culvert is undersized, we continually see water over the road and we want to replace it with a bridge and that was the plan. If they had to wait and put that bridge in their general capital improvement process, it could have taken them another decade to replace it, right? But because they had a plan and that's the direction they were already headed, now that the culvert washed away, it's going to accelerate in the direction of the change that they were already headed, which is towards the bridge, which is great. . .They thought ahead of it and now they're taking advantage of it in terms of trying to get additional funding”

As another interviewee put it, the hazard mitigation plan becomes a way to think more strategically about the federal funding component in critical infrastructure development at the local level.

Put this way, forward planning has a major role in anticipating and taking advantage of already-existing funding and construction opportunities. To repeat, when the focus is on mitigating major emergencies, missed opportunities to correct for known vulnerabilities are mitigable errors to be avoided. As such, the hazard mitigation plan also becomes a mechanism to think through how the bridge would alter road transportation in ways another culvert would not.

Implications for emergency management with respect to M9 events in the two states

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[10] “The Federal Disaster Mitigation Act of 2000 (DMA) established requirements for state and local government agencies to prepare comprehensive Disaster Mitigation Plans in order to be eligible for hazard mitigation grant funding. . . .The purpose of hazard mitigation is to implement and sustain actions that reduce vulnerability and risk from hazards, or reduce the severity of the effects of hazards on people, property, and the environment. Mitigation actions include both short-term and long-term activities which reduce the impacts of hazards, reduce exposure to hazards, or reduce effects of hazards through various means including preparedness, response, recovery, and resilience measures.” (Accessed online for one such plan at https://www.sccoplanning.com/PlanningHome/SustainabilityPlanning/LocalHazardMitigationPlan.aspx#:~:text=The%20Federal%20Disaster%20Mitigation%20Act,for%20hazard%20mitigation%20grant%20funding.)

A close reading of the preceding sections makes clear that the first place to turn to for adding value are those initiatives already underway by infrastructure practitioners and researchers to manage the interconnectivities and vulnerabilities of lifeline infrastructures in Oregon and Washington State.

From our perspective, this means capitalizing on existing opportunities beyond the official emergency management structures and plans at the local, regional, state and federal levels there. The aim is to leverage existing initiatives that have already "seen the light." The priority in focusing on those who actively acknowledge the centrality of interconnectivities is made all the more visible because these are early days in thinking through emergency management in terms of infrastructural connectivities.[11] Further, the more intensive focus of those already acting on the importance of lifeline interconnections is why, in our view, "building in resilience" with respect to interconnected vulnerabilities is not the same thing as official emergency response and restoration, even at its most successful in real time.

Ongoing professional efforts focusing around inter-infrastructural connectivities are the Cascadia Rising exercises in the two states, the Cascadia Lifelines Dependencies Collaborative ("CSZ Lifelines Group") in Oregon, the Regional Disaster Preparedness Organization (RDPO) in Washington State, various city and county groups in both states, as well as state personnel with emergency support functions, whose duties and responsibilities explicitly entail lifeline interconnections. In addition, there are the separate state programs, one-off studies, hazard mitigation plans, and specific local projects we were told about and identified in Part I. Should it need saying, many such instances must be out there, about which we have yet to be informed.

A priority is assembling and undertaking major table-top exercises and improvisation drills with these groups around unfolding M9 scenarios centered around shifting interconnectivities of water, electricity, telecoms and roads in western Oregon and Washington State.[12] Such exercises extend well beyond the Cascadia Rising initiatives. One core competency of emergency managers and infrastructure professionals is to identify pre-disaster opportunities—including new options and strategies for increased requisite variety to improve real-time disaster response, and not just in their own infrastructures. The core competency called for in these

[11] We've been told, *inter alia*, that emergency management is a relatively new profession, that in Oregon it has only just gotten more organizational visibility, that a focus on interconnectivities and their regional implications is an even more nascent development, that it's been only a decade or two that they have taken a subduction zone M9 seriously, and that no one there (including the large-scale BPA) has had to deal with an M9-like catastrophe.

[12] As for courses involving improvisation: "The course also included care of simulated casualties, cross-country movement and land navigation, small unit (squad and platoon) leadership, field preventive medicine, and emergency rapid reaction and improvisation drills. Many of these elements are similar to training exercises for tactical law enforcement and TEMS [tactical emergency management support] personnel and for wilderness rescue teams and expeditions" (accessed online at https://journals.sagepub.com/doi/epub/10.1016/j.wem.2016.12.008)

recommended table-tops is in the area of interconnectivities. These people are targeted because they already work outside their infrastructural or sectoral siloes.[13]

The advantage of starting with ongoing or already-existing major initiatives is that they involve professionals and researchers who know much more by way of what needs to be done in preparing for large-scale emergencies, not least of which will be the unfolding events of an M9. This means that when asked, "Have you read this report on seismic vulnerability here?," and they answer "No, we haven't," no one should assume these professionals aren't as knowledgeable as they should be. Instead, the professionals may explain their "no" by referring to and explaining the skill sets and work already done in actual emergency operations to address shifted interconnectivities and vulnerabilities, with the staff and resources they have.[14]

That said, we believe these existing groups and professionals could benefit from our research findings, especially the focus on jointly improvising around overlapping or shared system control variables. (To repeat: In our view, it is a mitigable error not to recognize that lateral-level micro-coordination, including inter-infrastructural improvisation, is needed to respond to problems and shifts around these system control variables.) In addition, were their resources in time and attention increased as we believe they should be, these professionals would be better able to identify those other reports and publications, among the myriad out there, of actual salience to their interconnectivity work.

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[13] We stress that the focus is to be on groups that already give attention to lifeline interconnectivities. Far more interviewees know these interconnectivities are important, but their attention bandwidth is taken up with far more intra-infrastructural concerns. Only occasionally may they focus with others on interconnectivities, as when BPA and a utility work together during a heatwave to see if their respective real-time analyses coincided. In this example they demonstrated the potential to shift to pooled interconnectivity ("Are our bottles lining up, so we're seeing the same things?," according to our BPA informant). Clearly, such recognition that interconnectivities matter represents a form of latency that could itself be activated in other table-top exercises.

[14] One particular important part of the skill-sets in assessing vulnerabilities is "the reliability-matters test." In this example, does the seismic study have direct implications for the task volatility of infrastructure operations and/or options with which to respond to that volatility by control room operations and their wraparound support staff mandated to ensure real-time infrastructure reliability? Answers immediately lead to issues of inter-infrastructural connectivities. A case in point was provided by a senior BPA operations supervisor:

> We identify potential issues on other people's systems more so than they ever will say anything about ours. . . I mean a lot of the things we do protect other people's systems. So we're adept at trying to figure that stuff out. . . Real -time study engineering is a perfect example. They can run their little contingency analysis and determine that if, you know, this particular happens, it would overload this other utility's line potentially up to a certain percentage and then we will generally tell them that we saw this, they will run their own study and verify it.

Cleary, BPA's having more options variety is a major resource for its emergency management.

Given the priority we place on utilizing already-existing groups centrally concerned with large-system interconnectivities, we suggest that research, programs and funding support also be provided to these groups. A particular need is to separate out the error avoidance we have been discussing from under the overarching umbrella of "better risk management." Disaster risks are specific, but to be managed more or less effectively; the mitigable errors we are talking about are also specific but to be avoided—not more or less, but categorically. We argue strategies and interventions for mitigable error avoidance should have their own dedicated funding sources and defined programs. One major priority of interconnectivity table-tops, programs, modeling and related interventions should be, we urge, updating and revising existing emergency management playbooks and documentation for the M9 earthquake.[15]

None of the preceding diminishes the strategic role that remains with the Oregon Department of Emergency Management, the Washington State Division of Emergency Management, and their federal partners. The state and federal Incident Command System remains the pivot for M9 events at the site level in the two states for improving immediate emergency response and initial service restoration.

But just as central are the interventions to manage latent interconnectivities because of the mitigable errors and vulnerabilities they entail. Retrofitting a bridge turns out to be an effort to manage ahead the interconnected road patterns entailed in the M9 earthquake. Actual hazard mitigation plans could be open to all manner of managing latency, as we have seen. One interviewee underscored the missed opportunity of a rural town not having used its plan to anticipate the accelerated gentrification that unfolded after a major wildfire:

> . . .it's like that the shift that they were already experiencing towards like gentrification has been giantly accelerated by the wildland fire that was there. If they had had a plan to combat gentrification and that had been a discussion that they had, or if they, if they recognized the risks that they were already facing that this fire could accelerate, they could have managed their response and recovery in a different way. So they could have let people stay on their own property and an RV longer so that people didn't feel like they had to sell and move. They could have done a lot more programs in place to kind of prevent gentrification.

The town must find resources to address the consequences arising out of its failure to anticipate the accelerated gentrification (including presumably new water and wastewater infrastructure).

We are, in other words, suggesting that the early-on recognition of latent infrastructural interconnectivities and the promotion of shared planning, improvisation, resources and communication can be a form of inter-organizational reliability and a foundation for inter-organizational resilience. As for the importance of that reliability, what better acknowledgement of society's major dependence on critical infrastructures than the immediacy given to restoring

[15] We don't believe it is sufficiently recognized that control room and field improvisation around shared system control variables during an emergency is also necessitated by inability to rely on system models (like BPA real-time contingency analysis) during the loss of systemwide telemetry. In highly automated systems, the ability to revert to manual operations during emergencies becomes paramount.

service delivery in the backbone infrastructures of electricity, water, telecoms and roads just after a disaster? The institutional niche that society has created for reliable critical infrastructures should also promote further rapid response, inter-infrastructurally, and by implication an ongoing inter-infrastructure resilience during major disruptions and emergencies.

Nevertheless, interconnected critical infrastructures are more vulnerable and complex than many in the public and other professions know or could know. The intensive and specific knowledge requirements for identification and prevention of the vulnerabilities and related errors, such as we have been describing, would be significant impositions on infrastructure and emergency staff. It must also be recognized that organizations can and do create vulnerabilities that come with relying on single-source suppliers, hardware and software in their major operations. The latter reinforces a mitigable error already identified: Not to jointly improvise under emergency conditions is an error when shared improvisation turns out to be the only real-time option left for major infrastructures who have hitherto opted instead for their own single-source technologies and suppliers.

Part II concluding remarks

We end by returning to an important methodological issue raised in Part I, namely: Won't calls for more detailed disaster scenarios with respect to M9 events actually lower their predictive validity? That is, will greater specificity render them even less likely to happen exactly in the way set out?

To be clear, we are calling for increased granularity in planning scenarios with respect to: interconnectivity configurations; overlapping/shared control variables; and mitigable errors to avoid along with vulnerabilities to correct for. We are also saying, however, that these more detailed scenarios do not render them more likely to be inaccurate in response to specific unfolding M9 contingencies and events. This is because—and it is a very big "because"—joint improvisation is now a key part of that scenario mix. Scenario details identified beforehand with respect to control variables, interconnectivity configurations, repositories of supplies and the other factors discussed above can and must be rethought on the fly by multiple participants during the unfolding events.

The wager here is that the more specifics thought about beforehand via the scenarios the better, ***if*** those specifics center on control variables, flexible configurations of interconnectivity along with special errors and related vulnerabilities and ***if*** jointly undertaken improvisational behavior and its requirements are expected and accepted to occur for the purposes of providing an extension of real-time contingent requisite variety.[16]

[16] Please note the phrase, "flexible configurations of interconnectivity," does not diminish other forms of interconnectivity. such as sequential interconnectivity. With respect to the latter, one cannot overstress the importance to enhancing *both* requisite variety *and* positive redundancy via activation of serial dependencies in shifting to contact trees and notification protocols in an emergency. "Like if I email you, and you don't reply, I'll call you, right? Or if I call you and you don't pick up, I'll text you," a state resilience officer told us, adding: "Like if there's an emergency happens, I call Chris. If Chris doesn't answer. I call Coop. If Coop doesn't answer, I call Abby. If Abby doesn't answer, I call the governor directly. . ."

This more specific focus on lifeline interconnectivities is incredibly important since the interviewees are quite correct in saying there are not enough resources to mitigate everything that needs to be mitigated beforehand. A long-term BPA employee with control room experience highlighted, “you're not going to spend the cost to be able to replace everything that you think might get damaged. That would be a ridiculous cost, and it's not likely going to happen, right?” We are not suggesting that as a strategy. We are recommending that those who take inter-infrastructural interconnectivities seriously focus their concerns for costs and tradeoffs on the four variables of interest specifically.

Finally, other important matters follow from the preceding sections. First and foremost, Oregon and Washington State emergency management organizations and personnel can think of themselves as state partisans for maximizing options and resources (requisite variety) in immediate response and initial service restoration.

We see emergency management personnel and agencies as champions for and the producers of requisite variety for immediate response and initial service restoration in their respective states. Accordingly, they would also be on the look-out for potential changes in plans or policies that undermine this important form of resilience.

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