Reconciling Rhythms: Plans and Temporal Alignment in Collaborative Scientific Work

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ABSTRACT

Plans and planning assume a central role and challenge of collaborative scientific work, bridging and coordinating often discordant rhythms and events emanating from the organizational, infrastructural, biographical and phenomenal dimensions of collaborative life. Plans align rhythms embedded in local practice with those operating at larger institutional levels, and establish shared temporal baselines around which local choice and action may be calibrated. This paper develops these arguments through ethnographic study of the Ocean Observatories Initiative, a prominent U.S.-based large-scale long-term collaborative research program in the ocean sciences. We emphasize the intersection between rhythms and plans at two crucial moments: formation ('plans-in-the-making'), and enactment ('plans-in-action') across complex fields of practice. Our findings hold important implications for CSCW research and practice around scientific and large-scale collaborative efforts, and for federal science policies meant to support productive forms of cooperation and discovery.

Author Keywords

Science, collaboration, policy, collaborative tools, cyberinfrastructure, rhythm, temporal factors.

ACM Classification Keywords

H.m. Miscellaneous.

I. INTRODUCTION

A growing body of CSCW work has advanced the proposition that "time matters" in the study of distributed collective practice in scientific and other workplace settings [8, 16, 23, 24]. From the micro level of an experiment's run time in the laboratory to the macro level of grant deadlines at a funding agency, aligning the heterogeneous forms of time that structure and constitute distributed work activities represents a central and arguably growing challenge of effective collaboration in the sciences – and undoubtedly many other sites of distributed collective practice.

From the standpoint of understanding the real world of collaborative work, time is both an unwieldy abstraction and a tough object of study. While chronologies, schedules and timelines are powerful tools we regularly employ, and the design of specific time-management artifacts has attracted the periodic interest of CSCW scholars [18, 22, 33], explicit attention to temporality as such often fades into the background, in our work both as researchers and as practical actors in the world. Because of this, we often recognize it only in the breech: at moments when conflict between discrepant temporal orders is brought to (painful!) awareness through breakdowns in expectation and action that may delay or derail larger collaborative efforts. For this reason, with some important exceptions treated below, understandings of time in collaborative practice and CSCW scholarship occupies an important hole or lacuna at the center of the field, at once centrally present and conspicuously absent: or to paraphrase Coleridge's ancient mariner, "time, time, everywhere, and ne'er a drop to drink" [4, 13].

Our own way into this problem is through the language of "rhythms": roughly, the temporal patterns and regularities that stem from and in turn help to frame and support ongoing forms of action in the world. From the standpoint of large-scale distributed work in the sciences, rhythms have a number of important roles to play. Rhythms support regularities of practice, allowing work to unfold in predictable and routinized ways across spatially and temporally distributed sites. Rhythms establish structures of convention and expectation, allowing actors to mesh and coordinate otherwise disparate temporal flows. And rhythms organize time itself, ensuring that the temporal forces that shape and frame our working (and indeed personal) lives come to us in some form of navigable order. In all these ways, rhythms are 'circumstantial' to collaborative action in the sciences, in philosopher Michel Serres' [30] quite literal usage of the term: that which 'stands around', supporting and giving structure to flows of human activity in the world.

But rhythms – especially at their points of intersection – can just as often *fail*, limiting or derailing rather than supporting the cooperative flow of scientific life. Rhythms emanating from the biographical or organizational spheres may contradict those found in the infrastructure or the natural

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world. Rhythms at local levels of practice may fail to mesh with those emanating from larger scales and institutions. Rhythms may intersect in unpredictable ways with events: single-point occurrences that can accelerate or retard, disrupt or redirect, and sometimes set in motion new kinds of rhythm. The sheer variability in these results calls attention to the active and strategic quality of human interactions with the forms of time we engage. To echo a point suggested by Orlikowski and Yates [21], while we work in and through time, we also work *on* it: bending its structures and flows to accommodate the activities we set for ourselves (and others) in the world, while amending our actions to coordinate with temporal forms and structures coming to us as given or "found" (a category that may certainly include the structures and flows that other strategic actors seek to promote, but also the forms of time we find encoded in the built and natural worlds around us). Such forms of "alignment" work [16] constitute central and under-theorized elements within the coordination of collaborative work and life more generally.

Within this work, plans and planning take on special role and importance. Plans and planning (and its associated artifacts and practices) are a key moment or technology of alignment work. Plans bridge and coordinate rhythms and events emanating from the organizational, infrastructural, biographical and phenomenal dimensions of collaborative scientific life. Plans gather and align rhythms across scale, linking temporalities embedded in local practice with those operating at larger institutional levels. And plans establish shared temporal baselines around and against which local choice and action may be calibrated.

This paper extends recent CSCW approaches to the study of large-scale collaborative science in three ways. First, we link the two literatures of planning and of time to demonstrate a gap in our understanding of rhythm as an object of study. We begin by connecting collaboration studies literatures that have previously placed time and rhythm in the margins and draw this together with literature on plans and planning.

Second, we establish plans as an important site for unearthing practices of temporal alignment and identifying discordant rhythms. Following the seminal work by Suchman [31] and colleagues in other contexts, we explore how plans are actively deployed, negotiated, enforced, and adjusted as a site or mechanism of temporal alignment within the complex and 'heterochronic' (many-timed) worlds of large-scale collaborative science today.

Lastly, we demonstrate the ways in which rhythm emanates from both top-down and bottom-up scales of influence, where both directions are shaping and shaped by formalized plans. We explore how plans and planning gather and align separate rhythms at scales ranging from the small to the large and mediate between the temporalities embedded in local practices and those emanating from larger institutions of science planning and policy (e.g., NSF and Congress).

Through empirical examples of plans in-the-making and plans-in-action we detail how a large U.S. research network, the Ocean Observatories Initiative (OOI), moved into and through a planning process imposed by the U.S. National Science Foundation (NSF). Drawing from ethnographic field research within the OOI and other time-series oceanographic research initiatives, we identify forms of alignment work that attempt to reconcile conflicts in rhythms through plans and planning. We conclude with implications for research, design and policy.

II. LITERATURE REVIEW

II.A. TIME & RHYTHM

CSCW has long considered the design and use of specific collaborative artifacts with affordances that draw awareness to time, such as systems built for temporal orientation, reminders, archiving events and reflecting on activity patterns [2, 7, 17, 22, 33, 34]. This work often conceives of time as a discrete object that can be captured, represented, and designed around (e.g. as timeline [34] or trace history [25]). While these studies depict time as a depersonalized, divisible object within a design frame, others have adopted a more embedded approach, exploring time as it is experienced by individual users or as reflected and enacted through organizational form and practice. This body of work has included attention to time-sensitiveness and synchronicity, with special interest in the way that temporal factors may shape collaboration through verbal communication [17] or interaction with electronic information spaces [2, 7, 23]. Others have investigated the relationship between synchronous and asynchronous work, often with focus on a particular built environment and its affordances [3, 11, 35]. Still others have explored the design of information tools that are used to coordinate temporal structures and the mobile, changing nature of rhythm [20, 23].

Such artifact- or design-centered approaches are broadly paralleled by a wider reassessment of time currently underway within the social sciences more generally. Sociologist Eviatar Zerubavel has explored the significance of time as a neglected parameter of social life, arguing that social phenomena from institutions like hospitals [38] and monasteries [39] to revolutionary movements and religious communities [37] are best understood as "sociotemporal orders," established through carefully produced temporal regularities which constitute the foundation of collective action, meaning, and identity. Central to Zerubavel's account are the key temporal artifacts of schedules and calendars, and their role in bringing the potentially infinite sprawl and diversity of time into more coherent and collectively shared regularities.

Writing from an organizational science perspective, Orlikowski and Yates [21] have argued that social science approaches have tended to represent time in one of two ways: either as a subjective and socially-constructed abstraction (e.g. time-sensitiveness, synchronicity) or as an objective and substantive form existing outside of human action (e.g. clock time, age). Orlikowski and Yates seek to reconcile these perspectives through the language of ‘temporal structuring’, arguing that the temporal dimensions of organizational life are best approached as a process both shaped by and shaping of human actions. For example, when a team of programmers works toward releasing their application by a collectively established deadline, they reify calendar-time, imbuing a specific date with meaning. Yet, the deadline is subject to contingency and the same meaning could be reorganized around another date, time, or phenomena. The authors offer ‘temporal structuring’ as the social process that establishes and reinforces the temporal rhythms that shape ongoing practice. Im et. al. [12] extends this analysis to the assemblage of tools and communication strategies for aligning temporal structures, which provides understanding of the social problems of coordination. Collective action requires the alignment of rhythms in order to develop standards, routines, and associations of human action and calendar time.

Complementing this blended understanding of our interactions with time, Jackson et. al. [16] identify “collaborative rhythms" as evolving, durable, and active *objects* of collective life (p. 252). Rhythms establish temporal structures within our social lives, often fixed or recurring as part of convention like calendar time, seasons, deadlines, and holidays [37]. Rhythms can be episodic, tied to specific events, or emanate from complex and long-term factors like climate change.

The authors provide a heuristic to map collaborative rhythms to ongoing forms of work and agency. Organizational rhythms are regularities within institutional forms found in academic calendars or the grant review process. Biographical rhythms emanate from the flows of human life, including identity and role shifting, or changing relationships emanating from life events such as death and disease. Phenomenal rhythms emanate from an event such as a tsunami or earthquake. And rhythms can be infrastructural, emanating from the built environment (e.g., timelines of maintenance and decline associated with legacy systems of scientific equipment). Rhythms can represent hybridizations of these categories, and intertwine in variable and complex ways. And they can also conflict: for example, when an instrument deployment is scheduled for a date conflicting with a lead scientist’s tenure review, organizational and infrastructural rhythms may be prioritized over the biographical rhythm of the scientist’s ascension from associate to full professorship. The manner in which such tensions are resolved may be deeply embedded in the structures of authority that govern collaborative life: or as Jackson et. al. argue, “the question of which rhythms are adjusted to which (and *whose* rhythms to *whose*) turns out to be an important site for the exercise of power and control” [16].

The language of rhythm provides a vocabulary to describe some of the central temporal processes and challenges at the root of cooperative work. The authors demonstrate that discrepant rhythms are brought into coherence through many under-recognized forms of alignment work in a creative process of temporal alignment that requires efforts to bend pre-existing structures to fit environmental and collaborator needs into one reconciled trajectory. Collaborators reorganize resources, schedules and priorities; build or reorient instruments and facilities; shift their personal time and trajectories. Rhythm provides a structure to capture temporal factors as well as conflicts of a dynamic and complex nature, but leaves very few indications of its existence. However, many technologies and documentations act as archives of collaborative work (calendars, trace histories, edit logs, version control systems) that unmask new opportunities for identifying rhythms. In the following section, we emphasize the unique central role of plans as one technology for identifying rhythms and practices which reconcile conflicts of rhythm.

II.B. PLANS & PLANNING

An important contribution to the understanding of plans comes from ethnomethodological traditions within sociology and CSCW scholarship. These studies consider the role of plans as resources in (rather than mechanical executors in) coordinating work. Within these works plans can mean any structured or informal delineation of a set of temporally organized actions poised to achieve a goal. Our investigation focuses on the relationship between formalized plans and local culture.

In particular, Suchman's canonical research [32] offers the flagship example of this perspective; she defines “plans and situated actions” to argue against the formalist fallacy in which sequential tasks delineated within plans invoke a specific, determined set of sequential actions. She removes any fully determinative relation between plans and action and power vis-à-vis worlds of situated practice. Suchman instead emphasizes the blended quality of plans and situated action, providing a better account of how plans and planning meet the real world of practice.

In consonance with Suchman’s theories on planning, Scott [26] provides powerful examples of the kind of error (and hubris!) that formalist approaches to plans and planning can lead us to. Scott’s examples emphasize the relationship between plans and local circumstances, particularly of plans enacted *without* reference to local circumstances and the significant losses resulting from those top-down infrastructural changes. Scott’s examples are drawn largely from state attempts to silo dynamic or nomadic populations, such as Le Corbusier’s geometrically standardized cities, Stalin’s Soviet collectivization and the Tanzanian “forced villagization.” The plans within Scott’s stories were developed without acknowledging the ongoing problems in the realities of implementation, shifting markets, labor economies, weather and soil, regimentation and collectivization. The failed attempts of Lenin to categorize and control without regard to the social and cultural standings of the people under that control, alongside the failed attempts of Tanzania to restrict nomadic populations to specific geometries, teach us that plans are subject to local human change and are not controllers of local human action themselves.

Scott draws on the notion of "metis" to describe forms of knowledge that are different from and in some sense in opposition to the models of top-down planning by Stalin and Tanzania. Metis is the "deep knowledge" that allows local people to respond to the complexities in their environment. Scott employs metis to explain that the state's success measures for a plan can overlook the negative effects on local culture. This discrepancy between local customs and state concerns can lead to economic and social failure as well as individual psychological harm, diminishing the self-perceived value of those who work within its constraints. For these reasons, Scott asserts that plans need to be flexible enough to react to local human change, adopt contingency, and provide room for emergence.

In Suchman's conception, in the real world, plans provide a structure that guides the continued actions of an organization, but are not strictly adhered to, blindly acted upon, or necessarily sequential. Plans are representative of a rational course of action and common practices and procedures, which are subsumed by the more organic, emergent and ad hoc world. Suchman's argument relocates the locus of control in purposeful human action, not in formalized procedures. Much of the mutual adjustment between plans and local culture may in fact have to do with the way in which plans and planning, as a temporal process or artifact, meet the real-world process of collaborative activity, including the different and potentially discordant rhythms embedded in specific features of the local collaborative landscape or situational context.

Suchman reveals the same kind of give and take found within Scott's accounts. According to Suchman, plans aid in making sense of these aforementioned complexities in the transient nature of cooperative work. Suchman characterizes plans as rhetorical devices for representing action and language, in the form of documentation and conversation. In this way, plans leave an identifiable trace of how collaborators perceived time, and are a resource for decision-making around actions. She describes plans as providing a pathway that offers a sense of stability as emergent changes become explicit. Garfinkel [9] similarly identifies that our tacit use of documentary method (such as generating plans) allows us to find standards, uniformities, and patterns that provide shared understanding of complex actions.

According to Suchman's characterization, plans are carried out through a blending of local circumstances, the internal common sense and knowledge of the actor, and interactions with the material world. Suchman offers that plans are interpreted in situ, where both the local circumstances within which they are to be enacted and an application of local knowledge (not literalistic following of the plan) are necessary to respond to unforeseen changes and adapt appropriately.

Across these literatures, plans are sites of negotiation. Plans represent the top-down decisions and assumptions of the stakeholders involved in the achievement of a goal that is also often also imposed from the top-down. Plans dictate the project goals, value and scope to its constituents, assign relations between resources and responsible parties, and provide a baseline of expectation during its execution via deadlines and deliverables. Once established, plans act as a standard for execution and control, often identifying protocols and hierarchical structures related to the achievement of tasks in pursuit of the goal.

But as Suchman and Scott also emphasize, plans may function as *resources* and sites of *negotiation*, places where disparate interests and understandings are brought together. As per Suchman and Scott, no matter the level of detail, plans are always incomplete and fail to reflect the depth and diversity of the worlds they attempt to put in order. Therefore, other forms of knowledge and action (Scott's metis, or Suchman's situated action) are always threatening to push through, disrupt, and reorient the plan.

Viewed historically, these separate literatures around timing and planning, rhythms and the plan, have made important contributions to CSCW research and practice. Attention to the multiple and often discrepant dynamics of time and rhythm have shed new light on an area of complexity and frequent tension in the design and deployment of CSCW systems. The work that actors do to overcome, work around, and calibrate action across the multiplicity of rhythms embedded in the worlds around them (named here as "alignment work") also constitutes an important and under-recognized element within broader CSCW processes of "articulation" [31] and "coordination" [27] work. For their part, CSCW literatures on plans and planning (including the seminal work of Suchman and colleagues at Xerox PARC) have produced richer and more satisfying accounts of how the formalism of plans meets the contingencies and resistances of "situated practice," with implications for the (in)sufficiency of plans and planning as a final guide or arbiter of collective action. This in turn has opened up new recognition around the modes of action available to participants in collaborative efforts, adding languages like bricolage, contingency, and improvisation to CSCW's arsenal of terms.

We argue that these insights gain additional force and clarity when put together, and that their connections have yet to be fully explored within CSCW scholarship. From this perspective, plans stand as agents of temporal alignment *par excellence*, gathering and aligning separate rhythms at scales ranging from the small to the large, and mediating between temporalities embedded in local forms of practice and those emanating from larger institutions of planning and policy. Plans call attention to (or sometimes render invisible) specific temporal conflicts that may directly impact the timing and completion of work. And plans establish common baselines of expectation around and against which local choice and action (including around the dispensation of local times and rhythms) can unfold. In the sections that follow we work out these arguments by reference to a case of considerable complexity and importance: the forms of planning and temporal alignment endemic to large-scale infrastructure development in the ocean sciences today.

III. RHYTHM, PLANS AND LARGE-SCALE SCIENCE

Growing investments in scientific infrastructure have increased pressure on policymakers and researchers alike to understand how to design, operate and maintain large-scale, long-term, and multidisciplinary scientific collaborations. Synthesizing these broader shifts, in 2003 the U.S. National Science Foundation published a blue ribbon panel report, "Revolutionizing Science and Engineering Through Cyberinfrastructure," which pointed to growing computational investments in the sciences as leading to a "new age" of science and engineering, marked by the growing complexity and scope of grand challenge scientific questions; the hardware, software and organizational capabilities centered around new scientific tools and methodologies; and new modes of high performance computing providing distributed knowledge across cultures, disciplines, and nations. Since the mid-1990s, investments in large-scale science and technology development from the NSF have been funded through a separate funding category called the Major Research and Facilities Competition (MREFC) account, intended to carry the weight of large-scale infrastructure builds that exceed the budgetary capacity of any single disciplinary line.

The high level of MREFC cost is matched with a proportionately high level of scrutiny, imposing a cascade of plans including a layered timeline and series of planning documentation. The five-year MREFC planning process prepares the champions of the initiative to tackle questions of scope and scale, solidify the science and technology requirements, and mobilize resources. This includes risk and contingency plans in order to prepare for the construction of the facilities.

And such formal planning processes represent just the tip of the iceberg. Subtending the list of formal MREFC requirements noted above are a wide variety of other planning activities – for example, individual investigators reorienting their research program, graduate students selecting their dissertation projects, and vendors positioning themselves for contracts – that are interwoven into large-scale scientific collaboration.

Our empirical work moving forward centers around one such NSF MREFC, the Ocean Observatories Initiative (OOI). In the case of the OOI, as well as other MREFC winners, its conscientious planning and documentation serves as passageway into the forms of alignment that reconcile the many rhythms of ocean science. We performed fieldwork at laboratories affiliated with the OOI at Woods Hole Oceanographic Institute, University of California San Diego, Rutgers University, Oregon State University, and University of Washington as well as unaffiliated offices in New Jersey and at Cornell University. We toured laboratories as well as both formal and informal workspaces (offices, conference rooms, docks, and museum spaces), capturing photographs and writing field notes as well as recording audio of our participants' presentations of each instrument and space. We conducted 31 in-person (23) and remote (8) semi-structured interviews with interview length between one and two hours. Interview questions centered on the kinds of work that led each participant to the OOI; the kinds of work they perform in their current roles; their involvement in OOI planning processes to date; and key temporal patterns and conflicts that affect their current work. We also traced and analyzed the informal and formal planning left within the iterations of documentation as the OOI came to be. We additionally mapped U.S. science policies around oceanographic research against OOI timelines and schedules, and further contextualized the OOI through histories of oceanography and time-series research found in the oceanography, science policy, and history of science literatures. On the basis of this data, and following grounded theory principles first established by Strauss and Glaser [6, 10] we developed memos around emergent themes (including around the themes of rhythm and planning explored here), which fed in turn into the ongoing course of the fieldwork. Memos were then written up into more substantive texts and findings that eventually fed into the text of this paper. The following sections report on this empirical work and develop arguments around the complex relationship between rhythms and planning as a key facet and complication of scientific collaboration and infrastructure development in the oceanographic research community.

III.A. PLANS IN-THE-MAKING

Historians often trace the rise of modern oceanography to a period during and immediately following World War II. While the U.S. Navy has a long history of supporting deep water and oceanographic scientific research, military patronage during wartime increased in volume significantly and helped to define the role of oceanography as a critical interest of the state. The practice of ocean science became inextricably linked to the operations of national military concerns, moving with changes in the political climate. This role was solidified with critical research expeditions in Bikini Island and Guantanamo Bay [19] where underwater sonar and acoustics were employed as powerful tools for submarine discovery and amphibious warfare.

In postwar oceanography, research was typically carried out through short-term soft money grants funded by the Navy where a single investigator or small research team would drop an instrument they had built into water off of a research vessel. The principal investigator or small team would then analyze and publish on the data collected by the instrument, largely structured by the rhythms of the academic calendar, tenure process and publication deadlines. In some cases these research teams would set sail multiple times, generally offset by 6 months to a full year between cruises. This period of oceanographic work was structured and determined by the time it took to develop, test and evaluate tools; determine areas of interest in which to position and deploy the tools; Navy ship availability and sponsoring; crew availability; fisherman and fishery involvement in the area; and phenomenal events in nature. This form of research only captured a series of snapshots about that area of water, often within a multi-week period. While critical to the understanding of Earth processes, only by luck would a configuration like this happen upon a hydrothermal vent or volcanic activity on the seafloor, as these events are unpredictable and difficult to capture.

In the late 1980s and early 1990s, growing concerns around the contributions of oceanic processes to wider processes of climate change sparked new interest and attention to the long-term coordination of ocean research. This period also marked a dissipation of the longstanding relationship between oceanographic research and the Navy. Visionaries in oceanography began to hold NSF-funded (not Navy-funded) symposiums to identify approaches to collecting data that would overcome previously held issues of transience and unpredictability. The underlying concerns of defense that were threaded into ocean initiatives funded by the Navy were shifted to concerns regarding climate [5]. Connecting through a common desire to address temporal concerns in long-term ocean observatories, a grassroots network of scientists and engineers involved themselves in the initial symposiums across the globe.

The U.S. efforts were primarily championed and led by a senior oceanographer at a large west coast university, backed by both national and international interest. Following an extended series of symposiums and discussions, the decision was taken to develop an initiative to wire and instrument an entire tectonic plate, building a long-term cabled observatory covering the entirety of the Juan de Fuca Plate off the coasts of Oregon and Washington in the U.S. and British Columbia in Canada. Funding from the NSF and the project leader’s home institution supported the drafting of what would be one of the OOI's earliest plans, "The Feasibility of the Northeast Pacific Time-Series Undersea Networked Experiment Project (NEPTUNE) Project." At the same time, a corresponding feasibility document was developed for “NEPTUNE Canada” through investment by the Canadian government’s ocean science funding body, Ocean Networks Canada. Together the Natural Sciences and Engineering Research Council of Canada and the U.S. National Science Foundation held workshops and symposiums together to address critical issues of engineering and science goals for the regional cabled observatory.

Many of our participants detailed the ways in which the international NEPTUNE project would turn the postwar characterization of oceanographic research on its head: introducing larger collaborative networks, industry-purchased instruments, real-time public data, and long-term and continuous maintenance and data collection without the need for research cruises (substitute maintenance cruises). While some rhythms of ocean science would remain primary (seasons and seasonal migration or mating patterns, temporal disruptions emanating from natural phenomena like hurricanes or tsunamis), many traditional rhythms of ocean science were not encompassed within the plans of NEPTUNE, such as the organizational rhythms of Navy funding cycles and field-wide ship scheduling, biographical rhythms of private data ownership, and infrastructural rhythms of short-term specific use instruments. At the same time the planning of the cabled network also unearthed a series of new concerns rhythms, which had little precedent in prior ocean science work, including the relation between research responsibilities and facility building for the MREFC planning process, activities related to managing the public attention and scrutiny of the initiative, and the long-term funding brought by a facility build unlike the predominant soft money structure of the field.

Through the initial development and continued construction of NEPTUNE we find organizational rhythms integrated into the planning of the facilities, such as the implementing organizations’ semester schedules, teaching obligations for faculty, departmental requirements, expeditions unrelated to OOI, and publication timelines (AAAS, American Geophysical Union). Plans served to integrate these traditional organizational rhythms with the previously unseen infrastructural rhythms of the MREFC: iterations of the formalized planning documents (Feasibility, Conceptual, Preliminary, Final); the milestones of the construction process; the specific engineering requirements and evaluation practices for large-scale deployments; the release cycles of the cyberinfrastructure; software design and development; and the production of educational materials and tools affiliated with the new observatory.

The first cracks in this productive and collaborative relationship appeared in the early 2000s, and were identified by our participants as variations in timing and funding associated with federal investments and interest on either side of the bi-national relationship. While NEPTUNE Canada began construction in 2003, the U.S. was still hovering over central ideas and initiating the planning process. Participants speculated that the fiscal cutbacks associated with U.S. funding of the Afghan and Iraqi wars, the Bush administration’s relatively lukewarm attitude towards science funding especially in areas associated with questions around climate change, and later the timing of U.S. economic slowdown of the 2000s drew significant federal scrutiny on science and ultimately delayed the U.S. efforts. This rift was further exacerbated by a brewing concern in Washington D.C. about NEPTUNE's distinct affiliation to its champion and his university, culminating in the decision to rebrand the U.S. side of the project as the 'Ocean Observatories Initiative' (OOI).

At this point the Consortium for Ocean Leadership was formed within the NSF, acting as a "unified voice in the nation's capital for oceanographic research", and as a liaison between OOI, Congress and the White House. As such Consortium of Ocean Leadership was tasked to oversee the planning process of the OOI, as a distinct entity from Canada's NEPTUNE. The OOI expanded its reach from the regional cabled observatory at the Juan de Fuca plate to additional coastal and global scale infrastructure largely formed by gliders and moorings implemented within U.S. waters as well as at the Irminger Sea offshore Southern Greenland, and Southern Ocean west of Chile.

In 2006, the construction of the "Ocean Observatories Initiative" became a line item in the U.S. President's budget, marking the start of the MREFC Conceptual Design, the OOI's first formal definition of plans including schedules, costs and contingencies. By this time, NEPTUNE Canada had not only completed the planning process but had become fully constructed and was collecting production quality, real-time data in its full operation: fully realizing the introduction of the unprecedented rhythms forecasted by our participants and generating new national and institutional policies surrounding their open data policies and publicly available instruments.

In 2008, more than $100 million from President Barack Obama's American Recovery and Reinvestment Act (the "Obama stimulus package") was awarded to the OOI, instantaneously accelerating its move into construction and prompting another reorganization and another iteration of the Conceptual Design plan. To cater to the climate change priorities of the stimulus package, a global node at the Argentine Basin was added to capture additional air-sea sampling and the budget was reorganized to accommodate this change. Multiple participants lamented the addition of the global node, as it forced the removal of a portion of the planned instrumentation from the original cabled observatory at what was once called NEPTUNE and was now renamed "Regional Scale Nodes."

A system engineer detailed for us the reorganization of his daily work that resulted from the removal of nodes. His original cooperation with Canada had led to the design of a circular architecture resembling a "big ring with the two leaves that became NEPTUNE and NEPTUNE Canada". The new resource constraints forced the engineer to collaboratively build a new architecture for the Southern leaf that no longer paralleled the circular configuration of its Canadian counterparts and rather employed a star-like architecture. Here we see the intertwining of the top-down rhythms of governing bodies at a larger, national scale, such as the NSF funding cycles built into milestones, the imposed MREFC five-year planning process detailed across the set of planning documents, the stimulus package and its corresponding reorganization of the OOI, the Afghan and Iraqi wars and financial crisis and their rescheduling of original timelines from the early documentation.

In November 2008, the OOI's Final Design plan was reviewed and accepted. By 2009, the construction funding for the OOI began, just as its Canadian counterparts became wholly operational. The separation between national efforts appears to be exaggerated if looking at only the plans (as Canada starts to drop out of the official documentation), but the stories of the participants reveal that on the ground the two countries remained very much cooperative, though at an informal level. Canada and U.S. hope to eventually connect their infrastructure, and each time the U.S. OOI plans change within the cyberinfrastructure or Regional Scale Nodes, their Canadian counterparts are informed and adjust their own plans accordingly.

Despite the seemingly increased separation between the two efforts, Canada still appeared within the lower-level (not MREFC-mandated) documentation of the OOI, as well as within the everyday activities of its affiliates. There remained an envisioned interchange between the U.S. and Canada where OOI would obtain NEPTUNE Canada data but also would move OOI data to Canadian repositories. While the two systems are not identical nor did Canada or the U.S. financially support their cooperation, there remained an interpersonal connection between the initiatives and our participants described the many regular collaborative efforts established at the local level: weekly phone meetings, laboratory visits, dinners at conferences and regular email exchange. In 2010, this connection was formally re-established when the U.S. Consortium for Ocean Leadership approached NEPTUNE Canada with a new Memorandum of Understanding, pledging to work together to manage and operate ocean observing systems.

The lag between NEPTUNE Canada and the OOI's Regional Scale Nodes greatly influenced the local adherence to the plans that would be detailed in the Final Design plan, and highlighted a disconnect between the operation of the OOI on the ground and the plans coming from the Consortium of Ocean Leadership. Some participants described that the extended time for any process to pass through Ocean Leadership slows operation to a point where they must consider breaking protocol in order to retain momentum. One participant described Ocean Leadership's desire to follow a strict MREFC process as sometimes being at odds with the local culture within one of the implementing organizations: "Because of this, at some point there were some rivalries in the program in terms of not wanting to be bound by Ocean Leadership restrictions or deal with them. It's been a constant problem with all of the implementing organizations about working together as a team versus running off and doing your own thing.” In order to circumvent the long MREFC process of procurement, one implementing organization would "go rogue" then reconcile the ‘damages’ after the diversion from the plans. In this case, human action superseded the adherence to the top-down plans coming from Ocean Leadership and the system adapted to incorporate the effects from those self-governing actions. As one participant noted, “Ocean Leadership has had times of more and less leadership… There's a plan, the overarching plan, and then there is putting out the fire of the day… Sometimes the plan goes out the window." However, this autonomous dynamic was not found in all of the implementing organizations, and was reported as promoting tension and at times conflict.

We see here how the work of planning (plans in-the-making) changes, reorients, and aligns rhythms across the broad range of temporal kinds (organizational, infrastructural, biographical, and phenomenological) and scales that characterize the ongoing work of ocean science. Through juxtaposing plans with human action, we reveal a shifting loci of control, prioritizing and valuation at different scales within the organization, and locations and human actors within the organization that are more and less autonomous within the planning process. We are able to dissect the initial local, more grassroots rhythms emanating from the ground up in the long-term biographical rhythm of the OOI's champion from his conceiving of the idea for time-series instrumentation on the sea floor, to mobilizing the field around that idea, to becoming the nucleus of a self-organized group, then eventually leading to a formalized organization in which the high-level decisions came from government bodies, not the champion himself.

III.B. PLANS IN-ACTION

The work of plans and planning in aligning ongoing collaborative work hardly stops with the formulation of the final plan; nor, per Suchman, is the impact of such plans fully determinative of the forms of activity that follow. A complex reconciling of rhythms at many scales led to the creation of the final MREFC plans, and plans continue to shape and be shaped by rhythms after their formalization.

One requirement of MREFC planning is the definition of a detailed Work Breakdown Structure (WBS) that attempts to bridge the diffuse goals of the individuals within the initiative and steer them toward grand project goals. The WBS is imposed by the NSF to manage the complexities of a nonlinear, large-scale project. The WBS defines the integration of team organization with primary responsibilities, scheduling and success measures. The WBS document contains the high-level tasks for the whole field program, each ship, and each robotic vehicle, for example. It is divided firstly by OOI components (coastal, global and regional scale nodes, cyberinfrastructure, education and outreach) and subdivided by responsibilities and milestones mapped to each implementing organization (university and institute affiliates), then accountable roles within the implementing organizations (project scientist, technician, lead engineer, project manager, etc.). This is representative of the hierarchical relationships between entities with the NSF and Consortium of Ocean Leadership at the top level. Rather than around collaborating teams, the WBS is built around deliverables, such as final requirements, instrument or resource procurements, and building schedules. The project manager of each OOI component is responsible for their own WBS.

The WBS also includes a very detailed Cost Estimating Plan and progress reporting; a dictionary of the physical components, all deliverables, subsystems; R&D; design; prototyping; fabrication; assembly; installation; acceptance testing; administration; system engineering; purchasing; reporting not directly related to a product; hierarchies; major contracts; and specific products and labor (manager, engineer, scientist, technician, secretary, construction worker, etc.) including considerations of sick or vacation days and employee rates [29].

The WBS acts as a plan that addresses dissonance between rhythms in developing large-scale infrastructure: vendor schedules for procuring instruments and industrial spin-off, communication time between implementing organizations, varying funding cycles and academic calendars, prior investment histories of each implementing organization (and how this affects going forward into the initiative), cycles of technology development and ability for involvement in the initiative within each implementing organization, varying scientific interests and biographical rhythms of the individuals enacting the plans, and the level of debate and deference to hierarchy within an implementing organization's culture (wrapped up in time to complete tasks through formalized or informal processes). The WBS is also a plan embedded in other plans, and is formally mapped to both higher-level science goals and to national concerns as well as lower-level execution protocols, intermediary documents and informal collaborative structures.

The ability to adhere to and enact the WBS milestones is dictated by the effectiveness of low level coordination and alignment activities. One engineer explained the intermediary alignment steps between WBS milestones that reconcile the many moving parts of the collaborative OOI construction. He explained, "The implementing organizations are supposed to be inch people. We are supposed to making things happen and things happen by inches, not by miles." He particularly emphasized the usefulness of calendaring in defining and completing each WBS milestone. One participant noted over 20 Google Calendars are set up to manage right down to the hour the kinds of work that will go into this summer's infrastructure build. These calendars are lower-level and informal breakdowns of the formal WBS, including team events, specific instrument builds, cyberinfrastructure development, and an out of office calendar.

Each piece of the infrastructure has its own cost; as one OOI project scientist described, if any project scientist needs to move money from ship time to buying a sensor, for example, a change review board needs to be advised and must approve the shifted allocations at the level of the implementing organization. The Consortium of Ocean Leadership also has a high level change control board for issues that cross OOI components or affect more than one of the components. Upon approval of the change, the WBS is formally adjusted by an NSF program manager or officer at the Consortium for Ocean Leadership. The WBS is in this way a living but carefully managed document, responding to changes in the various project sub-units while still trying to hold them to a tight and highly regulated schedule.

In the course of one of our interviews, a project scientist received an Engineering Change Request in his email and was tasked to review and send comments to its author (a project scientist at another implementing organization). The change request detailed the original plan for the initial infrastructure build in the regional scale nodes, positioned for a series of cruises to lay cables and core instruments over the course of three months in summer 2013 with the cooperation of two other implementing organizations.

The infrastructure build set for summer 2013 was predicated on reconciling traditional, more predictable rhythms of ship-based ocean science such as ship time, crew availability, academic calendars, and fishery operation off the coasts. However, these cruises are distinct from the common research cruise, as their mission was deployment, not research itself. Therefore, this removes the rhythms of developing research questions, determining a locale, and building or procuring a tool in any traditional sense.

The request alerted the project scientist to changes needed to be made in infrastructure build’s cruise plan, stemming from a significant delay on laying the 17km cable that connects one of the primary nodes to the shelf site on the seafloor at the Juan de Fuca Plate. The delay arose from what the scientists and engineers deemed as an unreasonable bid from the cable company, to which the OOI was forced to renegotiate with the vendor.

Various actors negotiate the WBS to address the change emanating from the unforeseen changes in prioritization by the vendor, and leading to an inability to lay the cable during the agreed upon schedule. Harmonizing the now muddled plans required a negotiation process between engineers and technicians to assess the ability for continued operation and development of all related technologies, including power availability, data flow range, and stereo or analog inputs. Additionally, project managers were involved to ensure the continued availability of human labor in the event of a changed schedule. Project scientists were consulted to assess new measures to reach science goals and requirements and a subject matter expert advised.

The resulting collaborative decision was to move the procurement and laying of cable to the following year, setting back the schedule significantly and rearranging priorities for the summer infrastructure build. Once all comments on this decision are gathered, the original author of the change request will synthesize all comments and considerations into the final Engineering Change Request then submit to his implementing organization's formalized change review board. The board will then collectively approve or disapprove the suggested changes and adjust the WBS accordingly.

At one level this change culminated in a formalized reorganization of efforts through the Engineering Change Request and WBS. At another level we find the more personal, biographical effects of removing ship time. Some of the scientists and engineers expressed a "restlessness" to get out to sea, citing damaging effects on morale, frustration with the vendor, and a humbling of the members in realizing that while their work was a top national priority to them, a cable company might not agree.

The phenomenal, emergent event of the cable company deprioritizing the OOI resulted in many local changes and shifts not only in the formalized plans but also in the lives of those within the OOI. The change in WBS impacts across scale, down to the individual, biographical rhythms of the project scientist who received the change request to review. The project scientist was responsible for a number of instruments set to be wired during the cruise this summer, but those procurements will now be instrumented next year. As a result, not only will the whole deployment schedule need to be reorganized (and ship time removed: affecting ship crews, fishermen, the Coast Guard, and the OOI itself) but also each individual's work plan that was involved in the summer cruises for the next full calendar year, and the WBS milestones which followed the anticipated instruments in production at the regional scale nodes. The delay in work must also be addressed by the OOI's Canadian collaborators, detailed in the previous section, who are awaiting the production-ready data from these seafloor instruments.

IV. DISCUSSION

As we have seen, plans and planning occupy a central position in the work of large-scale collaborative science, especially (though not exclusively) in their start-up phases. Viewed in a certain way, almost everything our informants do is about planning. The OOI’s champion developed a series of plans to mobilize the community, develop a network and gain funding by the NSF. The NSF developed a series of plans to structure the construction of the OOI, manage funding cycles and budgetary restrictions, and situate and reorganize the effort to fit within a broader society-state context. And the project scientist was required to integrate an unforeseen change in vendor relations into new plans for both his team and his own personal trajectory.

But as we have also seen, the same phenomena were also centrally about *time*. OOI organizers were subject to (and tried to influence) temporal rhythms emanating from a whole host of sources: NSF and MREFC funding schedules; the timing of their Canadian counterparts, cycles of interest (and disinterest) emanating from science funders in Washington; and arguably the rhythms of public concern around the central concerns, including climate change, that the new observatory was meant to address. Plans and planning – large and small, formal and informal – represented key technologies by which actors tried to manage, control or amend these varying temporalities, attempting to bring otherwise discrepant rhythms into more and less workable *alignment*. We believe that the structure and outcome of collaborative work, in this and many other contexts, is deeply bound to the success of precisely such alignment efforts.

In exploring the deep connections between rhythm and planning across the collaborative contexts, setting and scales of the OOI, our paper also seeks to frame a number of larger contributes to CSCW theory and research. First, we identify plans and reconciling conflicts in rhythm as a central and critical challenge of collaborative work. Rhythms act as a substrate for classic notions of alignment work, yet are difficult to tease apart and analyze. We offer that planning and the formalization of plans act as an important site for making visible this temporal work, particularly in reconciling conflicting rhythms across scale and prioritizing and valuing rhythms in the process. The analytical power we gain from uncovering rhythms lets us look at how work evolves, rather than capturing only a snapshot in a dynamic, socially and historically embedded scientific practice. Rhythms and plans provide insight on how emergent changes (such as someone is fired or tenured, a hierarchy is re-organized, a hurricane forms, etc.) reconfigure the way we perform scientific work. Plans can lead to an ossification problem: once a plan is frozen-in-time it becomes brittle and stale, unable to withstand the dynamic natural world. Much has been written about the need for flexibility in plans and planning [1, 21, 36] but little is known about the rhythms embedded in the plans and their relations to human labor and life.

Second, we recognize that rhythms are relational. The rhythms of a scientific campaign, such as described within our plans in-the-making example, with its fits and starts and long waiting pauses, looks very different from those of a political campaign, of the turnover of a new presidential administration or of the maintenance of an in-production real-time data-producing infrastructure. Yet, we see these disparate rhythms align to establish the OOI's plans. Rhythms are called out, elevated or de-emphasized by plans, pointing to actors and resources that are being served or are underrepresented by the plans. The prioritizing and valuation of rhythms gives us a better understanding of power dynamics that might be invisible otherwise. This notion is similar in part to Star and Ruhleder's [28] assertion of the relational nature of infrastructure: as changes (in infrastructure, in plans) become formalized, the meaning of those changes will be unique to each individual and will highlight power relations in the adoption and resistance to different rhythms.

Third, we see that both rhythms and events can disrupt, shape and reorient plans. Despite the efforts entrenched in the work breakdown structure and its web of documentation in attempting to account for complexity. Phenomenal events like the Gulf Oil Spill, financial crisis, or even the stimulus package change the course of a plan unexpectedly and in emergent forms that are then crystallized within the next iterations of the plans. Often at these points of breakdown and change, we prioritize (like the stimulus package call for climate change led to more global scale nodes and less regional scale nodes). On the surface, these rhythms may seem external to the OOI, yet in practice posed a distinct and integral change to the initiative's plans and rhythms.

Fourth, plans link temporalities embedded in local practice with those operating at larger institutional levels. The specific relationship between local culture and the state can shed light on a number of concerns at a policy level. Science at the large-scale is politically essential to the operations of the state and is itself fundamentally dependent on the state. We have learned from scholars such as Suchman and Scott that any change to the way in which work is completed must at the very least reference the existing social and material arrangements that would be engaged in that work. Suchman teaches us that plans need feedback and iteration, attention to local circumstances and need to be dynamic in order to withstand emergent or phenomenal changes. Suchman asserts breakdown occurs when machines don't support local actions. This is true of plans (as a parallel to machines and automation) in organizing scientific work, and is a useful consideration in the development of policies that support plans and planning scientific endeavors. More broadly, this point echoes the assertion to take policy processes more fully into account in CSCW work [15].

Lastly, we note that rhythm and time more generally is methodologically difficult to study empirically for the challenges of visibility and emergence we've detailed. We often default to the formal structure of plans and take the work they detail too literally, not considering the emergent properties of action [14]. Additionally, informants find it difficult to reflect on time and rhythm directly. Often a rhythm is called out only in moments of difficult temporal coordination, such as the realignment of work spurred by the shifting priorities at the cable company in our previous example. We offer plans as a productive artifact for the study of time and rhythm, but encourage alternative representations that might make practices of temporal alignment.

V. CONCLUSION

Our study has emphasized the role of plans and planning as a key site or modality for the alignment of the multiple temporalities that go into and shape large-scale collaborative infrastructure projects in the sciences. We have argued for the role of plans and planning in coordinating discrepant rhythms across multiple scales of collaborative action. We have emphasized the work of plans in calling out (or sometimes obscuring) specific points of temporal conflict that may undermine or derail larger collaborative processes. And we have argued for the role of plans in establishing common baselines of expectation around which local and timely action can be coordinated. As our empirical case has also demonstrated, the challenges of rhythm typically show up in blended form, caught up in other kinds of problems and tensions that confront and limit infrastructure development efforts, and never fully captured or contained within the formalized confines of formal planning processes: rhythm can emanate from top-down broad fiscal, political, or institutional entities, as well as bottom-up biographical changes or organic phenomenal events. Plans play a central but rarely uncontested role in negotiating these collaborative dynamics.

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