Lessons Learned from a Comparative Study of Long-Term Action Research with Community Design of Infrastructural Systems

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The question of how to develop and maintain appropriate, socially informed and sophisticated infrastructural systems is an ongoing concern for CSCW. Information infrastructure development efforts are usually large endeavors that involve many stakeholders, including several organizations that need to interoperate with legacy systems. Projects typically take several years to develop. The duration, variety, and sites of engagement in the development of information infrastructures can be challenging to approach with typical CSCW approaches. In this paper, we compare and analyze our varied experiences in order to generate lessons learned based on being embedded for three or more years as action researchers and ethnographers in infrastructure development projects in the domains of traffic engineering, vocational education, and ocean science. Drawing upon these experiences, as well as literature in infrastructure studies, design methodologies, and organizational studies, we extract guidance for researchers and practitioners seeking to understand and engage in long-term organizationally complex system development projects. Among these lessons, we encourage revisiting previously gathered data as scope and scale change, observing changes in the discursive "reference public" who will benefit from the system, and planning for different intellectual points of entry and exit. This paper lays groundwork for future developments in theory and method of collaborative design and development in and with complex systems.

CCS Concepts: • **Human-centered computing → Computer supported cooperative work**.

Additional Key Words and Phrases: infrastructure, action research, participatory design, grounded design

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1 INTRODUCTION

The question of how to develop and maintain appropriate, socially informed and sophisticated infrastructural systems is an ongoing concern for CSCW. Infrastructural systems are often large endeavors involving several organizations and many stakeholders, with projects that can take several years to develop. These time scales do not easily lend themselves to typical scholarly expectations regarding review cycles and publishing frequency. Furthermore, there are historical biases in CHI and CSCW towards studying direct users and specific end-user applications rather than

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platforms or systems [4]. Increasingly, there are calls for participatory research, also called co-design, where researchers have goals of their own but are also working alongside stakeholder partners on a shared vision. These processes involve "complex partnerships beyond here-and-now collaboration between users and researchers" [4]. The authors of this paper have been embedded as design-focused qualitative researchers studying the development of multi-organizational infrastructural information systems for three or more years. Each of our three field sites is what is called in this paper a *multiorganization*, an interorganizational collaboration whose distinct identity is developed in part through the development of an infrastructure system. In this paper we use a modified form of Grounded Design Case Studies to compare and contrast similarities and differences across our, still relatively unique, experiences as action researchers with a participatory focus for complex systems.

To undertake this comparison, we draw on the recent ethnographic and design work of our four authors on three very different projects to develop new multi-organizational information infrastructures. For each of our three cases, enrollment and particular engagements over time were opportunistic. Our role was often no more clear to us at the beginning of our engagement than it was to those who brought us on, and yet it was clear to all that we provided value because of the questions we asked, the UX methods we applied, and our ability to apply sociotechnical theory to suss out problems and quickly identify breakdowns in communication, as well as coordinative and collaborative work practices and workflows.

The goals and objects of design often must change in large multiorganizational projects; and this can be hard to square with well-defined research agendas. Nevertheless, we find significant value in longer-term engagement, allowing the tracing of emerging phenomena. "During such long-term engagements in a particular domain of practice, problems will evolve, shift, change, vanish, or emerge. The exploration of a domain of practice becomes a journey with multiple different starting points, milestones, and, certainly, endings" [51]. Stevens, et al. propose putting "longer time spans to use by facilitating the comparison and contrast of not only different (but related) design case studies but also a succession of consecutive research projects." Over the years of our project engagement, we took on many roles, often opportunistically and tactically, and learned *how* to research our projects as we learned *from* them. This paper begins to synthesize some of those learnings. Among these lessons, we encourage revisiting previously gathered data as scope and scale change, observing changes in the discursive "reference public" who will benefit from the system, and planning for different intellectual points of entry and exit and embracing varied roles in between.

We cannot yet provide a roadmap for how to consistently approach the kind of wide-ranging, "messy" [28] infrastructural/sociological/analytical/design work we describe, as we ourselves are learning its contours through practice. Indeed, the nature of "wicked problems" suggests that the "roadmap" may be a somewhat inappropriate metaphor. In lieu of this, we attempt to sketch out and find points of comparison and difference between the paths we have staked out so far. In reflecting on our ongoing experiences, we present initial lessons learned by comparing and contrasting a few different key themes: how we initially got enrolled in these projects; how the object of design was different at different times and thus our roles were as well; and, after years of involvement, how our participation has changed. Our hope is to lay the groundwork for similar research on design for complex systems.

The paper is organized as follows. First, we review diverse literature bringing together conceptual and applied work on infrastructure, large system design, and organizational studies. We then provide descriptions of the unique nature of each of our field sites and the specific histories of our engagement with it. We then describe the process by which we synthesized these highly diverse and long-running experiences to describe and analyze some "lessons learned" that researchers and practitioners in similar settings might find helpful when undertaking action research for multiorganizational information infrastructure development.

2 BACKGROUND

2.1 Infrastructures in Multiorganizations

The challenge of designing within and for infrastructural systems that span multiple organizations or levels of scale has been part of our practical reality for some time, but theory and methods concerning this object of study and design lag somewhat behind practice. We begin by situating the study of infrastructure in the literature, then describe some relevant work in CSCW and Sociology that address the study of what we call "multiorganizations." We use the approximative term “multiorganization” throughout this paper to incorporate many of the ideas from strategic action fields, coordinated action, and coordinative entities which we discuss below.

Fundamental work by Leigh Star on the ethnography of infrastructure raised the call to “study boring things” [50], a task to which we eagerly apply ourselves here. This valuable early framework allowed scholars to identify infrastructures according to analytical, sociotechnical characteristics (such as becoming “visible upon breakdown” and being “built on an installed base”) rather than as already well-known types such as bridges and sewage systems. As a consequence, the increasingly important world of technical infrastructures and the human processes built around them could be opened up to scrutiny using CSCW methods. Many scholars have developed fruitful additions and responses to this foundational work. Those working in the subfield of cyberinfrastructure [1], for example, have helped bring this kind of infrastructural thinking to large, ambitious scientific research programs. Ribes, in his work on the ethnography of scaling [38], compares several cyber-infrastructure projects to identify the useful concept of "scalar devices": tools and techniques actors in a cyberinfrastructure project use to manage the size and growth of sociotechnical systems.

Larkin’s anthropological perspective offers politically sophisticated critiques of infrastructure [27]. His study reveals how notions of technopolitics “reveal forms of political rationality that underlie technological projects and which give rise to an ’apparatus of governmentality’ (Foucault 2010, p. 70).” Larkin shows how infrastructures may not always be invisible: not only are the assumptions that drive how they are built, what they enable, and whom they serve are irreducibly political, but they are also “not just technical objects then but also operate on the level of fantasy and desire. They encode the dreams of individuals and societies and are the vehicles whereby those fantasies are transmitted and made emotionally real.” As the lenses of CSCW broadened to different forms of coordination and shared activity, novel methodologies such as trace ethnography [19] arose as a way of applying the insights and concerns of ethnography to new modalities of technical and human infrastructure.

Infrastructure studies–that is, works that either conceptually develop the concept of "infrastructure" or follow infrastructural development projects–have helped our field to think about complex systems of longer duration and greater scale. Yet researchers have struggled to identify how to conceptualize, approach, and talk about the study of infrastructure. A recent critique [32] explains how the term "infrastructure" has been exploded sometimes past the point of usefulness in CSCW. The authors encourage an approach that allows the researcher to traverse different levels of scale, since infrastructure itself evolves in a scale-spanning manner. They emphasize ”coordination among infrastructure-spanning practices and technical structures, researching management and coordination practices across heterogeneous, distributed ‘systems of systems’...in this type of work, artifacts and practices may have characteristics of being local and global simultaneously or serially.” The point is “to not only situate work practices within a larger context but also to actually understand the dialogic and emergent relationship between work practices and the practices and artifacts that are part of a larger sociotechnical milieu" [32].

In order to disambiguate the design space further, we focus on the concept of *multiorganizations*. For the purposes of this paper, a multiorganization can be understood as a collection of several organizations that are working on a system or project (typically an information infrastructure) for common use, and particularly where the process of creating, deploying, and maintaining that information infrastructure plays a part in how the multiorganization itself is defined. Its structure–who has what kinds of roles, responsibilities, and authority–are therefore often hard to align with existing hierarchies in any of the constituent organizations. However, the project around which the multiorganization is developing is considered valid and useful enough to the constituent organizations that sufficient resources (financial, human, and otherwise) are contributed toward system development and maintenance. Through the process of collaborating on this project or system, a community and some level of shared identity is also established. We use this fairly broad term to incorporate the diversity that we experienced and documented.

Information infrastructure development projects are often multiorganizational in their development as well as their goals, even if they are not directly connected to an observable multiorganization. Chisholm's [8] landmark study of the San Francisco Bay area transit system points to "multiorganizational systems" in the context of informal coordination that fills in the gaps of more formal coordination systems. Formal and informal coordination systems mutually support broad action such as a complex transit system. However, these coordinating entities, formal and informal, are not in explicit co-construction with a shared infrastructural system.

Some work in CSCW has begun to theorize multiorganizations from a CSCW/HCI point of view. Two recent works in CSCW model the characteristics [31] and types [36] of collaborative work. The Model of Coordinated Action describes seven characteristics of "coordinated action" that can be used to compare collaborative projects of various kinds, and is meant to be applicable to action at a variety of organizational scales, from small working groups to large institutions. In particular, the dimension of "nascence" offers some conceptual clarity about how types of collaborations (including our larger-scale multiorganizations) undergo processes of coming-into-being and how this often messy and difficult process is one where exciting new things can happen: "Nascence, it should be noted is not merely a simple synonym for 'newness' rather it implies a 'coming in to being'—a special kind of instability rife with future potentialities." In our cases, both the infrastructural projects themselves and the entities responsible for creating and stewarding them are nascent; their respective "future potentialities" are interdependent.

In their work on Coordinative Entities, Paine and Lee [36] empirically describe and theorize some mesolevel coordinative units (or entities) involved in work on collaborative scientific research. While it does not directly describe infrastructure development, the paper provides a framework for describing what kinds of entities (particular kinds of coordinated actions) arise and how they are combined and recombined with other entities to undertake and accomplish work at different stages of their research processes. Each stage may contain a focal entity (in this case a scientific laboratory led by a Principal Investigator, typically a faculty member at a university). The authors describe five "prototypical forms of organizing" that have different characteristics in terms of organizing focus, formality, and planned permanence. A single major research project will have many different combinations of coordinative entities over time. Taken together, the MoCA and the Coordinative Entities frameworks move towards conceptually disambiguating and articulating the social dynamics of multiorganizations.

Fligstein and McAdam bring key insights from sociology and organizational studies to our study of multiorganizations with their Theory of Fields. They define "strategic action fields" as "the basic structural building block of modern political/organizational life in the economy, civil society, and the state" [15]. More specifically, they are a constructed mesolevel social order in which individual or collective actors "are attuned to and interact with one another on the basis of shared (which is not to say consensual) understandings about the purposes of the field, relationships to others in the field (including who has power and why), and the rules governing legitimate action in the field." The authors attempt to strike an empirically realistic balance of agency and influence, acknowledging the importance of large-scale structural forces on strategic action fields, as well as showing how "socially skilled" individuals can make substantial contribution to the success of the fields they are a part of. Strategic action fields strive to achieve long-term stability via continual efforts to represent their field's interests. This is accomplished by the skilled actions of individuals and subfields, and constructive interdependence with other related fields. They claim that "all collective actors (e.g., organizations, clans, supply chains, social movements, and governmental systems) are themselves made up of strategic action fields." We find the theory of fields helpful when trying to understand aspects of the formation and stabilization of multiorganizations. Our ethnographic experiences have allowed us to observe still-emerging multiorganizations (as opposed to those already stabilized), where we see a contestation of interests and influence from various subfields.

2.2 Systems Engineering and Wicked Problems

When multiorganizations form around issues of common interest, and attempt to create shared systems, they are typically concerned with particularly challenging, multifaceted issues that each constituent member has partial control and visibility over, but which was previously "bigger than the sum of its parts." The intransigence of certain issues of this sort has become better accepted in many academic and practitioner communities, but it is helpful to revisit the origin of this idea. In the late 1960s, Horst Rittel presented the notion of wicked problems (WPs) as one way to articulate the complexities that accompany the planning and scoping of certain problems. Rittel first conceptualised WPs as "that class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision-makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing" [9]. The concept originated from Rittel's critique of the so-called "systems approach of the first-generation" [40]. As described, a first generation systems approach depends on the assumption that planning problems can be organized into distinct phases from the outset to the solution. This is the intellectual heritage of systems engineering (SE) [26], which itself is still a dominant form of infrastructure development and management. This dependency is particularly salient in government settings where projects are often required to have "systems engineering management plans" [43]. Rittel critiques the assumption that planning problems can be solved through approaches that rely on rational-analytic models of planning [10]. Instead, Rittel and Webber [41] claim all planning problems are wicked, and reject the "classical paradigm of science and engineering" as a basis for framing social science and modern professionalism [23]. The WPs notion has also been extensively utilized in environmental policy analysis, and as a result, environmental problems have become classic examples of WPs because they defy easy resolution.

Ironically, while a key idea in the concept of WPs is their intransigence and their likelihood of pre-set solutions making things worse, the concept has heavily influenced the field of design. Practitioners and researchers are teaching and learning the skills needed to facilitate bottom up, context-aware, collaborative solutions (or at least ameliorations) to wicked problems ([6], [10]). Methodological approaches such as soft systems methodology (SSM) [7] have also arisen in response to the limitations of systems engineering approaches. SSM in particular attempts to locate the "systematicity" in the sociotechnical system the WP is bound up in rather than in the problem itself, and to focus on improvements rather than solutions. In addition, human-centered design itself is beginning to make inroads into systems engineering scholarship, as the embeddedness and sociotechnical complexity of systems become more apparent over time [5]. In any case, stakeholders who manage and develop infrastructure are often required to be responsible for managing "wicked problems" domains (homelessness, community planning, natural resource allocation, etc.), whether the problems themselves are solvable or not. So it is important to support those stakeholders in their endeavors, and that means respecting the complexity of the problem space while still finding actionable approaches.

2.3 Participatory Design and (Participatory) Action Research

The challenge of participating in and studying the development of infrastructures in nascent multiorganizations is multifaceted and requires drawing from multiple approaches, particularly when finding ways to grapple with the sorts of problems multiorganizations often form around and develop through. Design-oriented fields have proposed their own methodologies and "meta-methodologies" to look past some of the positivist and often top-down approaches of systems engineering ([16], [13]). Action Research (AR) and Participatory Design (PD) are both participatory research methodologies, both of which explicitly address the democratic aspects of design and change processes. A democratic approach allows for debate and discussion, foregrounding varied political interests, making explicit processes that are part of developing multiorganizations, how those processes interact, and how that interaction shapes the system as it is created. AR and PD have both proven valuable in terms of involving multiple stakeholders in the process of innovation, development, and implementation, and each comes with its own conceptual and ethical commitments.

Action Research is a methodology that aims to induce change, to improve certain aspects of the targeted research domain. The way change is often created is based on explicit democratic, participative, and interdisciplinary values, which aim to support collective action ([18], [22]). AR often involves participants (e.g., members of an organization) in the preparation and implementation of the research. Lewin's original description of action research included a spiral of planning, acting, observing, and evaluating, also known as the "action-reflection spiral." This is an iterative approach where the group comes together to identify and work on a "thematic concern" after determining shared issues/problem clusters of mutual concern. How this happens can be flexible and responsive to changing conditions and constraints. As Ghoshal explains [20], this involves careful and ongoing understanding of and alignment with the community's own values and ethical stances, in part through building trusting and lasting relationships with community members. This happens in concert with the action-reflection spiral of AR, allowing the researcher to better understand and support the questions the community is concerned with and what drives that concern.

Participatory Design (or cooperative design) emerged from Scandinavian software development traditions, in a fruitful collaboration between academics and labor interests. When PD was originally developed in the 1970s and 1980s, it was driven by democratic Scandinavian labor values, which differed from more top-down management approaches that often informed the design of workplace technologies [11]. Instead, PD aimed to include direct interaction with users to articulate, create, and develop users' ideas and visions. Through the participation of stakeholders with different forms of expertise, goals of mutual learning and shared experimentation and reflection became central aspects of a PD process ([25], [49]).

Participatory Action Research (PAR) combines elements of both Participatory Design and Action Research. With PAR, McTaggart [34] notes the importance of being deeply involved in multifaceted production of tangible improvements to knowledge. McTaggart suggests that to call something an example of PAR implies that it had a positive impact. If it does not, the emphasis then turns to analyzing how it might have done better. Traditional action research places an emphasis on both ongoing learning, and the placement of both power and responsibility for those affected to decide on and enact the changes. However, McTaggart doesn't see standard action research as sufficiently bringing the affected communities in to develop their own theories of change. PAR also stresses the importance of all participants, not just the academic researchers, growing in theoretical and analytical sophistication [34].

Previous research has pointed out challenges when applying AR and PD to large scale (change) projects where multiple systems are involved ([33], [24]). We should first clarify that "scale" for an infrastructure is used in this paper to refer to size: this is most easily represented by the number of users, operators, or directly affected stakeholders. A lightweight inventory system used by a small business is small in scale, while a similar system created to be used by all the employees of a Fortune 500 company would be considered large scale. Martin argues that part of the problem is based on "the greater the size of the systems in a change effort and the greater the diversity of participants, the greater is the need for inclusive and accessible arenas and methods" (p 15). In the context of AR, researchers have emphasized that issues of power, inclusion, and implementation become increasingly complex as the numbers of stakeholders and the need for understanding multiple systems and contexts grow. Moreover, increased diversity of involved participants results in more (often varying) perspectives and interests ([33]). Similar issues have been emphasized about PD. The challenge to scale PD consists, among other things, in not losing focus on core democratic values while achieving design success for larger systems with much larger numbers of stakeholders ([4], [45], [52]). Ribes and Finholt show *why* it is hard to create appropriate systems in such settings, even when the methods are good. Via their own intensive multisite ethnography comparing scientific cyberinfrastructure projects, Ribes and Finholt uncover several "tensions" involved in creating and studying cyberinfrastructure. For example, "project vs. facility," where the system lifespan does not line up with the funding cycle; or "general communities vs. specific constituencies," where the interests of those meant to benefit from or use the system has to be disentangled from which participants are involved in development [39]. Builders of these cyberinfrastructures attempt to handle these tensions simultaneously in order to create a sustainable system that can operate for the long term. These tensions and challenges of scale–or similar ones–are bound to happen even in projects where participatory approaches are consciously used, so it is helpful to understand why, how, and what can be learned from them. In this paper, we hope to add to this conversation, adding both analytical lenses and practical implications.

3 METHODS AND RESEARCH SITES

The authors engaged in ongoing research at three different field sites with different domains, prior histories of interorganizational collaboration, development trajectories, and levels of technological focus. Each project involved both long-term ethnographic engagement and direct contribution to design. These engagements were formed and undertaken independently, and used a variety of methods and approaches appropriate to each situation. The first, second, and third authors independently engaged in in-depth action research over the course of several years, and then synthesized aspects of their experiences across an unusually wide range of domains. The fourth author studied and engaged in research across multiple multiorganizational information infrastructure design projects in science, engineering, and industry over the course of sixteen years. Taken together, they allow a particularly diverse and cross-cutting view of design-related ethnographic research in infrastructural settings in order to distill some lessons learned.

Three of the four authors were PhD students during most of their participation, and much of the narrative is presented largely in terms of their engagement, because the graduate student positionality was salient to our analysis. However, the fourth author is a professor who had direct engagement, including some action research, with two of our three field sites and was involved in post-hoc organizational stakeholder analysis of the third research site which led to a publication [35], further enabling our synthesis and cross-comparison. We describe below the analytical methods we used to investigate similarities and differences in our participation in the design and development of very heterogeneous multiorganizational projects (traffic management, vocational education, and marine ecosystem modeling) to develop information infrastructure for specialized kinds of work. After describing our methods, we provide detailed descriptions of the field sites themselves. For each, we describe the context and problem domain, history of inter-organizational collaboration, infrastructural project development area, and the duration and scope of each researcher's involvement in their field site. A concise summary of the descriptions of these four topics can be found in Table 1. The particular role of the researchers is an object of analysis and therefore this is also discussed in the Findings section.

3.1 Methods: Comparing Design Case Studies

Our analysis began with several meetings to discuss many different conceptual frameworks that could be used to guide analysis and provide sensitizing concepts. Despite the seeming commonality of the field sites all being non-profit information infrastructure development projects, getting analytical traction was initially difficult given the differences in our experiences and the content and trajectory of projects. Over time, we found effective ways to describe and analyze similarities and differences that were most similar to Stevens, et al.'s "grounded case studies," which marries comparative case study analysis over long term engagement with some of the rigor of grounded theory.

We draw on the Grounded Design approach [44], which is a design-research approach used in case studies. The approach aims to generate a comparative analysis which examines social practices that in some way help to identify and make visible potential problematic aspects of those practices [2]. In this way, the investigation "is targeted to inform the design of IT artifacts that are expected to mitigate the identified problems by providing features to enable practitioners to originate changed or new practices" (p 459).

The Grounded Design approach "can be understood as writing 'grounded theory' from design case studies by means of a comparative analysis of individual cases in their contextualized complexity" [51]. Moreover, the approach aims "to ensure the transferability of the rich yet local and context-specific design knowledge that emerges with such an [practice-based] approach." We take inspiration from grounded design to compare our three very different research domains and to further generate lessons learned across the three cases.

Design case studies constitute the basic element of the grounded design approach. A design case study often involves three activities that to some extent build on each other: Context Study, Design Study and Appropriation Study. The first activity refers to studies of varying ethnographic character with an analysis that describe already existing IT tools and their use. The second activity refers to studies that enable researchers to describe emergence of IT artifacts and the "final" result, as well as the stakeholders involved in the process and the applied design methods. The third activity refers to what happens after the IT artifact is applied in practice and how it affects social practices [51].

Our approach and object of focus is not identical to grounded design as Stevens, et al. lay it out. Their stance on research data is somewhat more intentionally idealistic: they believe researchers should strive to make all data publicly available, allowing other researchers to compare data even more broadly [51]. In addition, Stevens, et al. typically use the formulation of "IT artifacts," but in many cases we consider many objects of our study a kind of never-finished IT artifact, or even a "system-of-systems" that evolves with the multiorganization's identity and infrastructurally enables more forms of coordination and shared work over time.

However, we consider our approaches substantially similar, particularly in the areas of greatest concern to us. Grounded design has a practice underpinning, and we have in some form undertaken all three of their design activities (Context Study, Design Study and Appropriation Study) in all our case studies. Below we briefly describe some additional similarities with grounded case studies:

- **Complexity**: "because actual design practices are reflective and iterative, these activities are treated as overlapping, interleaving, and recursive" [51].
- **Similar methods**: "[C]onducting design case studies generates situated knowledge by applying established research methods, such as ethnographic field studies, participatory design and action research" [2].
- **Advocating for long-term engagements**: "A longer-term design process can explore the design space systematically and reveal additional insights into the alignment of practices with specific design options" and "A longer-term research approach is highly desirable, since practices do not evolve in an instant but rather need a longer period of time. It is highly desirable to describe how changes in practices were brought about and how individual learning provides, in time, new collective insights and new artifacts uses…"

Over a period of more than a year, still participating in their respective projects, the authors met repeatedly to analyze and compare characteristics of their field sites across many dimensions and in reference to many theoretical frameworks. In doing so, we abided by the Grounded Theory maxim of staying "in dialogue" with our data [21], moving beyond specific frameworks when we found they did not faithfully encapsulate our real-world experiences. Some of the specific analytical activities we performed were:

(1) Temporality: To investigate how the project work of our field sites connected to temporality, whether "units of work" that the projects were supporting were very short or long in duration, and how this connected to longer-term project planning and analysis, we each consulted our individual field materials and wrote accurate, detailed anecdotes of hypothetical work scenarios and diagrammed them in time. Each of these infrastructures supports different kinds of work. These types of work have different temporalities; for example, a traffic incident, (even a very long one!) takes place quickly and in "real time," while a new vocational education course is created over the course of months. We found that the Traffic Management project's primary "units of work" were short in duration but that each short action–such as dispatching a fire truck–eventually flowed up to data analysis and resource planning. Meanwhile, the modal units of work are performed more slowly at the other sites, and in the case of the Ocean Science project, in reference to changes in the natural world, which can occur over a wide range of time spans. Thus, while each system is an information infrastructure, embedded in each is a different level of urgency and rapidity, changing how data is gathered and analyzed.

(2) We initially attempted to map the types of entities present in our own field sites onto Paine and Lee's Coordinative Entities. While we found that the general characteristics of organizing focus, formality, and planned permanence were useful dimensions of comparison, the actual five coordinative entities themselves were too closely tied to the specifics of scientific research collaboration to serve as a complete taxonomy.

(3) We compared design-related work we had created during our engagement, in terms of how work and activities were portrayed and what impacts they had on design processes over time. In the Ocean Science project, UX evaluation tasks were used not only to evaluate the usability of a data portal, but also to stimulate discussion among the team about who the system was meant to serve. in the Traffic Management project, Figure 1 was used both in drafts of a policy document (its original purpose) and to explain workflows to other stakeholders.

(4) We diagrammed other characteristics of our field sites to compare each of our own initial individual positions, focusing on points of entry and our relative expertise on the project domains; in the process we discovered the relevance of tracing positional changes over time and how this connected to the seemingly messy, unorthodox design methodologies that we used.
(5) We candidly discussed challenges and confusions we had experienced, and discovered commonalities among these challenges.
(6) Following this intensive comparison and discussion, we compared and analyzed our answers to a set of prompts and sequentially discussed each of the following, incorporating both general characteristics of the projects and our own specific roles and relationships within the projects. In a sense, we qualitatively "coded" our various experiences along the following dimensions:
   (a) Initial engagement
      - Pre-existing relationships that facilitated the researcher joining project
      - State of funding/maturity/development of the project when the researcher first joined
      - How early "unofficial role" or informal participation was ascertained
      - How the researcher learned about the collaborators/groups involved
      - What technologies were involved at the time the researcher joined? How did the researcher learn about them?
      - What stakeholders were actively involved when the researcher joined the project?
      - Researcher's first deliverables on the project
      - How joining the project served the researcher's intellectual and professional goals
   (b) Current engagement
      - Project's current state of funding/maturity/development
      - Any current "unofficial role" or informal participation
      - How researcher currently learns about changes to collaborators/groups involved
      - What technologies are currently involved and how the researcher learns about them
      - What stakeholders are currently actively involved
   (c) Changes over time
      - How has the researcher personally experienced moving from the "meta-project" to "sub-projects"?
      - What are some key changes that seemed to happen quickly?
      - What are some key changes that seemed to happen slowly?
(7) After comparing and contrasting our answers to all of the above questions, we identified three cross-cutting themes that highlighted differences and commonalities in our experiences. Discovering common challenges helped us to generalize beyond individual challenges into lessons learned from sharing our lived experiences as participatory action researchers in infrastructure development.

3.2 Field Site 1: Developing a Platform for Complex Traffic Incident Management in a Large American City

3.2.1 Context and Domain. The first field site is a collection of public agencies (primarily city police and fire, county transit authority, and city and state departments of transportation) that work on traffic-related incidents in and near Seattle, Washington, USA. This field site aims to create organizational, policy, and technology infrastructure to support inter-agency traffic incident and congestion management, particularly for more serious traffic incidents. These efforts will, if successful, improve current issues with sub-optimal coordination and information-sharing during incidents, and after incidents, improve incorporation of data into ongoing process improvements. In a sense, the infrastructure supports the use of other other infrastructure–the road system.

3.2.2 History of Inter-Organizational Collaboration. Minor or highly specific types of incidents might fall entirely within the jurisdiction of one agency. However, for most complex incidents, multiple agencies will collaborate depending on various characteristics like location, what kinds of facilities or vehicles are involved, or the presence of injuries or other health hazards. There is no single "lead" agency–the "incident commander" varies depending on all the characteristics described above. For the purposes of this paper, we are focused on the agencies that 1. Tend to have primary jurisdiction over at least some sorts of incidents within the greater municipal area and/or 2. Have joined an interagency consortium called SAJOG (Seattle Area Joint Operations Group) that attempts to improve mobility and traffic incident response in the greater municipal area. This operational community includes city and state law enforcement, the city fire department, area transit agencies (particularly the county's bus agency, King County Metro Transit, which has the largest footprint on the city), and both the city and state departments of transportation (DOT), which each have associated roving incident response teams that can provide assistance to other first responders.

Personnel (e.g. operators, first responders, and transit workers) at these agencies perform numerous tasks responding to and analyzing complex traffic incidents, using a wide variety of communication and infrastructural technologies. Control room operators in the DOTs watch camera feeds and monitor first responder dispatch traffic, communicating with both the public (primarily via Twitter) and other agencies about what is going on and what responses might be needed. At times, they adjust some of the traffic facilities they have purview over, such as traffic signal timing, express lanes, highway overhead signs, and interstate lanes with adjustable speed limits. First responders and their associated 911 centers use computer-aided dispatch (CAD) systems to take calls about incidents and dispatch responders to the scene. Responders going to the scene can also use a radio patch to get in phone contact with their home dispatch center. King County Metro Transit (often shortened to King County Metro or just KCM) has their own CAD-like system that allows coordinators to address any issues bus drivers may have, from malfunctioning fare boxes to active shooters. As such, traffic-impacting information is often captured in their own systems.

These agencies often contact each other for information or provide guidance and assistance. For example, the Seattle DOT control room operators may see something on camera that could snarl up a bus route, and call King County Metro's coordination center to warn them, so a route can be proactively rerouted. Individuals often leave one agency for another, sometimes bringing important knowledge and contacts from their prior agency. There have been many, if typically un-systematized, technology and data sharing agreements between agencies. For example, the Washington state DOT's control room shares some of its camera feeds with the Seattle DOT's control room; and for historical reasons, various agencies sometimes call and request information from King County Metro. All of these informal and formal connections, often forged over decades, contribute in numerous ways to the brief, intensive, high-stakes tasks of working incidents.

While some rare and unusual incidents could draw upon possibly dozens of different actors, and many more typical incidents only require two or three agencies to interact, Figure 1 is a simplified depiction of how these agencies generally interact during traffic incidents (for illustration purposes the diagram portrays a situation where all applicable agencies are participating; however, such incidents are exceedingly rare).

3.2.3 Project Development Area. The aforementioned consortium (SAJOG) was formed in 2017 and formally chartered in 2018. While many of the agencies have decades of history working together on traffic incident management, SAJOG itself was created to improve upon this history. The group

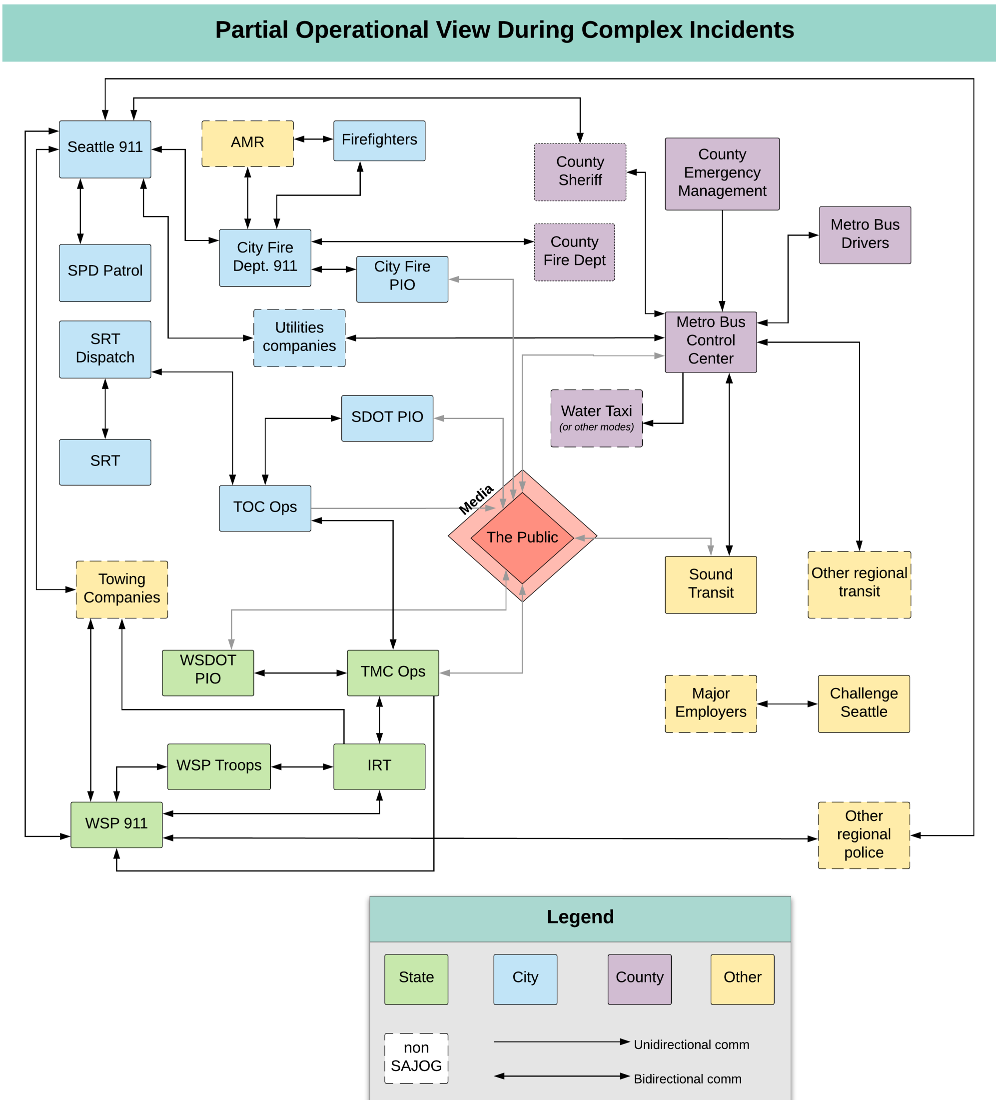

Fig. 1. Simplified, idealized communication flow during complex traffic incidents. Depicts which entities are directly communicating, color coded by type (state, city, county, or other). Double-headed arrows indicate bidirectional communication, i.e., both entities in a bidirectional communication flow are providing information to each other, updating each other's understanding of the situation. Communication may come in many forms, from phone calls to system entries. Unidirectional communication is typically the provision of instructions or information from one entity to another, without the expectation of mutually informative dialogue.

that became SAJOG was created in response to a particularly complex incident requiring intense interagency collaboration that took an unacceptable amount of time to resolve despite all agencies performing, according to their own protocols, adequately.

Since that time, the SAJOG agencies have improved their collaboration by meeting monthly, providing updates about actions they are taking and informally strategizing about how they might help each other with incident response and related traffic congestion. After several months of these meetings, the group decided that creating a shared system that would support and enable ongoing coordination and information-sharing would be a valuable way to further such goals. Led primarily by University researchers and a hired software development consultancy, SAJOG is currently in the process of developing an online platform to support improvements in coordination and information-sharing during incident response, and capturing data for later analysis and performance improvement. The development effort began in greater earnest after winning a substantial US federal grant in 2020, and full deployment of the system (called the Virtual Coordination Center, or VCC) is scheduled to happen in 2023. At the moment, SAJOG itself does not have an office with permanent staff, but the state DOT has agreed to serve as the VCC service owner post deployment, shifting their role to a more central one even though a majority of the relevant traffic management work is ultimately undertaken by city employees.

The design process is more "agile" than is typical for the city and state governments, and this is significantly driven by the software design consultancy performing much of the development work. The design process is also a process of mutual discovery about how those at other agencies make sense of an unfolding incident, which can be chaotic and multifaceted. In addition, the more intensive, intentional forms of engagement needed to adequately create the system have enabled the members of this operational community to gradually learn about each other's practices (sometimes solving mysteries about why another agency behaves the way it does during incident management or what a commonly used term means) and improve trust and communication in general.

3.2.4 Duration and Scope of Researcher Involvement. Since early 2018, one author has spent time in both a design-oriented action research role as this new system is developed; and in an ethnographic role, observing a variety of specific settings of incident response work, including DOT control rooms, 911 centers, and responder units. Currently, the author is heavily involved in the day-to-day work of system development, including participating in design meetings, writing user stories, creating documentation and mockups, and advising on system management. This design-focused engagement has become more systematic and predictable over time. As a graduate student without prior traffic engineering expertise, she initially engaged by observing regular meetings, only directly participating (in the form of helping to lead design workshops and interviews) after a few months.

The author who is a professor attended occasional meetings for over a year and actively participated in cross-functional meetings and contributed to project deliverables for several months.

3.3 Field Site 2: Innovation and design of data-based services in the context of vocational education in Denmark

3.3.1 Context and Domain. The second field site is a network of stakeholders that work to maintain and develop vocational education (usually by developing in-demand vocational education classes) for the industrial sector in Denmark. The network of stakeholders includes ministries, governmental agencies, trade unions, employer associations, and education secretariats. This project aims to improve organizational and technology infrastructure to support cross-organizational collaboration, specifically for the organization, maintenance and development of work done by committees across the network. Involved stakeholders work to improve this particular cross-organizational collaboration necessary for maintaining and developing vocational education in Denmark.

Our point of departure was an organization, Industriens Uddannelser (English: The Education Secretariat for Industry, hereafter the acronym IU is used). IU is an organization that assists the collaboration between these diverse stakeholders for the network to develop, among other things, education programs for vocational education and continuing education in the Danish industrial sector. For example, IU facilitates meeting structures that enable representatives from different organizations in this context to work and collaborate to address certain shared concerns, e.g., the development of new education programs. In Figure 2 we diagram IU as it is situated in a complex organizational setting. This figure is a result of insights from a long-term action research project. The diagram evolved based on discussions that addressed the challenge that we as researchers and designers were confronted with: How to understand and relate to the complex network of stakeholders that the organization collaborated with in order to solve its core tasks. We developed the diagram to support our discussions about how to characterize IU as an organization. Over time the visualization became an analytical tool for relating the data work at IU with the cooperation of different stakeholders in the network. The figure constitutes the 10th iteration. The process of developing the figure is described in [48].

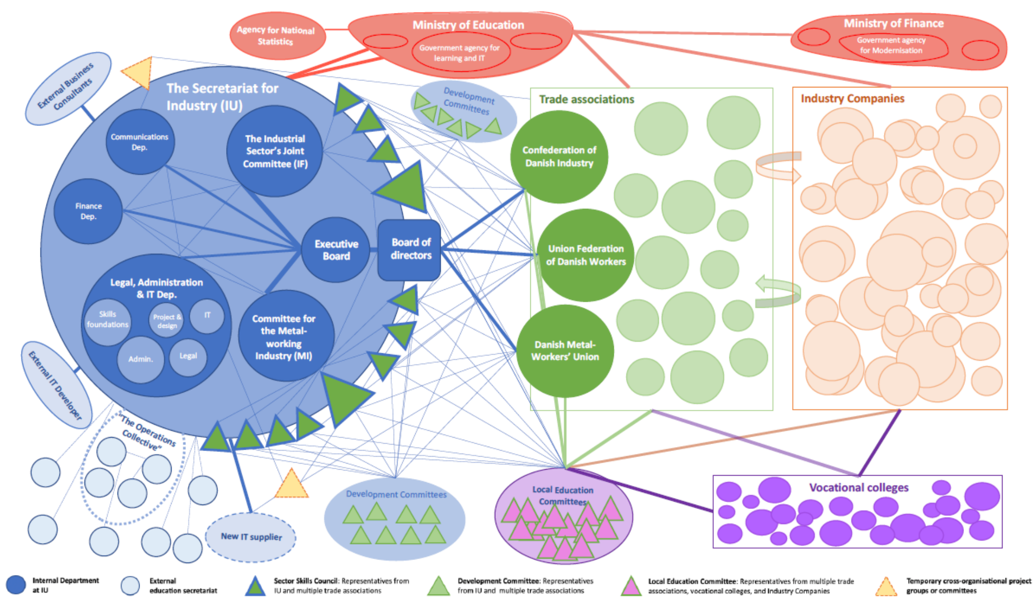

Fig. 2. Diagram of the public sector arena for vocational education and training in Denmark. The size of the diagram does not reflect the actual size of the organizations. The diagram highlights the perspective of IU due to the author's situatedness in the research project.

3.3.2 *History of Inter-Organizational Collaboration.*

In the context of vocational education in Denmark, the network of stakeholders is greatly influenced by the tripartite structure of the Danish labor market. Simply put, this organization of the labor market creates processes where social partners' interests are equally represented. This means that both employer associations and trade unions are part of negotiation and decision-making processes. As with most multiple-stakeholder environments in the public sector, the sector of vocational education and training is further structured to allow for cooperation around more specific concerns.

There is a concurrent concern for vocational education to "meet the needs of the labor market". This requires ongoing innovation and development. To do so, members from the network of stakeholders perform numerous tasks. For example: Representatives from employer associations and trade unions attend regular committee meetings, which are organized and facilitated by education consultants at IU. The education consultants prepare, facilitate, and follow up on continuous committee meetings, where representatives from external organizations come together to work on shared topics/issues. The education consultants are often in contact with people at the Danish Ministry of Education and are supported by administrative workers at IU who provide materials and data for the meetings. The administrative workers are in regular contact with other key stakeholders in this network, namely people working at local vocational colleges and examiners, which constitutes people from local industry who have been appointed by unions and employer associations to undertake this task. In this context, data work takes place among multiple stakeholders and requires cooperation across organizational boundaries. Moreover, changes in data practices in one site change cooperation among multiple stakeholders in the network.

3.3.3 Project Development Area. The work originates from a three-year action research project (2017-2020) with IU that explored how organizations innovate and design their data-based services. Through three overall overall action research interventions (sub-projects), one author explored (1) what common data practices in organizations are, (2) how organizations may design concrete, data-based services, and (3) how organizations may explore new data sources and experiment with their usefulness.

For the purposes of this paper, we are primarily focusing on IU and stakeholders who were directly involved in the first action research intervention. This project examined the redesign of an IT system that was used amongst IU and central unions and employer associations. The system aims to support the maintenance of information about members of the 165+ local education committees (LECs). The LECs constitute governing bodies that are in place to ensure that those issued by the Danish Ministry of Education and the Skills Sector Councils are implemented locally.

The LECs consist of representatives from the local industry and have been appointed by their affiliated union or employer association. On average, a LEC is made up of 4-8 committee members that represent both unions and employer associations, and two representatives from the local vocational college. It is required by law that LECs are made up of representatives from both unions and employer associations. Many LEC members are active in more than one LEC. To maintain this setup requires careful organization to ensure that each committee is staffed according to regulations. The involved organizations need to have access to all relevant information about individual LEC members and their affiliation. To ensure this need is met, IU acts as a central stakeholder as it has been entrusted with the task to collect, store, and maintain all relevant data in the so-called LEC IT system and its connected database [46].

3.3.4 Duration and Scope of Researcher Involvement. The project to redesign the LEC IT system was initiated in 2017 and aimed to identify how a new IT system could better support the cross-organizational collaboration that underpins the maintenance of the LEC information. One author and members of IU initiated a design process that ran from March 2017 to May 2018. During this time the author acted as a design-oriented action researcher. One of the objectives of the PhD project was explicitly to create a sustainable human-centered design culture in the organization. During the time of the PhD project, the members of the organization learned and established new human-centered design practices. Since then, the author has taken an ethnographic role, observing how the people at IU who continued the project cooperated with external stakeholders and how the project developed over time (2018-2021). The author has also been employed as a consultant to support a new innovation project, which required a higher level of expertise in order to ensure a user-centric perspective throughout the project. The fourth author participated in some post-hoc analysis of the data.

3.4 Field Site 3: Building a Research Data Infrastructure for the Ocean Sciences

3.4.1 Context and Domain. The third field site involves stakeholders that are members of scientific laboratories at universities and research centers across the United States, Canada and the United Kingdom. This project is part of a larger computational biogeochemical modeling of marine ecosystem project called CBIOMES, which aims to build a technical infrastructure to support cross-laboratory collaboration and allow for the systematic integration of physical, chemical, and biological oceanographic data sets that are being generated in varying spatial and temporal resolutions. CBIOMES researchers seek to integrate new data sets in real time as they are collected at sea to facilitate direct tests of theoretical predictions; quantify the skill of numerical simulations; and develop new models. Ensuring that such disparate data sets can be readily shared and combined is crucial for the involved stakeholders, who are collectively working on related questions pertaining to the organization of microbial communities and their role in mediating the global cycles of elements in the ocean.

3.4.2 History of Inter-Organizational Collaboration. The CBIOMES ocean initiative is home to a complex ecology of many collaborations that are largely focused on developing new conceptual and mathematical models to advance understanding about the structure and function of microbial communities. To support these efforts, CBIOMES researchers actively seek out and establish collaborative relationships with research groups in other initiatives supported by the main funder, the Simons Foundation. These initiatives (called Ocean Processes and Ecology [SCOPE] and SCOPE-Gradients) share a common interest in understanding microbial processes and finding new ways to leverage modeling as part of it. SCOPE and SCOPE-Gradients members mainly approach their research work through the collection and analysis of specific observational or experimental data, which is complementary to the modeling work of those in CBIOMES whose concerns center more around bringing together existing data sets to help optimize and validate their models.

Researchers (e.g., principal investigators, research scientists, postdocs, and graduate students) involved in the various CBIOMES collaborative modeling efforts work together on engaging research questions that cross disciplinary boundaries in order to address research goals that were previously unattainable through the approaches of a single discipline. To do so, researchers from SCOPE and SCOPE-Gradients perform numerous tasks in close coordination with those in CBIOMES. For example, principal investigators in SCOPE and SCOPE-Gradients will often put research scientists or postdocs in contact with their graduate students who can generate the kind of experimental data that is needed for the modeling work. Research scientists, postdocs, and graduate students typically lead the work on developing common standards by which different kinds of observational or experimental data can be combined and compared. All three are also responsible for preparing specific metadata around the provenance of the data set, its transformations, and cleaning methods that have been applied to it.

Although the SCOPE and SCOPE-Gradients ocean initiatives provide a rich stream of observational and experimental data to CBIOMES, making data from different sources comparable for analysis in modeling work involves a tremendous amount of coordination and data work among collaborators, many of whom still rely on teleconferences and email exchanges to support work to bring their data collecting, cleaning, and sharing efforts into alignment. The absence of a standardized data management policy across these ocean initiatives has resulted in data sets being dispersed across numerous data repositories and stored in a wide array of formats over the years which requires increased time and labor to bring data and models together properly.

3.4.3 Project Development Area. CBIOMES was formed in 2017 with a focus on advancing understanding about microbial communities and how they mediate the global cycles of elements that fuel food webs that sustain life in the ocean. As planning for the project took off, one need quickly became apparent to the group: a data portal that would allow researchers to sift through the mountains of oceanographic data collected from their own work and by other initiatives supported by the Simons Foundation. At the time, oceanographic datasets used by researchers were scattered across a wide range of sources and often required enormous downloads. Each data set had its own unique internal organization, making the task of comparing information across different data sets a confusing and laborious process.

To address such concerns, CBIOMES researchers elected early on to build a data portal that would support data integration and facilitate the sharing of data within and across the different ocean initiatives. Led by a small group of CBIOMES and university researchers, the team is currently developing a data portal (called CMAP) that aims to support the work of storing, retrieving, combining, and conducting cross-disciplinary analyses of diverse data sets. Development efforts began in late 2017 and new iterations of the system's features and functionality have since been demoed at annual all-hands meetings and made available for exploration and testing by researchers.

3.4.4 Duration and Scope of Researcher Involvement. Prior to formally joining the CMAP data portal development effort, the third and fourth authors (PhD student and faculty member) started as ethnographers embedded in a biological oceanography research lab (many of whom would go on to join CBIOMES and form a team dedicated to CMAP's development). From June 2015 to July 2017, one author spent time becoming immersed in the norms, values, and everyday concerns of the research lab and its members. Being embedded in the field site for an extensive period of time resulted in the principal investigator of the lab developing a close interest in how qualitative research methods could potentially be leveraged to inform design, particularly the design of a data portal to support cross-disciplinary collaboration that was being envisioned.

Following the awarding of funding by the Simons Foundation in late 2017 for the CBIOMES ocean initiative, the authors were formally invited to join the CMAP project. From September 2017 to September 2018, the authors spent time in a design-oriented action researcher role. They worked with members of CMAP to build consensus around a formalized design process and action plans necessary for identifying all stakeholders involved or affected by CMAP, capturing stakeholders needs and concerns, and defining the bare minimum useful amount of content and functionality the system must deliver. Concurrently, one of the authors also resumed their ethnographic role and observed how research is done in the ocean sciences (e.g., experimentation and field studies) laboratories, how data is being preserved and shared, and the methods and tools being employed with collaborators across disciplines (e.g., biological, chemical, physical) and geographic distances. Insights obtained from time in the research site informed the selection of research methods and approaches for guiding CMAP's design process. Currently, one author is actively involved in the design and evaluation work of CMAP's system features and functionality. At the time of this writing discussions are underway, initiated by project leadership, to explore our continued involvement as participatory action researchers in system usability and multiorganizational coordination.

3.5 Summary of Field Site Characteristics, Stakeholder Types, and Methods of Engagement

In Table 1 we summarize the key characteristics of each field site, both in terms of what infrastructural problems were being addressed and how the researchers generally engaged in the research site.

Table 1. Summary of Field Site Characteristics

Problem Domain	Organizational Topology	Systems Under Development	Researcher Involvement
Traffic incident and congestion management in a metropolitan area	Several public agencies with histories of informal agreements, evolved to semiformal chartered agreement with grant funding, with system development primarily led by University researchers (including paper author) and software consultants	New virtual coordination center allowing stakeholders from all participating agencies to coordinate and share information and gradually improve planning	First author joined as observer and complete novice in early 2018; has held variety of ethnographic and design-oriented roles and is currently funded by the project. Fourth author was heavily involved in 2019 and retained an advisory role until 2021
Vocational education development in Denmark	Government, trade unions, industry, and universities. Coordination managed by one organization. System development primarily led by the central organization and paper author as part of dissertation project	As part of a larger effort, redesign of an existing inter-organizational system for vocational course development intentionally based on action research and participatory design	Second author joined project based on prior relationships with IU members and completed dissertation research there. Currently external consultant to the ongoing project
International academic marine ecosystem modeling project	Scientific research collaboratory (CBIOMES) organized at paper author's university driving the data integration project, but serving wide variety of ocean science stakeholders	Data portal for integrating heterogeneous ocean science datasets and serving APIs for developers to query and understand the data, and for site visitors to explore the data on a geographically mapped tool	Fourth author gained entrée in 2008. Third author joined in 2015. Third and fourth authors have held a variety of ethnographic and UX research roles; third author currently involved in consultation, outreach, and stakeholder management.

In Table 2 we briefly outline the types and numbers of stakeholders we engaged with in each field site, and which forms of data collection we employed with each type. The numbers represent how many of each type we directly engaged with in a research capacity, not necessarily the entire population. For example, there are hundreds of first responders in the Seattle area, but we only directly engaged with 15. Because each field site was large and dynamic, the numbers are sometimes approximate, but should be a good indication of scale.

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Table 2. Summary of Stakeholder Types

Field Site	Stakeholder Type	Count	Data Collection Used
Traffic Management	First responders such as firefighters and police officers	15	Workplace observations, interviews, design workshops
	Response center operators such as 911 call takers and dispatchers	30	Workplace observations
	Traffic management control room operators (both city and state)	25	Workplace observations, design workshops
	Public information professionals	20	Workplace observations (minor), interviews, design workshops
	Agency IT professionals	10	Interviews, group meeting observations
	Agency departmental leadership	40	Interviews, design workshops, group meeting observations
	Software design consultants	7	Group meeting observations
	University research team (includes first author, previously fourth author)	15	Interviews, group meeting observations
Vocational Education	Management at the Industriens Uddannelser (IU) organization	7	Workplace observations, interviews, design workshops, informal correspondence
	IU Board	7	Interviews, design workshops, group meeting observations
	Education consultants who are employees of IU	7	Interviews, design workshops, informal correspondence
	Local Education Committee members	10	Interviews, design workshops
	Local Education Committee groups	3	Group meeting observations
	Vocational college representatives	4	Interviews
	Trade union representatives	8	Interviews, design workshops
	Employee association representatives	6	Interviews, design workshops
	Representatives from the Ministry of Education	2	Informal correspondence
Ocean Science	Principal Investigators who lead research labs	10	Interviews, design workshops, group meeting observations
	Research scientists	2	Interviews, design workshops, group meeting observations
	Graduate students and postdocs	25	Interviews, design workshops, group meeting observations
	Research consultants working in labs to provide specialized expertise	3	Interviews, design workshops, group meeting observations
	Research technicians who operate instruments and process data	2	Workplace observations, interviews

4 FINDINGS

Below we present key lessons from our varied experiences engaging in information infrastructure development projects, using ethnographic and action research approaches, over a relatively long (3+ years) period. We organize these lessons under three general themes: project scope and scale change over time, social/organizational change over time, and researcher role change over time. Although all of these themes are highly entangled with each other, we are separating them for the purposes of analytical clarity. Further synthesizing is offered in the Discussion.

4.1 Project Scope and Scale Change Over Time

All of our studied projects experienced changes in their targets, goals, and boundaries over time. As Ribes [38] has shown, these changes can be a key source of data and insight about the nature of the project itself. It is also, for those in an action-oriented role, an opportunity to intervene during important transitions. Scope changes are not necessarily monotonic; ambitions for the system both grow and shrink, so scope can be observed to "creep" inward as well as outward. These contractions have also been observed come from pessimism about changes to external issues that impact the project (e.g., a new law is passed that is likely to be unfavorable to the project) or a harsh new sense of realism that emerges once concrete designs show the difficulty of some of the original targets. Below we share a few examples of how we were able to learn from and leverage scope and scale changes. To give concrete illustrations, we'll briefly recap scope and scale for each site when researcher began engagement, versus current or last known scope and scale. Note that these are "points in time," and many expansions and contractions happened between the starting and ending points.

Our projects' field sites experienced many changes in project scope and the expected scale of their to-be-completed infrastructural system(s). We should note that changes in "scope" can mean two different things here. Scope changes explicitly approved by formal change control processes are not quite the same as more experience-oriented ones, where through ongoing discussion, participants' desires and ambitions for the size and extent of the final project grow or contract, a form of "scope creep" [53]. We are primarily concerned with the latter sense, though the former and the latter will certainly interact, often through narratives driven by key individuals. As Walton explains, "project narratives are at least as much about the project leader as the project: both descriptively and literally, the projects are difficult to separate from their leaders" (106-107) [53]. We also further distinguish scope from scale, where scope has more to do with how many kinds of problems are being addressed, and scale refers to the "reach" of the system: its userbase, size of its stakeholder community, or its centrality or importance in major operations.

When the first author first began engagement with the Traffic Management project in 2018, some of the groundwork had already been laid. The state governor and other leaders required the convening of a TIM-CM (Traffic Incident Management-Congestion Management) group in 2017 after several high-profile incidents. There were early funding commitments by entities like the state department of transportation (WSDOT) and Challenge Seattle (an association of major employers in the area), but SAJOG had not been formally chartered and the large federal grant eventually obtained was still in early planning. Meetings mostly centered around setting the structure for interaction, talking about incident severity categories, and initiating the conceptual discussions about shared work that would eventually lead to the processes we have now. Now the VCC is in active system design. Funding is currently stable, and after receiving a federal grant, longer-term planning is more feasible. Governance structures are somewhat stabilized, though existing questions continue to linger about specific decision-making power and how it is split between different subgroups such as the steering committee and key agency representatives. The state DOT will be the product owner and will be responsible for hosting and management, enabling some longer-term planning and data management policies to begin being laid out.

When the second author began engagement with the Vocational Education project in 2017, The need for a new IT system for local education committee members had been articulated, but had not been formalized into a project. Individual members had researched possibilities for external developers who could potentially be involved/lead the project. The project *per se* started when the second author started research in April 2017. The research was funded by Innovation Fund Denmark and Industriens Uddannelses og Udviklings Fond. The PhD "meta-project" ended in February 2020. The LEC Database project ("sub project") has continued since. In spring 2021, the Education Secretariat for Industry (IU) implemented a new LEC IT system, which enables core stakeholders (beyond members of IU) to participate in the production and maintenance of the information related to LEC members. After the LEC database project was no longer a part of the PhD project, involvement with external stakeholders decreased. According to an IT developer at IU, there are still several manual processes. However, the plan is to digitize these processes by 2022.

The third and fourth authors began including design-oriented action research in their work on the Ocean Science project in 2017. At this time, the primary university's CBIOMES team received funding to take the lead on building a data portal specifically tailored for mapping and interpreting marine microbial biogeography. The team understood from the start that this complicated undertaking would require the compiling, annotating, and managing of oceanic data sets of widely different qualities, formats, and sizes. However, there was no formalized process or structure in place for how to go about defining the priorities/scope of the project, capturing stakeholder needs, and identifying new solutions through prototyping/testing when the third and fourth authors joined. Early meetings centered around trying to envision what the system will be and for whom as well exploring interesting technologies that could serve as the right tools to help manage vast amounts of diverse oceanic data sets generated by researchers that are publicly available. At the moment, funding is stable, having been renewed through 2024. The CMAP server is now live and currently delivers >200 distinct datasets and four programming interfaces that enables CMAP data retrieval and visualization in R, Julia, and Python. A web-based validation tool helps ensure datasets adhere to format requirements that ensure consistency and database performance. A data portal is currently under development that will provide a searchable version of the catalog and the ability to create a variety of web-based visualizations. Usability testing led by the third author helped the web version move closer to full functionality. A research coordinator was hired in 2021, and serves as a point of contact for communication and feedback from collaborators and users. The team has started to adopt project management tools for project work and resource tracking. Currently, the team is continuing to evaluate how CMAP's existing technical stack (e.g., compute resources, programming resources, and web features) and staff can meet the needs of not only core stakeholders but also the "broader public," which has not been fully explored or defined.

4.1.1 Understanding and working with changes in scope and scale. Because our analysis focuses on project participants' developing beliefs about project scope and scale rather than those formally signaled by, say, an amendment to a project charter, such changes in scope and scale can be challenging to trace. To do this, and to know how to analyze its impact, we offer a few key points of entry we observed.

Infrastructural prehistories. Although the specific projects we worked on were generally new, they did not arise out of a void. The infrastructural "prehistories" of our three projects significantly shaped both the initial scoping of the projects and how the projects were able to evolve. The projects are built within the context of a variety of formal and informal agreements, trust and mistrust, partly overlapping procedures, system integrations, legal constraints, workarounds that gradually become common practice, and individual relationships, all of which may go back years or decades. These are the "raw materials" from which the information infrastructures are built. For example, in the Traffic Management project, most of the agencies had been sharing information, systems, and responsibility, for decades. Throughout the project, even though the system and any related offices and policies were new, there was continual reference back to what currently existed, whether we could failover to current systems, whether future users would have to juggle systems with partly overlapping functionality, and the like. In the case of Vocational Education, there was already an existing sociotechnical system in place. As such, the involved stakeholders were already used to certain ways of dealing with information and sharing division of labor. In a sense, changes to project scope can be seen as continuing evolution from these various "prehistories."

Creating stability. As stakeholders learn and try ways of solving their shared problems, scope can change even at the level of the project's primary focus or approach. The project on vocational education in Denmark changed its scope from being platform-centric to practice-focused. Initially, one of the project's main objectives was to "have a solid idea of how to establish a user-friendly and well-functioning platform to present relevant data to their [IU's] stakeholders" (text taken from funding application, 2015). However, the author's initial engagement with the organization (2016-2017) showed that for IU to be able to establish such a platform, it was necessary to start somewhere else: IU needed to develop internal IT and design capabilities as well as understand data work across the network of stakeholders. This was already visible during the first intervention where the redesign of the existing LEC system emphasized a lack of internal IT expertise and understanding of data practices across the network of stakeholders. Specifically, the involved members of IU were incapable of articulating the requirements for a new LEC system to external IT suppliers (fieldnotes February 2018). One of the main outcomes of this initial intervention was an organizational change which constituted the establishment of a small IT department at IU (consisting of an IT consultant, junior IT consultants, and later on a senior IT developer), creating a kind of "positive inertia" or "installed base" [50] advantage for the project and its approaches.

Reference publics. An infrastructure is created to enable a wide variety of processes in a coherent, predictable way. It is important to understand what kinds of people, groups, and systems are intended as end users or recipients of the infrastructure [42]. How the multiorganization talks about such recipients, which we call "reference publics," provides helpful clues about how they are currently making sense of the project scope, whom it is intended to serve, or whom it will even have the capacity to serve post implementation. For example, discussions in the Traffic Management project about what value the VCC will provide to the traveling public at large, including the distant possibility of a publicly-available interface for travelers to use, correlate strongly to the current understanding of how large and visible the footprint of the eventual, fully deployed system will be, as well as how long-term its expected use is. Changes in available resources, as well as frequent changes in the local political landscape, affect the profile of this "reference public." In the Ocean Science project, new groups of scientists and their associated concerns were brought to bear over time, and some recent planning has started to explore the potential for making CMAP available to high school science teachers, as opposed to only professional researchers and advanced undergraduates. This suggests that the people working on it have come to realize that it may be possible to make it more accessible and didactic than was initially planned, which is not only an expansion of format and approach, but ties in to the increasing boldness of their mission-driven approach to scientific outreach, in the context of global climate change.

The concept of reference publics may appear similar to "indirect stakeholders" in value sensitive design [17]. Ideally, a participatory or VSD researcher would directly pursue the participation of indirect stakeholders. However, these reference publics are quite different, at least analytically, because 1. They may or may not be direct system users, and plans for how they should be affected by the system will change over time as benefits of the infrastructure accrue to the overall system it serves; and 2. They are primarily discursive (developed by the builders and operators of the infrastructure, on whom our particular ethnographic engagement was most focused) rather than a specific, real-world individual or group.

Our findings suggest that an action researcher or practitioner embedded over time in the development of an infrastructural project should observe and analyze changes in project scope, what kinds of "hopes and dreams" are infused into those changes, and what pre-existing conditions shape how significantly and how quickly scope is permitted to change. To identify and (if appropriate) act upon these changes, investigate whether there may be "prehistories" you may initially have limited access to, and how appropriate are these earlier conditions in framing the current project. Look for inertia as a source of stability and comfort, and draw upon that when pursuing innovation. Identify conversations on reference publics as a barometer for how much participants believe in the project, and be cautious about deliberately deflating their infrastructural hopes and dreams. Use a broad and careful ethngraphic lens to identify how widespread different perspectives are on scope and scale change. What impacts will they have on actual project development and deployment?

4.2 Social Structures Change Over Time

The infrastructural development projects we engaged with were heavily framed by the configurations of coordination and collaboration between the organizations that collaborated to create them; and in turn, their experience co-creating an information infrastructure affected these same organizational structures. This is akin to what in value sensitive design is called the co-evolution of social and technical systems [17]. Shifts in which stakeholders were more prominent and influential in system design or policy creation could happen gradually or rapidly, and it is not always obvious where such changes come from (often it is outside the boundaries of what the analyst has access to). The configurations of who is involved and how *formal and required* their participation is can change as well. Reflecting on all of these possibilities, the situation of the system development within a multiorganizational structure combinatorically increases analytical complexity, as it generates many more possible paths for change, and more potential points of departure for those paths.

To tame a bit of this complexity, it can help to look at how the organizational structure is emerging with respect to the system development, particularly attending to who is driving the design at any given time. Crucially, how does this compare to the broader stakeholder map? Two of our three field sites (Traffic Incident Management and Vocational Education) did not initially place a single entity at the center of development; while a majority of the development work was done by one of the entities in the multiorganization, the actual topology in terms of who actively shaped the project was more diffuse at first. In the Traffic Management project, the city agencies' (the Seattle department of transportation, police, and fire department) experiences and preferences were foregrounded somewhat more in the beginning of the project–most of the relevant events happen within the city and thus generally within city jurisdiction. However, once the large federal grant was obtained, the federal grant's support system, which is administered by the state government, gradually foregrounded state actors more. At other times, the design process itself prompted a discovery that also affected the relative presence and influence of different entities. In particular, there was an early exercise analyzing data gathered from different computer-aided dispatch systems from the same time period (the time shortly before, during, and after a known major incident), allowing the design team to compare what data and insights came from each of the systems and how often. Both the design team and the agency stakeholders were surprised to learn that data from King County Metro provided more and faster-produced incident data than other systems. The county bus system contained real-time reports from bus drivers, who are far more numerous and spread across the city than any of the traditional first responder groups, thus serving as unexpected "human sensors" about the emerging major incident. This realization drew county stakeholders into the spotlight. But what is important to note is that there was not one single, stable foreground of action or control that clearly determined how the project would work and who would generally "own" its structure. By contrast, site 3 (Marine Ecosystem Modeling) is in some respects even more organizationally diverse than the other two, since it comprises institutions from several countries, but the project is being driven by one key institution. Given the collaborative nature of the field, new stakeholders may request to participate or they might be invited by that institution. As system development and the emerging multiorganization shape each other, how centralized the project design/development is affects how influence can flow between the component entities, which in turn shapes the multiorganization itself.

In the Vocational Education project, we observed how participatory design activities supported the multiorganization in achieving greater clarity on ways of working with data in different organizational contexts. As described in earlier work ([47]), the participatory design activities brought together stakeholders from different parts of the project who not only worked in different domains, but even had different understandings of what counted as "data," e.g., records about particular education programs or schools. The workshops performed as part of [47] supported a joint understanding of how the same LEC data were used in different ways across organizations, and moreover how data practices in one place–such as how notation was used in a data entity's system of origin–affected data practices for other members of the network of stakeholders.

4.2.1 Identifying and Analyzing Boundary-Negotiating Artifacts. Because social, dialogic changes in the project can emerge gradually and sometimes be hidden from view, it is often useful to look for tangible representations of changes under development. Boundary-negotiating artifacts (BNAs) are one such variety of this kind of representation. As an extension to Star and Griesemer's traditional notion of boundary objects, BNAs also "record, organize, explore and share ideas; introduce concepts and techniques; create alliances; create a venue for the exchange of information; augment brokering activities; and create shared understanding about specific design problems" [29]. BNAs can be composed of single artifacts or multiple related artifacts, as long as they play the correct functional role. BNAs help to establish and stabilize the multiorganization and its infrastructural work. Through our comparison of design artifacts and activities, we found that many of these concepts, documents, diagrams, and the like can signpost emerging understandings and practices as they move through the developing multiorganization. In the case of the Traffic Management project, a key concept is the "VCC incident." Users of the completed VCC system will be able to create and edit a page (called an "incident model") for each VCC incident in the system, where they and other VCC users can input key information about the incident as it develops, and collaborate on incident-related tasks. Creating an incident model signals to other users that a traffic situation may require their attention and possibly their direct action. Automatic triggers in the VCC work alongside human users to identify conditions that should "count" as a VCC incident, such as a fire on the freeway. The *idea* of what a VCC incident should be continues to evolve, but it is also instantiated in both the VCC system and in supporting policy documents as the key unit of shared work. This complex of shared concept, policy, and tangible incident model artifact is most readily classified as a *structuring artifact.* Structuring artifacts are "used to coordinate media and understanding, ... to establish ordering principles, establish tenor in narrative forms, and to direct and coordinate the activity of others" [29]. The VCC was initially conceptualized as a system to support better management of "major" traffic incidents. Early conversations centered around an "incident severity scale" which went from typical traffic all the way up to system-wide catastrophes such as serious earthquakes, and attempted to locate where on that scale the VCC would most typically be used. Throughout the three years of its development, this notion of "what kind of incident or work will this system be best suited to" has continued to evolve, and despite immense progress, has not yet reached a final resting point.

All kinds of developments continue to affect what the current best understanding of a "VCC incident" is. For example, once a prototype version of the VCC was made available to realistic operational test users, they were more hesitant than expected to initiate a VCC incident model, because there is not yet a clear enough sense of chain of command baked into it due to the default open and collaborative stance of the system. Generally, the VCC's member agencies orient much of their work around clear chains of command. This suggested to the design team that new functionality needed to be added that would allow users to flag potentially interesting phenomena in the system without declaring a VCC incident. Users can still declare a VCC incident if they wish, but now they also have a "softer," intermediate form of alerting. For a project participant, this apparent lack of ability to define what seems like a simple and central concept can be quite frustrating. But it should not be surprising: it in a sense encapsulates all the key ideas about how this new multiorganization, built with pieces from very old patchworks of interagency collaborations, understands what its identity actually is.

In the case of the Vocational Education project, a key boundary negotiating artifact is "the LEC data". Similar to that of "VCC incident", it acted as a structuring artifact. Through workshop activities, participants became more aware of the central role data played for the cross-organizational collaboration, for instance in terms of division of labor. The LEC data was initially conceptualized as "the data that's already there" (in the previous system). However, over time this shifted as the participants realized ways in which additional data could for example ease their own administrative tasks in their day-to-day organizational context. In this and other cases, it is important to pay attention to who gets to shape the BNA, via what means, in addition to what boundaries it is helping to negotiate.

4.2.2 Who is "At the Table"? The composition of who is in a multiorganization changes over time. As the multiorganizations develop, they are often able to bring on new member organizations (or more parts of existing member organizations), which in turn change the shape and reach of the multiorganization itself. Unlike a highly stable strategic action field [15], a developing multiorganization has interests and internal power structures that are less clearly defined, so new participants can more significantly shape its direction. Depending on the strength of the association it has with its member organizations, and how bound up the multiorganization's projects are in the member organizations' internal work and goals, the multiorganization can shape those member organizations beyond what was initially intended. In the case of the Ocean Science project, the CMAP development team (most of whom are also researchers in biological oceanography) initially saw other researchers as the primary stakeholders to involve in the process of defining which data sets, features, and functionality should form the initial core of this envisioned system. That is, their approach to defining the system and its "reference publics" was shaped by their own constituency on the project. However, members of the development team became more cognizant of the different types of stakeholders that needed to be taken into account as they engaged in new research endeavors that involved collaborators from diverse disciplines such as statistics, chemical oceanography, and remote sensing. These collaborators brought with them different methods, work processes, and types of data which not only shaped how shared research goals were being addressed on the ground but also the direction of CMAP development.

The learning and improvements the multiorganization creates can cause it to increase in interest to others still outside it, which can attract new stakeholders or component organizations to become a part of it. Current participants may also realize the need to bring in new participants, as the systems and processes under creation come to have a clearer structure, so where additional information and contribution would productively fit in becomes more obvious. This can be highly valuable in the processes of infrastructuring [37], as demonstrating broad usefulness is typically a good sign. However, adding new stakeholders also means adding new stakes–meeting new needs, protecting new data, complying with new policies, and perhaps even becoming indispensable in a way the multiorganization isn't yet prepared for. In the Traffic project, as the VCC grows nearer to completion, its unique combination of data and functionality has led some agency IT personnel who were previously only tangentially involved to investigate the possibility of bringing the VCC in to their agencies as a more core, daily use system for some of their users. This would definitely change the expectations and user support burdens for the VCC, which is not yet fully accounted for in its long-term support plan.

Action researchers and practitioners embedded in these multiorganizations should pay close attention to differences in the ways new stakeholders are enrolled over time. These can be challenging, fraught experiences, because enrolling a new stakeholder is also a process of incorporating some of the new stakeholder's own resources–in terms of money, systems access, or human capital–which can then shape the infrastructure development project. Therefore the multiorganization must convince the new stakeholder of the worth and manageability of their participation. At the same time, new stakeholders often bring disruptions, which can be positive as well as negative, as they can bring in strong energy and desire make change and while lacking relevant historical knowledge about previous work that led to current states. The action researcher can help to scaffold such transitions by watching the daily discussions and work practices of the infrastructure development for boundary negotiating artifacts under development, and shoring them up to increase the overall coherence and stability of the multiorganization.

4.3 Our Roles Change in Dialogue with Project Changes

While a researcher may enjoy greater stability and predictability when entering an established field site with well-understood boundaries, there are particular opportunities that arise from being able to join inchoate projects that are relatively early in development and "get in on the ground floor," or close to it. Each action research project allowed us to join at different stages in this formalization due to connections we were able to establish and a willingness to be of use when the program of development was a bit unclear; and each of these very diverse experiences help create a holistic understanding of the project.

One way such individual roles can begin is as part of the formations of connections between component organizations in the new multiorganization. For example, in the Vocational Education project, the second author was initially meant to use the research project as a case for her master's thesis project. However, the then employed PhD student chose to move to another country for personal reasons before the project started. This resulted in a new recruitment process, where the author applied and was hired as the PhD student for the project. The author experienced how her role changed from being "the researcher who's doing something with data" to being considered a member of the organization, participating in both formal and informal events. Over time, her opinion became highly valued during IT development projects and upskilling of the other employees' skills and knowledge about human-centered design. After the end of the project, the author was employed as external consultant to further support IT projects in the multiorganization. The author was able to pursue specific activities of research interest and take on varied roles; but without a liaising/"glue" role earlier in the development of the project, the multiorganization might have developed along different lines [30].

Throughout our engagements, we each played a role in the formulation and creation of very diverse design artifacts and activities. The first author in the Traffic Management project assisted in the creation of wireframes, led design workshops, performed ethnographic observations, interviewed public information officers, managed the creation of policy documents, assisted with grant applications, and contributed to user testing. The second author in the Vocational Education project designed three action research interventions which involved additional design of co-design workshops, ethnographic observations, interviews, and development of educational material about human-centered design and innovation. The third author in the Ocean Science project assisted in the creation of project planning documents (e.g., charter, schedule plan), moderated design thinking activities, conducted ethnographic observations, interviewed individuals that were stakeholders in the Simons Foundation ocean initiatives, designed and deployed a survey to complement the interview data, and led usability testing efforts.

A researcher in a setting similar to those in our field sites must cultivate many relationships and, especially if the scope and demands of the project change, must continually demonstrate value and credibility so as to stay in the "middle of the action." Broad experience across different facets of the project, and the ability to compare and contrast how different "slices" of the multiorganization (for example, people with similar job types in different component organizations) come to understand various facets of the shared work of the project can, over time, give the researcher a position as a knowledgeable, trustworthy integrator. If there are periods when our role becomes less intensive, we can draw upon our academic resources to continue offering value. In the Ocean Science project, during one such lull the author served as a connector to the academic world of UX and human-centered design by sharing readings and concepts from those readings to the stakeholders. This enabled them to grow their own level of sophistication and insight into these topics, and better incorporate ideas and methods into the project. This recalls PAR principles, where theoretical learning and enrichment should be happening for every person working on the project [34], but the path to enrichment in this case was more fluid and opportunistic. In the ongoing work of stakeholder management, we ourselves are stakeholders that must be managed as well.

Over time, our roles changed, sometimes in response to changes in our own research agendas, and sometimes in response to changing internal and external exigencies of the projects. Since each of the three authors primarily involved in our three sites was a graduate student at the time, we had less power to structure and plan our specific activities. Practitioners who are already intimately familiar with the domain may wish to take a different path and may have enough authority to specify their own path. For senior researchers, such as the last author, who are usually brought on board due to their expertise, they have more authority and influence than graduate students over decision making and proposing new directions. The senior researcher, like any action researcher, must also necessarily "navigate the waters" when it comes to the needs, desires, culture, and politics of stakeholder groups; including funders and contractors who may have their own timelines. What is considered urgent or feasible to work on changes over time, so if longevity and continual engagement are a goal, one's roles and approaches will naturally need to shift a bit. For the action researcher or practitioner entering such a project, the uncertainty and vagueness that can arise from such shifting roles can be frustrating, and can cause one to wonder whether there will be enough analytical clarity and depth for rigorously developing concepts. However, if one is prepared for such shifts and willing to go where the action is, changing roles can actually provide a wider analytical lens. Those observing the various changes in the project and its organization might realize that the times when there are pressures for the action researcher to change their own role are times of important transition for the project and multiorganization, and thus worthy of extra analysis.

4.3.1 Maintaining Data for Reuse. As an action researcher's role changes, sometimes in unexpected ways, the types of data and the methods she uses to collect it may change as well. This can be a significant asset, as the duration of engagement allows a researcher to reuse data in different ways. Because of the processes of learning and development that happen during researcher engagement, the multiorganization may be better prepared to integrate and make use of data years after it was initially collected than it was within a more narrow, time-bound analysis task that initially spurred its collection. Especially if a particular task is cut short due to shifting capacities and constraints, it can be frustrating and seem as though the work was all done in vain. However, maintaining such data—perhaps ethnographic field notes and associated memos—and continuing to look for opportunities to share them at later dates and for later tasks, will be both practically and analytically valuable. A clear example of this played out in the Traffic Management site, where a set of workplace observations initially intended to assist in the creation of a specific policy document generated significant field notes and system diagrams that more or less lay dormant for over a year, after the plans for the policy document were rapidly changed due to external factors. After a time, however, the inventories and diagrams were used to plan the ingestion of new data sources, write other policy documents, and guide the creation of personas. Some of the resulting diagrams were also presented at academic workshops. This is all to say that action research data may live many lives throughout the course of a project, and a researcher's change in role may offer new and even more useful opportunities to repurpose it. The long term engagement of ethnographic study creates opportunities to ask and answer more and different kinds of practical and research questions.

5 DISCUSSION: LESSONS LEARNED FOR DESIGN AND RESEARCH IN INFRASTRUCTURAL SPACES

What are the consequences of working in a space where the scope is changing, where our roles are changing, and where the organizational context is changing? The first is that the experience can feel quite chaotic. Each of these foundational elements is a moving target, and affects the others as it develops. An action researcher has to remain cognizant of the fact that these multidimensional changes are always happening, but the researcher can only observe one thing at a time, and cannot be solely responsible for the design. In addition, how the multiorganization and its component entities are involved in the ongoing work will change depending on what the immediate problem is and what has been learned. Even in an infrastructural project, where the general scope of the project is understood to be large, there will be moments of focus on larger and smaller aspects of the work.

Yet this chaos is not totally intractable; a comparative case study of our diverse field sites revealed commonalities. One such commonality is the unique value of longer-term engagement, particularly if one can begin engagement early in the formation of the project or multiorganization. When so much is uncertain for the participants–and this uncertainty can carry a great deal of risk–the possibility of becoming a dependable, trustworthy person can create a great deal of advantage. In our role as designers, we are called upon by people who have a commitment to co-design and see a need for someone in our general position. They usually do not know what to ask us to do, so they delegate it to us to figure it out. This gives us the opportunity to explore many facets of the problem space and build trust with many different participants. In essence, we can learn many of the "dialects" of the emerging shared language of the project and multiorganization, which can help us be materially helpful during the challenging formative processes where shared understandings can be difficult to achieve. We sometimes experienced a kind of pleasant surprise among some stakeholders that we were still there and participating after a long time–in our case over a period of years.

It can be challenging to disentangle research goals in these projects from the influence that the researcher's own activities and contributions have; that is, there is often a persistent and serious "observer effect" at play. It can be hard to know if a design element or social configuration developed because of inherent phenomena in the multiorganization, or because we as researchers knew about the possibility of such phenomena and created designs or interventions that reflected that knowledge. As we participate and share our knowledge, even in ways stakeholders find genuinely valuable, our perspectives may influence their own. Reflexively and carefully examining our own evolving stance and stakes is important, particularly in a setting where we have direct, tangible influence on the course of the project. Finlay [14] explains that in participative social science projects, "researchers openly acknowledge tensions arising from different social positions in relation to such factors as class, gender, and race." In our field sites, such tensions also relate to our project roles; our professional and academic fortunes are bound up in the progress of the project, which can create incentives we should pay attention to. This problematizes the relationship between the researcher and the "field site," where we must stay analytically aware of our own activities and influence to be able to adequately understand the phenomena we're observing.

Though action researchers should, for both practical and intellectual reasons, approach their influence on projects with care, that influence can be positive, as long as one remains honest, self-aware, and measured in exerting it. For example, by introducing human-centered design to the multiorganization in the Vocational Education site, the researcher helped an HCD approach become a "natural" way of working. In the Ocean Science project, the grant was originally for a data repository, but the goals for the system changed over time in concert with learning, development, internal and external influences–among them, that of the influence of the multifaceted participation of the action researchers. Because of the roles of three of our authors as PhD students, there is also a kind of double loop learning process: the multiorganization is developing and learning, and we ourselves are learning our own roles as action researchers. For the faculty member this is also a learning process to discover when and how to participate when involve in multiple interdisciplinary, multiorganizational infrastructural projects.

Our action-oriented researcher role, the multiorganization's development, and the project scope co-created one another over time. Analytically, confirmation bias was and is a constant danger in such a situation. For example, when an infrastructurally oriented researcher joins a new setting, it can be very tempting to look for an opportunity to study the creation of infrastructure *per se*, but not every large multiorganizational project needs to achieve that result, even if the researcher would find it most desirable and interesting.

Even community-centric forms of engagement often retain a more typical design researcher-community binary format, where the researcher enters a design space, often requested by the community themselves, identifies and addresses issues, and exits once a project is completed. This is understandable and valuable, as executing a rigorous research project requires planning, and is typically meant to be applicable to many settings. Our experiences reflected an often "messy" style of engagement that provided value for stakeholders, but we often did not have this same level of control over the methods we used and roles we inhabited. However, being embedded for longer times and having more varied experiences than such well-scoped projects often permit, we attempted to learn as broadly and opportunistically as we could from the changes we took part in creating.

While all concerned with the building of information infrastructures to support shared work between multiple organizations, our projects were quite different in their relationships to outside technology and data usage. In the case of the Vocational Education project, there is a level of general capacity-building around reasonably well understood office technology systems, while in the Ocean Science project, many participants are or learn to be command line programmers with fairly sophisticated data science capabilities; and the Traffic Management project is somewhere in between. However, none of these infrastructural projects, while having some high-tech aspirations, were primarily innovative in the development of fundamental technologies, they are all finding innovative ways to match technical capabilities to emerging needs. The "cutting edge" being explored in these projects is centered on their process improvements and societal contributions–whether in science, engineering or education–and the community-driven sociotechnical development efforts that we are documenting, participating in, and analyzing.

Drawing on our comparative study of three long-term participatory action research-oriented studies, we describe some "lessons learned" for practitioners and researchers working in these kinds of spaces. Some of these lessons are not new to systems analysis or design but are important to include as key considerations in the pursuit of ethnographically informed action research in the development of information infrastructure.

5.1 Implications for Practice: Participatory Infrastructural System Development

- **Expect key ideas, even seemingly basic ones, to take years to define.** There will be many discussions seeking to define the most basic terms, concepts, practices, and groups of stakeholders. Labels and concepts that come up again and again in conversation, and sometimes end up being applied to key system components, probably won't have one single, clear, persistent definition.
- **Expect role transitions and changes in the multiorganization's stakeholder constituencies to have significant structural effects.** Individuals leaving a member organization, and external forces on which member organizations have prominence, will often drive priorities. As new stakeholders participate, or as old participants are able to spend more time "at the table" or being active "constituents" [39] in project development, terms, concepts, and goals may be redefined and new decision-making structures (new sub-components of the multiorganization) may be created that will also need to be navigated. These changes are part of organizational learning. Learning is sometimes inefficient. It can also trigger a great deal of frustration. Sometimes it can be helpful to remind participants of how previous work led to the current state of a design object or design objects.
- **Do not make key decisions based on the assumption that scope will stay the same.** As we've previously discussed, how participants engage with the project, what their ambitions are, and what external factors become more or less important, can all change the scope and scale of the project. Sometimes this will mean an unexpected expansion of the project's mandate, and sometimes this means a scaling down. Not until completion–and sometimes not even then–can any of these changes truly be considered final.
- **Check in from time to time to understand the variety of views on who the "reference public" is.** Infrastructural development projects are usually not only composed of multiorganizations but are also usually serving mulitorganizations. There may be multiple notions about who should be served by components of and/or the overall infrastructural system. At times some stakeholders may hesitate to be fully candid. Members of the design and development team will also have different priorities and ambitions. Furthermore, these notions change based on learning about needs, technical constraints, or external factors. Therefore ideas about who the reference public is vis-à-vis system elements and the overall system should be continually revisited.
- **Check in from time to time on who are the current collaborators and decision makers.** Collaborative structures like committees, working groups, and intermittent exchanges are always evolving. Sometimes this happens very quickly and is dramatic and obvious–such as when people in a large group meeting energetically bring up a problem that had been simmering under the surface, and the large group quickly appoints a selection of interested parties to work on it. Other times it happens very slowly, such as when an existing group gradually changes its focus or methods. Informal coalitions of different stakeholders may

come together and exert influence quickly before ever being detectable on an organizational chart, perhaps making some useful new terminology ubiquitous in meetings almost overnight. Meanwhile, more "stable" groups that are considered core to the collaboration can impose slower cadences of change even if their official position in the project is supposed to be one of experimentation and innovation. For example, an "agile" development shop may be brought in to increase the nimbleness of development, but have deeply entrenched methods that they are unwilling to change. Paying attention to the on-the-ground facts of where organizing and influence are happening as opposed to only formal structures and agreements can better inform where the levers of influence and sticking points are for successfully moving through the project.

- **Periodically revisit data collected in the past for new analysis.** Working on “infrastructure time” does not preclude work that needs to be done quickly and on a tight deadline. However, it does mean that some time and effort needs to be reserved to think in terms of longer term and larger scales. Data collected today for a particular project may be useful three years later. Care should be taken to create metadata and maintain accessibility for longitudinal analysis and long-term decision making.
- **Consider delegating specific people to keep “infrastructural” or longer-term thinking in mind.** The work of system design in these settings is complicated, with many priorities and tasks that have to be juggled. It can be easy to get lost in specific trajectories of work. If there is someone who can set aside part of their work time to think broadly about how the system being built can function as long-term, valuable infrastructure, you can avoid building it in an inappropriate way. The role is often beyond the scope of work for a project coordinator who is busy “keeping the trains running on time.” Part of the shift in practice here is to designate a role for someone who can accumulate social and technical knowledge and relationships to think and act strategically and unite local and global concerns for the overall infrastructural project.

5.2 Implications for Research: Infrastructure and System Development Studies

- **Different points of entrée and exit.** Points of entrée and exit were all quite different across our projects. Our initial forms of engagement bore little resemblance to how we currently engage. Pre-existing relationships between senior researchers and communities can facilitate entrée into a development project and may bring with it a level of trust based on past experience. There are mechanisms, such as consulting, that can continue engagement, cooperation, and information flow once the official project has ended.
- **Taking on different roles.** The action researcher may need to take on different roles– wearing different “hats” at different times. The researcher may find it necessary and useful to work in different parts of the multiorganization and in different levels in the organizational hierarchy. One may find oneself involved in organizational strategy meetings one day and designing and user testing wireframes another. The action researcher must seek to be of service while also maintaining a strong vision of their own identity, and research goals and priorities. This is not easy to do when faced with project demands. Less-experienced researchers may need to seek ongoing political and instrumental support from senior co-workers in order to meet their own professional research goals.
- **Flexibility about the “object of design” and how to approach research about it.** All of our projects had a participatory orientation, combining design contribution with ethnographic observation. Yet in complex problem spaces and in large projects, we may need to be willing to be flexible and opportunistic in regards to specific research topics. A systems perspective and a desire to involve more stakeholders as needed and to foreground the network and

community helps provide conceptual and practical scaffolding even when activities and priorities change. It is also important to consider that in this complex design space, work may be undertaken at different levels of analysis and with different scales and scope. Taking on approaches that center evolving human needs and understandings requires a flexible, curious, iterative stance. At the same time it is crucial to maintain an infrastructural lens which allows different design artifacts and activities, which may initially appear unrelated, to be contextualized in relationship to the multiorganization and overall infrastructural project.

- **Sensemaking can be slow and identity-constructing for the multiorganization.** A nascent multiorganization discovers and constitutes itself in part through discursive processes in design. As Weick, et al. [54] explain, "The operative image of organization is one in which organization emerges through sensemaking, not one in which organization precedes sensemaking or one in which sensemaking is produced by organization" and "Situations, organizations, and environments are talked into existence." Part of our responsibility as we play a part in the emergence of the multiorganization is to participate in this sensemaking as well as to document it.
- **Community-building aspects of multiorganizational system development.** Project members may have narrow expectations about design which delimit it to requirements specification and technical system development. However, since a multiorganization is partly constituted by its development of a shared infrastructural system based upon various infrastructural prehistories, there are opportunities to help constituent organizations and stakeholders learn about each other's needs, wants, and current practices and systems. Action researchers can bring concepts and methods to these discussions that can enhance this learning and build common purpose. Part of the action researcher's work on the development of a multiorganizational system may involve the creation of new ways of collaborating and, when necessary, framing or re-framing the work as community-building efforts, and multiple overlapping ones at that.
- **Evolving, service-oriented role as political.** One's role as an action researcher can be quite valuable for the project. The infrastructural action researcher (by virtue of their broad and long-running research) sometimes becomes a unique source of institutional memory in addition to creating unexpected insights and progress. The role can become rather political. When and where you participate will influence discussions, priorities, documentation, design artifacts or project scope. Moreover, once you are advocating for human-centered design or values-driven methodologies by creating experiences such as workshops, or artifacts such as design prototypes, you bear some responsibility for how such values are enacted.
- **Long-term participation makes a difference.** The participation of an action researcher with knowledge and skills in HCD in the multiorganization over time becomes quite powerful as this researcher develops a more holistic view of the different stakes, practices, norms, and artifacts of different people in the collaborative ecosystem. The researcher in an organization can gain expertise as an individual whose knowledge is broad (vis-à-vis the multiorganizations involved in the project) and grounded in experience. Being a long-term participant rather than a short-term participant affords the opportunity to overcome skepticism and build trust through a researcher's knowledge of everyday practice and their commitment to the success of the overall project.

6 CONCLUSION

In this work, we have presented extended, comparative case studies of mid- to long-term engagement in multiorganizational information infrastructure design projects, extracting "lessons learned" for others who might find themselves in similar settings or who might wish to reorient their position within such settings to be more action research focused. This was possible in part because of deep long term engagement of three student researchers and a professor who has familiarity with all projects extending for at three or more years. We believe further comparative studies will be useful for creating generalizable theory and practical guidance. These field sites are multiorganizations with their own unique dynamics and configurations, and the political and economic realities internal to them and externally influencing them are quite different. There are limitations to generalizability of some of these lessons learned; we all studied non-profit information infrastructure development–a particular kind of endeavor. This research may provide guidance for those embarking on similar research and also as provocations for further work in defining probes, methodologies, and theories around these kinds of challenging projects.

This work is but a single step towards developing theoretical concepts based upon these lessons learned, and additional practical tools and methods to help designers and researchers engage in these complex spaces. Disambiguating the organizational complexity in an ongoing way is challenging but necessary. Simply describing who (individuals, groups, departments, agencies, consortiums) is working on what, when, and how is a decidedly non-trivial problem. Thus we rely on the notion of the multiorganization as a frame for examination, with a need to further identify differences between these multiorganizations and other collaborative organizational configurations that support large projects. Such disambiguation is also necessary for addressing not only specific design problems but also larger problem spaces and longer temporalities that contain multiple, often interrelated problems [32]. Because of their scope and scale of action and the variety of relationships that they generate, these multiorganizations are the contexts where such intransigent "wicked problems" may have some hope of large-scale improvement. However, they are also a place where major risk can also lie: enormous budgets can be misused, critical reputations can be tarnished, and relationships between the constituent organizations may be damaged, causing harm to other projects they may do together. With this level of both risk and opportunity, we recommend returning to "classic" long-term participatory engagements on even anthropological time scales, such as Ehn's [12] or Bødker's [3] rich and fruitful studies. It is with such multifaceted, patient study that the answers to our greatest practical and theoretical challenges can reveal themselves.

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