7-13-2020

How to Build a Supercomputer: U.S. Research Infrastructure and the Documents That Mitigate the Uncertainties of Big Science

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Citation Details

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Key Words: infrastructure, technical reporting and documentation, big science, risk, actor-network theory, genre

Abstract

In this article, I argue that technical reporting and documentation processes function to mitigate uncertainty and enable complex systems in the endeavor of big science. The argument draws on two years of field research investigating technical reporting and documentation processes at a federally-funded supercomputing center dedicated to scientific research. A central question the study sought to answer was, "How does one build a new supercomputer?" One of the answers that emerged is that supercomputers are built by the genre assemblages of documents that mitigate financial, political and technological uncertainties, and their attendant risks, that are inherent to technoscientific cutting-edge enterprises. Given their centrality, these genre assemblages function as essential infrastructure for the US national laboratory system and for big science endeavors in general. In conclusion, this article argues that documentation that mitigates uncertainty serves an important infrastructural function for organizational life more generally.

How to build a supercomputer: US research infrastructure and documents that mitigate the uncertainties of big science

"National laboratories are crucibles of *uncertainty*. While their scientists eagerly probe the frontiers of knowledge, never knowing where their research will lead, their managers grapple daily with questions of relevance and survival." (Holl, p. ix, my emphasis).

Big science is uncertain. So much so, in fact, that Alan Schriesheim, a former director of the US national laboratory that was the field site for the research reported in this article, wrote the fact of uncertainty into the first line of his forward to a volume about the laboratory's post-World War II history. The uncertainty faced by scientists and managers, Schriesheim writes, is driven by questions of "relevance and survival" (Holl, p. ix), such as:

- How to anticipate society's emerging technology needs?
- How to mount credible research programs to meet those needs?
- How to secure government funding and public support and an ongoing national commitment to the future?" (Holl, p. ix)

Given that Shriesheim goes on to characterize the challenge of big science as "daunting" and "success [as] ephemeral," it can seem incredible that any project of big science, such as the United States' Hubble Space Telescope or the Europe's Large Hadron Collider (LHC), ever comes to fruition: there are countless reasons why big science can't and won't work. This is because "Big science is hard" (Turner, 2015), a notion that becomes comprehensible when "big"

is understood to mean "expansion on many axes" (Galison & Hevly, p. 2), and not just simply a science project with a massive budget and an expansive timeframe. These axes include geographic (projects that have an impact on whole regions or even nations), economic (budgets of millions or billions of dollars), multidisciplinary (engaging scientists from many areas of science) and multinational (the investment of multiple nations). Given these axes of complexity, it is easy to see that uncertainty, and the risks that uncertainty create, are inherent to the enterprise of big science projects. Likewise, mitigating uncertainty must be inherent to big science projects as well, if they are to succeed. Writing, this article argues, plays an essential role in this mitigation.

This article reports on a study of technical reporting and documentation processes at a site of big science, a national laboratory facility operating the world's fourth fastest supercomputer (when it came online in 2012). The study began as a project to document a complex annual reporting process to the supercomputing center's funder, the Department of Energy, but it evolved into a broader study that examined the multiple functions for technical reporting and documentation at a large technical facility, including the function to mitigate operational, organizational, technological, financial, and political uncertainty.

In retrospect, it may not seem surprising that insight into the essential function of documentation to mitigate uncertainty in complex systems came at a supercomputing center at a national laboratory. Why? Due to their scale and complexity, big science projects require an uncommon level of coordination among stakeholders and the mitigation of substantial financial, political and technological uncertainties, and their attendant risks, to come to fruition. With so much uncertainty, how can the associated risks ever be deemed acceptable to the stakeholders in government, science and industry who stand to either gain or lose a lot depending on the success

of the project? This question is especially relevant in a post-Cold War world where the rationalization for government funding of big science has changed from national defense to economic development via collaboration with industry (Jacob & Hallonsten, 2012, p. 413), and it has shaped the stories of how big science projects in the US and around the world were conceived and developed during the post-Cold War era.

And big science projects do fail. In 1993, the US Congress cancelled funding for the Superconducting Super Collider (SSC) to be built in Waxahachie, Texas after decades of development and $2 billion dollars of investment. But the indisputable material existence of the machines of big science, such as the supercomputer in this study, shows that, unlike the case of the SSC, the uncertainty and attendant risks of big science are not always terminal. Big science projects succeed in part because they are able to overcome the uncertainties inherent to such complex endeavors, and writing plays an essential role in this success. Writing Studies researchers can learn a lot from big science about how technical reporting and documentation processes function to mitigate uncertainty and enable complex systems. This insight gives writing researchers, as well as facility staff, tools to understand the value and the purpose of high stakes documentation processes that consume so much staff time but that are often considered to be secondary in value to time spent on the daily operations of the machine and other technical work.

The notion that writing and writing processes have an essential function for scientific and engineering organizations, and organizations in general, is not new to Writing Studies research (e.g., Bazerman & Paradis, 1991; Doheny-Farina, 1986; Fountain, 2014; Geisler, 2001; Paradis, et. al, 1985; Read, 2019; Read & Papka, 2014, 2016; Spinuzzi, 2003, 2008, 2010; Wickman, 2010; Winsor 1989, 1994, 1999, 2003; Yates, 1993). As a body of research, Writing Studies has

established that writing, the practice of knowledge-based professions, and the operations of organizations, share a complex relationship. Indeed, we have come a long way: When Paradis, Dobrin & Miller (1985) began their research into writing at Exxon ITD, writing activities in industry were "hidden," "an afterthought to serious research," and "just got done" (p. 281). They argued that the "consequence of this neglect" was a poor understanding of the functions of what they called "in-house" writing (p. 281). Since 1985, Writing scholars have developed and drawn on genre theory, activity theory, and actor-network theory (ANT), often in combination, to study and theorize writing products, processes and activities as mediational means (e.g., Geisler, 2001), as standing sets of transformations (e.g., Spinuzzi et. al., 2016), as constitutive of normal organizational operations (Read & Papka, 2014), and as tools to create and maintain the structures and activities of a workplace (e.g., Spinuzzi, 2010; Winsor, 1999).

Despite this extensive body of research, however, the various functions of writing have not always been systematically articulated or codified in a way that can be applied in industry and inform writing pedagogy. This article adds to the documented functions of writing in technical organizations by presenting a case of how writing functions in a context that is not readily accessible to students or the general public: a supercomputing center at a national laboratory. In the case of the supercomputing center as a site of big science, this project begins with the assumption that, similar to economic and material infrastructures, processes of technical reporting and documentation are essential to the national research infrastructure for big science in the US. Understanding the infrastructural function of documentation processes at the supercomputing center is one step towards a fully theorized notion of writing as infrastructural (Read, 2019).

To make visible how common documentation processes mitigate the uncertainty at the supercomputing center, I draw on genre theory and the construct of *genre assemblage* in particular. According to Spinuzzi, genre assemblages function collectively as constituent genres that are "arrayed in a standing set of transformations (SST's)" (Spinuzzi, et. al., 2016, p. 8). SST's are stable sites of rhetorical transformations that allow writing researchers to see how a genre assemblage reliably mediates a technological, managerial, or political uncertainty, or "trial" (p. 8), that, in the present article, must be overcome in order to build a new supercomputer. Based on the analysis of documentation processes as genre assemblages, as described by supercomputing center staff in interviews, I argue that the mitigation of uncertainty is one case of an "infrastructural function" (Read, 2019, p. 234) for writing in organizational environments. A theoretically informed notion of the infrastructural function of writing has applications in both industry and the pedagogy of writing for technical professionals.

Background

Research Infrastructure for Big Science

It is not a coincidence that the US has been relatively successful at developing and operating big science projects in the post-World War II era. This is because over time the US has developed stable government infrastructures that reduce, or at least regularize responses to, the inherent uncertainties of big science projects. Researchers in the field of science and public policy have already established that ensuring the long-term success of a big science project

requires this kind of infrastructure, including a government policy for setting priorities for

scientific research and for allocating reliable funding streams that account for inevitable future

cost increases and economic changes (Hallonsten, 2015; Traweek, 1992). Without this policy

infrastructure, projects risk running aground on the shoals of the ugly politics of allocating

additional funding to a long-term project that has outgrown its original budget. In contrast,

European science has generally not codified policy and procedures for multinational big science

collaboration across Europe, and so each project has to effectively reinvent the wheel and

navigate the political and policy landscape of the day. This lack of policy infrastructure exposes

projects that rely on the investment of multiple nations to the fickle winds of politics when big

science projects develop over decades and require a stable and centralized science policy and

economic infrastructure.

In contrast to the largely ad hoc European approach to the development of big, multi-

national science projects, such as the LCH, the US's Department of Energy (DOE) system of

national laboratories, including the host laboratory of the supercomputing facility, has a much

more developed research infrastructure for managing the costs of projects and their timeframe

for development. The US system has developed a relatively stable policy and economic

infrastructure for negotiating "priority and investment" (Hallonsten, 2015, p. 3) for the

development of big science projects. This development has been motivated during the post-Cold

War era by the removal of a geopolitical or military motive for maintaining a system of

government-funded scientific laboratories. In response, the DOE laboratories have managed to

persist via gradually transforming their missions and activities to align with the social, political

and economic conditions of the late 20th and early 21st centuries (Hallonsten & Heinze, 2012, p.

458). This means that the laboratories have developed new policies and practices for sharing the

risks of big science with stakeholders in industry and with universities as the "moral economy"

for funding big science has shifted to valuing "entrepreneurship and measurable utility"

(Westfall, 2012, p. 448). These policies and practices are codified in documentation processes

that are essential to the research infrastructure of the US national laboratory system.

 For example, a key document in the contemporary national systemic research

infrastructure for the DOE national laboratories is the Management and Operating (M & O)

contract. This contract positions the DOE as a steward and overseer of each individual laboratory

in the system, but not as the operator, which is usually either a university or an LLC. The M &

O contract codifies a relationship between the DOE and the non-governmental operation in a

way that:

> "enables the Government to establish objectives for the laboratories' research programs
>
> and to exercise controls necessary to assure security, safety, and the prudent use of
>
> public funds, while allowing private sector organizations selected for the technical
>
> ability and managerial expertise to carry out the laboratories' day-to-day operations"
>
> (https://science.energy.gov/lp/management-and-operating-contracts/).

This defined arrangement shares the uncertainty of operating a national laboratory with

government, public and private universities and helps to mitigate the financial risks (and

therefore also political risks) of operating the laboratories by freeing the laboratories to pursue

non-governmental sources of funding. These sources are mainly industrial, which have become

increasingly important as federal funding for science has waned since the end of the Cold War.

Because the M & O contract codifies a set of complex negotiated arrangements among multiple

stakeholders, it brings stability to the national laboratory by functioning as a layer of financial

and political risk mitigation at a systemic level.

As I studied technical documentation and reporting processes more generally at a supercomputing facility hosted at a national laboratory, I discovered the following: where there is a financial, political or technological uncertainty there is a document or document process to mitigate it. The emergence of my thinking is important to understanding this project, as I did not set out to study organizational risk or risk communication, both of which are independently established areas of research. Rather, I set out to study the functions of writing and documentation at the supercomputing center, and over time, I made connections between the highly contingent environment of a national laboratory and the documentation processes that I was studying. These connections revealed the centrality of technical reporting and documentation processes to the mitigation of the inherent uncertainties of a big science project at the cutting edge of technological development. Over time I also realized that these connections turned out to be one of the answers to the overall research question that I brought to the field site: "How do documents build a supercomputer?" This insight was a product of the methodological lens that I brought to the data I collected during fieldwork, that of an actor-network theory (ANT) informed view of how writing functions infrastructurally for organizations (Read, 2019).

Actor-Network Theory: Viewing documents as traces of the actor network that assembled the supercomputer

Standing in the chilly, roaring machine room that houses the supercomputer among rows and rows of black metal cases that enclose 786,432 processors capable of processing 10 quadrillion calculations per second, nothing could be more certain than the supercomputer's substantial materiality [Fig. 1].

INSERT FIGURE 1 ABOUT HERE

Figure 1. The supercomputer Mira in 2014. Photo by author.

What is less immediately comprehensible is how the supercomputer was built, or "stood up" in the parlance of high-performance computing, since none of the rhetorical, political, technical or manual labor required to build the machine leaves an explicit trace on the supercomputer. Even the decorative images on the computer's casing do not reveal information about where the hundreds of millions of dollars come from to build it, who had to be persuaded to spend so much money, how many people (hundreds, if not thousands) it took to design, manufacture, build and now operate and use the machine, how their work was coordinated and how it was that the cutting-edge technological innovation behind the machine's unique computing architecture happened to work and at the right time. This lack of information presses on the curious visitor to the supercomputing center as questions that are not easy to answer, even by a facility staff member touring me through the machine room. This is because the answers are distributed across the experiences, memories and documentation of up to 85 staff members, and even more when players in Washington, DC, such as DOE program managers and members of Congress, are taken into account. While the machine is also unable to answer these questions for us, Latourian Actor-network theory (ANT) offers a helpful methodology for exploring where an object, especially a material object of technology, came from and how it was possible that it could come into being at all given how many threats challenged its existence (Latour, 1996; Read & Swarts, 2015).

From an ANT perspective, traces of the assembled actor network of which the supercomputer is an outcome (Read & Swarts, 2015, p. 17) exist in forms of documentation that underwrote the development of the new machine. For Writing Studies researchers, ANT helps us to answer questions about the machine's origins by focusing our attention on the *rhetorical settlements,* or negotiated alliances among human and non-human actors, that are inscribed in documents and documentation processes, and when they recur, genres and genre assemblages. As inscribed nodes of social action that mediate socio-technical networks in complex organizational environments (e.g., Spinuzzi, 2003, 2004), genres codify, stabilize and make visible (Read, 2016) the translations among actors essential to big science projects, including building and maintaining a supercomputer.

Genre Assemblages and Standing Sets of Transformations (SSTs)

Genres of documentation at the supercomputing center are one site to explore and theorize the US national research infrastructure. When genres related to a defined network effect, or outcome, are studied collectively (Spinuzzi, 2004, 2010), the larger socio-technical network that is mediated and inscribed by the complex system of genres comes into view. In other words, tracing the accretion, or successive enrollment, of actors via the various official genres of documentation handled by the facility staff answers the question that confronts the visitor to the machine room at the supercomputing center: how was it possible to build such a complex and expensive machine? This study traces how several genre assemblages mitigate the political, technological and financial uncertainties that are inherent to big science projects and, specifically, to the work of building a new supercomputer.

Because genre assemblages recur over time in response to the recurring need for certain types of rhetorical settlements, they become a site for "represent[ing] and transform[ing]" (Spinuzzi, 2010, p. 368) a series of complex translations that ally essential actors to a project (Read & Papka, 2014; Spinuzzi 2004; 2010). This rhetorical work is reliably accomplished across the successive genres of a genre assemblage (the partial analogy of an assembly line comes to mind here) by what Spinuzzi (2010, 2016, et. al.) has referred to as standing sets of transformations (SSTs).

For Writing Studies researchers, standing sets of transformations (SSTs) instantiated in genre assemblages offer a useful lens through which to study documentation processes as essential research infrastructure for big science. In some ways, SSTs are akin to stations on a rhetorical assembly line. They do rhetorical work that has been codified within the context of the social action that the assemblage's genres enact within a community or organization. For example, as a rhetorical product (e.g., a pitch argument for a new technology company) bobs down the assembly line of genres, it is successfully revised and refined as essential stakeholders (e.g., investors, customers) in the project are allied, or interested, with it (Spinuzzi et. al, 2018, p. 7).

SSTs are essential to complex systems because they bring relative stability and predictability to the processes that they mediate (Spinuzzi, 2010; Spinuzzi et. al, 2018). In other words, one of their functions is to mitigate threats to the success of a complex project. SSTs mitigate uncertainty, and the risks that uncertainty creates, via reliable processes of rhetorical transformation that result in rhetorical settlements, or negotiated alliances among essential actors. Over time, succeeding rhetorical settlements "become a set of accretions that [are] hardened into operational procedures…" (Spinuzzi, 2008, p. 97) that, I would argue, function as

an infrastructure. Making visible these SSTs and the genres of documents that instantiate them foregrounds for scholars and stakeholders in industry how documents and documentation processes that have normalized into tacit operational procedures remain critical sites of negotiation upon which the success of a project depends.

Similar to that of genre assemblages and SSTs, Sauer's (2003) ethnographic study of how documentation rhetorically mitigates uncertainty and risk in the mining industry offers another foundation for studying the rhetorical fate of uncertainty in large industrial environments. Sauer documented how miner's experiences in a hazardous work environment are rhetorically transformed across six moments in a document cycle (accident reports, statistical reports, policy and regulations, practices and procedures and training procedures) that incrementally transform the miners' individual experience of risk into changes in training procedures that will improve safety in the mine. Over time the rhetorical settlements accrete, or accumulate in successive layers that create stability, to become part of the history of the industry and, ideally, an improvement in safety for miners.

Although Sauer's study was focused on a different type of risk than I take up in this study, that is the health and environmental risks of working in a hazardous environment rather than the financial, technological and political uncertainties of complex organizations and projects (see Jardine & Hrudey, 1997 for types of risk, including uncertainty), the rhetorical mechanics of Sauer's "Cycle of Technical Documentation in Large Regulatory Industries" (p. 66) are similar to that of genre assemblages and SST's. Both analytical constructs serve as lenses for making material successive "moments" (p. 76) of rhetorical negotiation in complex, multi-document processes. However, while Sauer's model focuses primarily on the transformation of the documents' content, SST's foundation in actor-network theory places the focus of rhetorical

transformation on the goal to ally essential actors to the project. In addition, the origins of SST's within the context of genre study, with its focus on bringing stability and predictability to otherwise rhetorically chaotic processes, foregrounds for writing researchers how genre assemblages, and the SST's they instantiate, function as infrastructure for a broader socio-technical network of which a complex project of big science is an outcome. Without this genre infrastructure and its machine-like power to enroll key stakeholders, big science may not happen at all.

Risk as an Explicit Concern of Management

Given that risk is an explicit concern of management in industry, an obvious starting place for the study of documentation processes that mediate uncertainty at the supercomputing center may initially appear to be the Risk Management Plan (RMP). The RMP documents the formal process of Enterprise Risk Management (ERM), which is an approach to "organiz[ing] uncertainty" (Arena, et. al, 2010, p. 659) broadly adopted by risk-adverse enterprises in government and industry, including the Department of Energy (DOE). ERM emerged in the 1990s in response to changes in the competitive environment, including the increasing exposure of enterprises to complex global economic and political forces (Arena, et. al, 2010). ERM considers risks such as financial exposure, information system interruptions, fraud, client bankruptcies and regulatory change (p. 660).

At the supercomputing center, the RMP manages project risks (for machines in development) and steady-state, or operating, risks (for machines that are up and running) via a formalized process that follows the ERM model and directives set by the DOE. As the Advisor

to the Director of the supercomputing facility said in an interview, "[DOE] will do anything to avoid having anything unexpected happen to them." She went on to explain that risk in this context does not equal worker or facility safety—a completely different area of concern overseen largely by the national laboratory's facilities management department. She further clarified that risk means "situations that in some way impact the [supercomputing facility's] ability to meet the needs of the user, either financial impact, operation of the machine, performance of the machine, having the machine available because our power fails or cooling system fails and so forth." In other words, the RMP manages risk at what we might call a meta-level by creating a model that incorporates all of the processes that go into building and operating a supercomputer, such as the ones this study documents in detail.

The RMP (or ERM) is not, however, the explicit focus of this study, even though formal risk management plays a role in the project development and management of the supercomputing center. This study focuses, by design, on document processes that are not already explicitly or conventionally primarily understood by Writing Studies researchers or by industry stakeholders as related to risk management or communication. ERM, and risk management in general, is a prolific area of research in academic fields such as accounting and management studies, and senior management at the supercomputing center would already have exposure to this literature. Instead, this study took up Bowker and Star's (1999) notion of infrastructural inversion as a project to "look closely at technologies and arrangements that, by design and by habit, tend to fade into the woodwork" (p. 34). For writing researchers, this means revisiting common industrial documentation processes that have low-visibility outside of the immediate work context with lenses that "give them causal prominence" in contexts that otherwise attribute

technological achievements to "heroic actors" over seemingly inert reports, spreadsheets and other genres of technical writing (p. 34).

Study Design and Method

The Study

The field work reported in this article is part of a larger study, conducted 2014-2016, that explored technical reporting and documentation processes at a supercomputing center at a Department of Energy (DOE) funded national laboratory near Chicago, Illinois. Data were gathered under the auspices of the Institutional Review Board at DePaul University. The center serves scientists from around the world who are granted time on the supercomputer to process data for developing models of scientific phenomena, such as climate-related models, air turbulence over an aircraft wing and the flow patterns of a new, more environmentally friendly form of concrete. Around 85 staff work at the facility and their jobs range in function from the strategic and political work of the director and senior management to the daily maintenance of the machine and its supporting systems.

The main aim of the study was to document the reporting processes that supported the development and operations of the facility for the purpose of making this information available for strategic decision making by center staff and to demonstrate the value of these reports for the facility. During the period of fieldwork, 25 facility staff were interviewed and the audio files transcribed in full, over 500 pages of documents were gathered and catalogued, and I did over a hundred hours of on-site informal observation, most of it sitting in a cubicle waiting to interview staff or attend meetings. The main focus of data collection was an annual operational review process that the facility undertook with its funder, the DOE, to renew its funding. Data were

coded and analyzed incrementally, resulting in a series of papers reporting on portions of the study (Read, 2018, 2019; Read & Papka, 2014, 2016, 2017).

The accounts of the documentation processes discussed in this article are reconstructed from five interviews with facility staff during a second round of interviews that focused on what I had come to understand as "infrastructural" writing. The construct of infrastructural writing originated in a first-round interview with a systems administrator who referred repeatedly to the computing "infrastructure" that he maintains in order to ensure that science gets done on the machine. I approach "infrastructure" (Read, 2019) as a term commonly applied in a computing context to standards, software and hardware as a metaphor that in common use entails an underlying foundation that enables work or activity but that also has relational entailments that expand infrastructure beyond a material substrate (Dourish & Bell, 2011, Star & Ruhleder, 1996). The metaphor of infrastructure, however, has not been as systematically developed to apply to documentation, and the second round of interviews aimed to gather data to do just that. These interviews specifically aimed to garner explanations from staff who managed document processes mentioned during the first round that had potential as infrastructural documentation processes. These documentation process had caught my eye because the mission of the supercomputing center seemed to depend upon them even though they were not explicitly viewed in this light by staff. These document processes included user agreements, multi-division DOE review processes, IT documentation, lease agreements, and project management. The latter two—lease agreements and project management—are the focus of this article.

While the supercomputing facility is publicly-funded and so subject to the Freedom of Information Act, I was limited in my access to documentation that had not been formally published for public circulation. This was particularly the case for the documentation processes

that are the subject of this article, which were largely outside of the annual reporting processes that I was directly authorized to study. As such, much of my documentation of the less public writing products and processes at the facility relies heavily on accounts recorded in interviews with staff or my observation of documents on a screen. This lack of access to the documentation itself limits the analytical work that can be done with these artifacts primarily to description in the words of the staff interviewed. In fact, the accounts of documentation processes that I examine in this article are written largely in the transcribed words of the staff interviewed, although only quotes with special significance are attributed since no single person owns the processes described here.

As a theory-making project, and similar to previous arguments I have made about theory in Writing Studies (Read, 2016; Read, 2015; Read & Swarts, 2015), this article is the product of a methodology through which insight is gleaned inductively from experiences, interviews and artifacts gathered during fieldwork. I understand theory development as a process of documentation and operationalization of field-specific knowledge during which the specialized training of the researcher is dialogically engaged with the voices and artifacts gathered at the field site. The product of this theory-making process is not a model that claims to reflect a stable reality at the field site (although it should be recognizable to study participants); rather, the product is a theoretical tool that has utility for researchers and study collaborators. With these tools, researchers are better able to translate the often-tacit professional writing practices and knowledge of study participants into explicit, documented knowledge that ultimately contributes to what we know about writing more generally. Site collaborators take away a greater knowledge of their organizational writing processes that they can use for strategic decision making.

How Documents Build A Supercomputer

This section will deploy the analytical construct of standing sets of transformations (SSTs) instantiated in genre assemblages to show how two document processes rhetorically transform the financial, technological and political uncertainties that are constant threats to building a supercomputer. Within this framework, financing and project management are both sites, or nodes (Spinuzzi, 2008, p. 49), of rhetorical transformation where rhetorical-political settlements are negotiated and then inscribed to mediate the alliance of key actors with the project (e.g., a bank, a reasonable interest rate, a working chip design). Taming unquantified uncertainties into known and acceptable risks requires inscription (Latour, 1987; Latour & Woolgar, 1986), so that the negotiated settlements can be circulated among stakeholders for discussion, review and, ultimately, codification. Documentation processes, therefore, are a natural site of study for risk mitigation.

Neither of the genre assemblages documented in this section are commonly studied within Writing Studies research. Bringing financing, lease negotiation and project management within the purview of Writing Studies broadens our notion of what counts as writing and also moves our study of writing in organizational environments closer to the documents that might be part of what Susan Leigh Star (1999) counted among the "boring things," or "accretions that have hardened into operational procedures" (Spinuzzi, 2008, p. 97) that function as the infrastructure for much of life, especially in the socio-technical realm.

In order for a new supercomputer to be built, or "stood up," at least two risks must be satisfactorily resolved so that key stakeholders can be allied:

1. The money to pay for it must be secured on favorable terms (financing) (Fig. 2)

2. The development and construction of the supercomputer must be coordinated to fit a given budget and timeframe (project management) (Fig. 3)

INSERT FIGURE 2 ABOUT HERE

INSERT FIGURE 3 ABOUT HERE

Risk #1: Can it be financed? The money to pay for the supercomputer must be secured on favorable terms

Getting a loan to buy anything is always a process of negotiation and trust building. The bigger the loan and the more complex and varied the uncertainties that affect how and when the loan will be repaid, the longer and more complex the process of negotiation. The negotiation cannot end until both parties feel that the risk inherent to the transaction is acceptable to them. Whether it is a student applying for a credit card ($10,000 or less in credit), a first-time home owner applying for a mortgage ($100,000-$300,000) or a national laboratory securing financing for a new supercomputer ($100 million), the negotiation of trust is underwritten by a slew of documents, each of which contributes in some way to reducing the uncertainties that might discourage either party from completing the deal. For the negotiation of a financing agreement to purchase a supercomputer, these documents include: the purchase agreement with the

manufacturer of the computer, a due diligence package, a preliminary lease agreement, a financing agreement, and spreadsheet financial tools for bid analysis.

In a rational banking system, no bank will lend the money for a home mortgage to a hopeful homeowner who cannot establish themselves as credit worthy. The same is true for national laboratories and some of those same big banks. But in the business of procuring and building supercomputers, there is an additional wrinkle—the risk that the bank takes on is not limited to the credit worthiness of the customer. Unlike a house, which is either already built or likely to be built using tried and true building technology and designs, a next generation supercomputer will be built using technology and materials that are still under development and may not yet be proven to work as specified. Whether the supercomputer can be built to the original technical specifications and on time is an additional arena of uncertainty that must be mitigated in the process of securing financing for the supercomputer. What this means is that the terms of the financing and the technical specifications of the supercomputer are interdependent. According to the finance advisor at the supercomputing center, it's a simple relationship:

> "How much money we have impacts the size of the machine. If we're spending a lot on interest [for a bank loan] it means we get less machine."

During the initial process of securing financing for a lease on a new supercomputer, however, the processes of determining the technical specifications of the machine and the terms of the loan for financing are separated. This is because the banking institution originating the loan does not have an interest in the technical aspects of the machine. Their only interest is the credit-worthiness of the national laboratory applying for the loan. However, although the technical specifications and

the negotiation to secure a favorable interest rate and terms for repayment are initially independent, once there is a preliminary agreement on a bid for a loan the technical specifications may come into play in the negotiation of the final terms of the loan. This is because when a new supercomputing machine is delivered by the vendor, one of the world's leading chip manufacturers, it must go through a series of tests to ensure that it meets the technical specifications that were initially agreed upon with the machine's vendor in the purchase agreement. If the machine fails on certain specifications, which would not be wholly unexpected given the cutting- edge nature of the technology, then this is grounds for renegotiating the price of the machine with the vendor. Renegotiating the price of the machine changes the amount of principal for the loan and also the timeframe for repayment if the acceptance date of the machine is pushed back, and this can affect the interest rate as well. Although initially the negotiation of the loan terms is separated from the technical specifications of the machine, the extent to which the machine's vendor is able to deliver a machine that meets those specifications within the agreed upon time period ultimately affects the final conditions of the loan.

The rhetorical settlements that must accrete to mitigate the financial risks inherent to procuring a supercomputer are [Fig. 2]:

1. The trustworthiness (credit worthiness) of the national laboratory to make good on the loan.
2. Acceptable financial terms for the loan (including the amount of principal, the interest rate and the rate and time frame of repayment).

3. Demonstrated viability of the new technology and its ability to function to specification within the project timeframe.

A closer look at each area of risk reveals the documentation processes that mediate the rhetorical settlements that in turn enable the alliance of key actors.

Rhetorical Settlement 1: Trustworthiness

The trustworthiness of the national laboratory is the first rhetorical settlement [Fig. 2, Risk 1] that must accrete in order to satisfactorily mitigate the financial risks of building the supercomputer. According to the finance advisor at the supercomputing center, trust is the most important element in a finance deal: "It comes down to trust on both sides. Do I trust that they are going to deliver the cash when I need it and do they trust that we will pay it back? There's no document that you can produce that will guarantee either of those." True, there is no document that can substitute for the most fragile and essential element of relationships, but documents can and do inscribe rhetorical settlements upon which trust is founded. The national laboratory establishes its trustworthiness with financial institutions to take on a large financial liability via a document process called the *due diligence process*.

The due diligence process is mediated by a packet of materials that includes financial reports, biographies and information about who works at the laboratory and how these people have successfully built supercomputers before. These materials must explain how national laboratories are funded and why investing in them is a safe investment. Collectively, they must

persuade the top executives at a banking institution, called the credit committee, that the laboratory is trustworthy enough to take on a loan of $50 million to $100 million, or more.

The bank credit committee makes its decision based on its assessment of the case that is presented by the front-line loan officers. The loan officers have been working directly with the personnel in the procurement department at the national laboratory to begin the bid process for the loan. Given that it is likely that this banking institution does not specialize in funding supercomputing projects, these front-line loan officers have a hefty job of persuasion: to make an unknown and mysterious entity (the national laboratory) into a knowable and trustworthy one— as opposed to an organization, in the words of the finance advisor, "where we have a bunch of incompetence and failure." And there is a lot at stake: the safer the bet the laboratory appears to be for the bank, the better the financing terms will be for the laboratory.

Rhetorical Settlement 2: Acceptable Financial Terms

Acceptable terms for the loan are the second rhetorical settlement [Fig. 2, Risk 2] that must accrete in order fully mitigate the financial risks of building the supercomputer. These are negotiated and codified via standing sets of transformations instantiated in an assemblage of genres that includes a type of loan document, a preliminary master lease agreement, as well as an invitation to bid on a lease, financial analysis tools, and the financing/purchasing agreement. The rhetorical settlements that must be inscribed and accrete to move along the supercomputer project are acceptable financial terms, which include the amount of principal, the interest rate and the rate and time frame of repayment.

A lease might be the legal document that most adults have encountered or signed (whether for an apartment, a car, or a supercomputer) but that few have read closely in its

entirety. Yet, lease documents and mortgage documents mediate the highest-risk financial transactions that most people ever encounter in their own personal lives. One reason a lease document makes dry reading is that the majority of the terms of the lease are common to all similar leases and only a few terms are actually open for negotiation (when it comes to apartment leases, cities often have boilerplate forms with only a few fill-in-the blank lines for the negotiable items, such as the monthly rent and the term of the lease). Most of the terms on the lease form a foundation that have been previously negotiated in arenas now distant in time and place from the current transaction. This is usually a good thing, because those standardized elements have been worked out by advocates of both the lessee and the lessor to stabilize and minimize the risk of both parties and to ensure a measure of equity across all similar lease negotiations.

In the case of procuring a supercomputer, which is among the riskier transactions that the national laboratory would engage in because of the large amount of money involved, the situation is not all that much different from other, typical leases. Much of the language on the lease is standardized before the negotiation of the highest-risk terms of the lease, including the amount of principal and the interest rate, begins. The document that inscribes these standardized items is called the *preliminary master lease agreement,* which is a generic lease document that states all the general terms for the lease. All of the financial institutions that want to qualify to make a bid to finance the machine must sign the preliminary master lease agreement before the bid process is started in order to signal that they accept those terms as a foundation for further negotiation.

The next document that goes out from the procurement department at the laboratory is the invitation to bid on the lease. This document goes out to all of the "qualified" banking

institutions that have declared themselves by signing the preliminary master lease agreement. The invitation includes the specifications of the kind of financing deal that the lab is looking for: the amount of money, the length of the lease and the interest rate. Then the banks submit their bid and the laboratory culls the list to a manageable number, around half a dozen.

Once the list has been culled, a writing-intensive part of the process begins as negotiation for the terms of the loan proceeds in earnest, and the seriousness of the bidders is tested by the laboratory. The finance advisor characterized this phase in the following way: "Okay, you're on our short list. Do you want to sharpen your pencil with respect to your bid?" During the negotiation back and forth, emails and document sharing mediate phone calls and meetings between the bidding financial institutions and the national laboratory. Sharpening a pencil is an apt metaphor for a negotiation during which both parties are assessing the amount of risk involved and insisting on even better terms for themselves. Pushing too hard for better terms, especially if the rhetorical settlement of trust has not fully accreted, could break off the tip of the pencil and end the negotiation and the possibility of a deal.

One of the purposes (and advantages) of a multi-step, multi-document bid process is that it takes a long time and as time passes the amount of risk can decrease for both parties. In Figures 1 and 2, time is a vector across the top of the table because time and risk are deeply interdependent in projects at the cutting edge of technology. Most essentially, advances in the development of the new computing technology that creates the value in the new supercomputer make the delivery of the machine on time and to specification more likely. Money market conditions may also have changed to make interest rates more favorable for the laboratory (of course the reverse can also be true). When the laboratory gets the bids, they look at how they vary and use their financial tools to try and figure out which bid is the best deal. The bids can

vary in a number of ways. Some have upfront fees, but lower interest rates; or, if the term of repayment is shorter, the interest rate may be lower. In order to assess which bid is best, the finance advisor has developed analytical tools for playing out all of the bid scenarios for the laboratory and to determine which one presents the least risk. Using his spreadsheet financial analysis tools, he is able to document, with a 90% confidence level, that given all of the uncertainties in a financing scenario (e.g, changes in the market that affect the interest rate and the future cost of electricity, since the machine consumes *a lot* of it), the laboratory will be able to make good on the deal, and that the terms of the deal won't unduly restrict the mission of the supercomputing center.

In the end, the successful bidder and the laboratory signs another document, a financing agreement that says, in the words of the Finance Advisor, "We're giving you $100 million. You're going to pay it back and you're going to pay it on this schedule." Despite the large amount of money of the agreement that is reached, the final document is actually quite short, about the same number of pages as a home mortgage. This brevity belies the reams of supporting documentation, including all of the legalese required to protect both party's interests that was already agreed up on with the signing of the preliminary master lease agreement. By the time the final agreement is brokered, trust has already been built on the foundation of the mutual consent to those previous terms.

As a brief thought experiment to underscore the essential function of these documents and the standing sets of transformations they instantiate, imagine how this lease negotiation process would proceed without inscription in written documentation of any kind, but with only oral communication. How would financial officers at the national laboratory solicit, collect and negotiate leases with six banks? How would they keep it straight which bank offered which

terms for the lease? How would the finance advisor analyze the strengths of the offers? In their head? While this exercise might seem simplistic, it recalls for us the broader history of the development of writing and documentation and how the growth of modern economies and bureaucracies relied on writing technology to coordinate massive amounts of resources and people to keep a record of these expenditures. Big science is largely enabled by the mature development of modern economies and bureaucracies that have become so efficient at creating documentation infrastructures to coordinate massive amounts of resources, technologies and people and to mitigate the uncertainty inherent to such enterprises.

Rhetorical Settlement 3: Demonstrated Viability

The demonstrated viability of the new technology and the successful development and delivery of the supercomputer to specification constitute the third rhetorical settlement [Fig. 2, Risk 3] that must accrete in order to satisfactorily mitigate the financial risks of building the supercomputer. However, discovery and innovation in science and technology is, by nature, more or less impossible to pin to a financing or production schedule. For example, the Large Hadron Collider particle accelerator was conceived of in 1984 and not run at full energy for research purposes until 2010, after multiple delays due to budgetary and technical problems. Despite the recalcitrance of innovation of bleeding edge technology to adhere to a time schedule, an unknown or unlimited time frame for building the supercomputer presents unacceptable risks for all of its stakeholders. The laboratory needs to know when to promise scientists that the new machine will be available for use, the bank needs to know when the technology is certain enough that it can release the money to pay for it, and the chip manufacturing company developing the

machine must know when it will make the sale of the computer to the laboratory so that it can report the sale (which is sizable, even for a globally important technology company) in its earnings. Time and risk are, again, deeply interdependent.

While some of the risks of building a supercomputer are satisfactorily mitigated during the negotiation to secure financing for the supercomputer (such as the laboratory's trustworthiness), wrangling time in order to reduce uncertainty and its attendant risks for stakeholders, or perhaps, thought of in a more positive light, to generate certainty, is an area of professional expertise that supports the process of building a supercomputer: project management. This second major area of risk mitigation merits its own discussion.

Risk #2: The development and construction of the supercomputer must be coordinated to fit a given budget and timeframe

Project management has not often been discussed or formally researched as a form of writing or documentation within Writing Studies, except as an aspect of technical communicators' practice (e.g., Lauren, 2018; Hackos, 2007) or technical and professional writing pedagogy (Pope-Ruark, 2015); yet, at the same time, it is arguably the single-most essential site for coordinating and enabling the large-scale projects of big science. When "big" is understood to mean "expansion on many axes" (Galison & Hevly, 1992, p.2), meaning that projects might have impact on whole regions, budgets of millions or billions of dollars and depend on the investment of multiple nations, the sheer complexity of coordinating this many often competing stakeholders against a fixed budget and timeframe becomes apparent. Without a site to codify and stabilize the negotiated agreements regarding the development of a large project and a way to track the

progress of the project against time, budget and other factors in a principled, validated way, large engineering projects of any kind (including large buildings that have been built many times before) would have a hard time proceeding and/or coming to fruition.

At the supercomputing facility, I observed the project manager for the development of the new supercomputer sitting, like me, at a computer in a cubicle outside of the office of the deputy director of the facility. It struck me as incredible that the labor to coordinate such a complex project was almost entirely symbolic analytic work (Johnson-Eilola, 1996) that relied on the power and strength of inscribed and circulated rhetorical settlements to manage the constant risks that might otherwise obstruct the progress of the project. In an interview he explained to me how he does his work: most simply put, "there's documents for everything."

When building a new supercomputer, it is the job of the project manager to track progress and to manage risks as they emerge within the inscribed environment of the project management software. As a professional endeavor, project management has its own standards, body of knowledge and lexicon (Project Management Institute [PMI]), theory, best practices, certification processes and controversies that require extensive training and experience to master. However, in the simplest terms, project management is a principled approach to tracking progress on a project against its budget, timeline, scope and other factors. The careful tracking of progress ensures that the project stays in compliance with what the major stakeholders, such as the funder (the Department of Energy (DOE)) and the contractors, have already negotiated as acceptable parameters for deviation from the plan. In the simplest terms, more deviation means higher risk for the success of the project.

For writing researchers, viewing project management as a genre assemblage focuses our attention on the negotiated rhetorical settlements that are the outcomes of project management

documentation processes. Each of these rhetorical settlements accretes to mitigate an uncertainty that might otherwise overwhelm a project to build a new supercomputer. The rhetorical settlements related to project management risks documented in this study are [Fig. 3]:

1. Defined parameters for compliance to remain in good standing
2. Compliant relationships between budget/time/progress
3. Continuing stakeholder (funder) support of the project

A closer look at each area of risk reveals the documentation processes that mediate the rhetorical settlements that enable the alliance of key actors.

Rhetorical Settlement 1: Defined Parameters for Compliance

Defined parameters for what counts as compliance in order to remain in good standing with project stakeholders [Fig. 3, Risk 1] are the first rhetorical settlement that must accrete in order to satisfactorily mitigate the project management risks of building the supercomputer. As discussed above, building a new supercomputer is rife with uncertainty not only because it is a complex process with many moving parts, but also because the supercomputer depends on chip technology that is still in development. It might seem more practical that the supercomputer would not be approved for purchase until the chip technology had actually been developed and proved functional by one of the world's leading chip manufacturers. But this is not how it works, because in that case all of the risk for developing the new chip would be placed on the chip manufacturer and there would not be a good business reason for the company to take on such a

risk. On the contrary, modern big science has been able to be successful via creative partnerships between public and commercial partners in order to control costs without disabling the opportunities for innovative breakthroughs (Boisot, 2011, p.116-134).

Because the risks of the development of the new chip technology cannot be eliminated before a commitment to build the new machine is made, these risks are folded into the project of building the new supercomputer. What this means is that the uncertainty around the timeline on which the new technology can be developed is accommodated by a document called the *project execution plan* (PEP). The PEP is a long document (around 100 pages) that codifies the compliance parameters of the project. The PEP document is the outcome of negotiations between the federal funding agency and the administration at the national laboratory and the supercomputing center. It is the governing document that determines the parameters for measuring compliance and that sets out objectives for the project and how they will be accomplished. The document is thorough and meticulous at breaking down the steps of the project by section so that no step is left unknown. Extra time is allotted as a buffer for steps, such as chip development, that are difficult to control. Another important outcome of this document is transparency, which is essential for maintaining the alliance of taxpayers to the project via the documentation of the national laboratory's legitimacy and credibility.

This also means that the project plan doesn't only include steps in the project that are about the physical installation of the machine. Far from it—included in the plan, which spans several years of work, are steps that involve upgrading the utilities at the supercomputing center in order to accommodate a machine that uses more power than previous machines, teams of software engineers who develop software that can run on the new chip and test it using simulated environments provided by the chip manufacturer, and efforts at education and training so that

when the computer comes online it can be put to use right away. While, in essence, at the point

of initial agreement to purchase the machine, it cannot yet be built, all of the stakeholders agree

that risks inherent to developing the new machine have been satisfactorily mitigated in the

project execution plan. As long as an acceptable level of risk is maintained, arguments cannot be

marshalled that would impede the progress of the project.

Since project management is, by definition, a principled approach to managing projects,

the principles that guide a project vary by industry, project-scale and type. Therefore, a large-

scale project is managed based upon a set of principles that have been agreed upon prior to the

project beginning. In the context of the national laboratories, a set of principles have been

previously codified as a part of the nation's research infrastructure in a manual called *Earned*

Value Management System and Project Management Standard Operating Procedure

(Department of Energy, Office of Acquisition and Project Management). As a set of principles

and guidelines developed originally by the United States Air Force, Earned Value Management

System (EVMS) guides the project management of many public projects. One of the goals of

EVMS is transparency, which is important when public money is being used to ensure that trust

is maintained with the public and its political proxies. The objectives of EVMS include:

- *Relate* time phased budgets to specific contract tasks and/or statements of work.

- Provide the basis to capture work progress assessments *against the baseline plan*.

- *Relate* technical, schedule, and cost performance.

- Provide valid, timely, and auditable data/information for proactive management action.

- Supply managers with a practical level of summarization for effective decision making.

  (from Humphrey's Associates, *EVMS Education Center Basic Concepts of Earned Value*

Management (EVM), pdf downloaded from Humphreys-assoc.com 9/23/16, my

emphasis).

While these objectives are difficult to understand in the abstract, notice how the fundamental

notion underwriting them is the relationships among elements of the project (e.g., "relate,"

"against the baseline plan"). In an EVMS project management plan, the complex relationships

between budget, time, and project progress, including planned project progress and actual and

future project progress are tracked in a type of chart called a matrix. One of the advantages of a

standardized set of principles for project management is that a project's progress can be defined

against a standard that is already acceptable to the federal funding agency. Importantly, unlike

many commercial building projects, EVMS matrixes don't incentivize contractors to finish

projects either under budget or ahead of schedule—and this on purpose. For most public projects,

the ideal is to transparently meet budget and timeline projections right on target, since public

funders usually don't have a mechanism to take money back from a project once that money has

been allocated to be spent in a certain way.

Rhetorical Settlement 2: Compliant Relationships

Compliant relationships between the three axes of budget, time and progress [Fig. 3, Risk

2] are the second rhetorical settlement that must accrete in order to satisfactorily mitigate the

project management risks of building the supercomputer. The careful tracking of a project's

progress against its budget and its timeline is often inscribed via a commercially available

enterprise software program, such as Oracle's Primavera or Microsoft Project, by a project

manager with professional training to manage projects of this scale. Initially, every single step of the project is entered into the program by the control account manager (CAM) responsible for any given part of the project (and in a large project, there would be many CAMs), including information about each step's start and completion times and budget situation. As the project moves forward, progress can be tracked via tools in the software for visualizing relationships among elements of the project. These visualization tools make it possible to assess when steps are out of compliance given the negotiated parameters for what is an acceptable rate of progress given time and budget constraints. What is considered an acceptable tolerance for being out of compliance is a previously negotiated quantity codified in the project execution plan (PEP) and expressed in terms of plus or minus a number of percentage points.

One of the more commonly known types of inscriptions that enable project managers to track progress against time is called a Gantt chart, after the engineer who invented them in the early 20th century, Henry Gantt. A Gantt chart is a horizontal bar chart that visualizes activities, or steps, of a project displayed against the time interval planned for each step. As the project proceeds, the status of each step of the project is kept up to date so that it becomes visible which steps are out of compliance. The project manager for the new supercomputer explained that a step is out of compliance when its bar turns red. A step can be out of compliance for several reasons: 1. if it is behind schedule, 2. if it is ahead of schedule, or 3. if it is either over or under budget based on the parameters that have been determined as acceptable for this project. In this way the progress on the project is objectified (Callon, 1986), or codified and stabilized, so that its status can be circulated among the CAMS who each oversee small slices of it. For example, the data center floor manager oversees the installation of the cooling and electrical systems for the new machine, and the Early Science Program manager oversees the development of new

software for the chip. Once the CAMs can see how their portions of the project are out of compliance, they can be held accountable for bringing them back into compliance or for coming up with arguments to justify their status. In this way the Gantt chart mediates between the abstracted, data-centric work of project management and the creative and material work of building the new supercomputer.

Rhetorical Settlement 3: Continuing Stakeholder Support

Continuing stakeholder support of the project [Fig. 3, Risk 3], in particular that of the funder (DOE), is the third rhetorical settlement that must accrete in order fully mitigate the project management risks of building the supercomputer. In EVMS, maintaining relationships among elements of the project includes relationships among people and the data they need to maintain their stake in the project. One of the EVMS principles is to provide valid, timely, and auditable data/information for proactive management action. In other words, project management of a complicated engineering project relies on data about the project being accessible to those who need it when they need it. This access is maintained via formal documentation and reporting processes unique to particular organizational environments, such as the Department of Energy's (DOE) Risk Management Plan described above, but also at a more abstract level by the practice of project management itself.

The importance of inscription to project management, and of project management to project success, is a fact that the companies that develop and sell the most common project management software systems know well. On the website of a well-known software company, an infographic in the sales materials poses the question, "Now, where is my data?" The problem

is summed up under a heading that reads, "The issue with word of mouth: Information is needed by all parties in large maintenance, engineering, and construction projects. But where is it? Does Bob have this information on his notepad? But where is Bob and how will this information be shared if there isn't one source?" According to the infographic, the implications for keeping all of the project information in the mind or the personal computer of one person are disastrous—in fact, the project will crumble like a teetering tower built from play wooden blocks. This illustration recalls the thought experiment above about managing a bid process with no way to write anything down.

Once the project begins, agreement is maintained that the project is on track via the circulation of a status report document called a contract performance report. These reports maintain agreement among stakeholders and with the funder (DOE) that the project is on track within the previously negotiated parameters in the project execution plan (PEP). These monthly reports show trends in the cost index and the schedule index and map budgeted costs and actual costs into the future. Aspects of the project in alignment with the negotiated parameters earn the value of 1. Steps that are out of alignment must fall within the acceptable parameters (either plus or minus an amount from 1) for the project. If they extend beyond these parameters, then they turn up as red bars and a corrective action plan is sought. Any change to the parameters generates more documentation. As the project manager interviewed at the supercomputing facility said about what happens when parameters change, "It will be documented."

Discussion

This section closes the circle on the argument I have been developing about big science, the

functions of writing for technical organizations, mitigating uncertainty, and infrastructure. I do this by connecting the existing US research infrastructure with "infrastructure" as a metaphor for technical documentation and reporting processes in the context of big science and more broadly. Simply put, I argue that the essential function of the technical documents that comprise the genre assemblages in Figs. 2 and 3 to mitigate the uncertainty of building a new supercomputer suggest that they, too, are part of what science policy scholars recognize as the national research infrastructure (Jacob & Hallonsten, 2012, p. 412). Foregrounding documentation that normally hides in the background of the activities of high-performance computing undertakes a project of infrastructural inversion (Bowker and Star, 1999) with the goal of ascribing "causal prominence" (p. 34) to documents that have low-visibility outside the immediate work context. While it might seem more appealing to study the published products of science produced with the help of the machine, such as beautiful data visualizations of climate models or protein structures, this study has purposefully focused on the documents that enable the mission of the supercomputing center. For Writing Studies, one point of interest in this argument is the potential to theorize what it means to define technical reporting and documentation processes as infrastructure at a more general level and to consider the implications of this definition for contexts beyond the supercomputer and the US national laboratory system.

To speak of writing as "infrastructural" offers a new rhetorical commonplace for discussing the functions of writing in Writing Studies research and new opportunities to define what it means in conjunction with more established theoretical approaches, including rhetorical genre studies (RGS) and actor-network theory (ANT), particularly as they have been discussed in this article. A theory of infrastructure for Writing Studies proceeds from prior research (Hart-Davidson, et. al., 2007; Frith, 2020; Grabill, 2007, 2010; Read, 2015; Swarts, 2010) that has set

precedence by importing notions of infrastructure from the extensive scholarship done in information studies by Susan Leigh Star and her colleagues (e.g., Bowker & Star, 1999; Star & Ruhleder, 1996). Star's body of work develops a relational theory of infrastructure that explains how information standards, which are negotiated, inscribed in and circulated via documents, enable much of our daily experience, such as the electrical grid and the internet. However, in previous research the application of the notion of infrastructure to writing has not been consistent or developed sufficiently enough to account for how writing products and processes are different from information. A theory of infrastructure for Writing Studies synthesizes elements of Star's relational theory, such as a functional definition and a focus on relationships among actors (ANT), with established theories and approaches, including what we count as writing and genre theory.

For Writing Studies, a theory of infrastructure (Read, 2019) begins with a commitment to an inclusive definition of writing, including, as Winsor (1992) helpfully articulated, writing that does not include words, does not require the direct presence of human being and that is not the product of the free creation of meaning. In the genre assemblages illustrated by Figs. 2 and 3, several of the documents rely on just such an inclusive conceptualization of writing. In Fig. 2 this includes financial analysis tools (i.e., spreadsheets), financial reports and machine specifications. In Fig. 3 this includes project management matrices, Gantt charts and other project management software interfaces. How writing is defined makes different kinds of inscriptions either visible or invisible to the writing researcher. To follow through on a project of infrastructural inversion requires adopting the broadest possible definition of what counts as writing.

A relational theory of infrastructure also relies on a functional definition for what counts as infrastructure. This means that what counts as infrastructural is defined by what the document

or genre actually does for the community (i.e., its social action) for which it has meaning, not by material characteristics, such as number of pages, format or a glossy presentation, or bureaucratic fiat. In Fig. 2, a preliminary master lease agreement must be signed before a financial institution can be invited to submit a bid to finance the new supercomputer. Signing the document signals agreement with the non-negotiable terms of the lease before negotiated terms, such as interest rate and repayment timeline, can be discussed. In Fig. 3, a project execution plan (PEP) has an infrastructural function because it codifies the compliance parameters of the project and the steps required to complete it that have been negotiated by the federal funding agency and the administration at the national laboratory and the supercomputing center. Without such a codified agreement it would not be possible to move forward with building a new supercomputer, which includes maintaining compliance in order to continue to receive project funding. By contrast, consider documentation processes that were created to be infrastructural, but have failed to be so, such as environmental impact statements (Miller, 2015), or, I might argue, the strategic plan of a university, where turnover at the upper-level administration and on the board of trustees has left it without a champion.

While Star did not develop her relational theory of infrastructure within the context of genre studies, her model invites a synthesis with Writing Studies' notion of genre as social action. Genre is an analytical construct that helps make causal connections between the formal, discursive and rhetorical aspects of a text and the social, political and technological context that it both constitutes and is created by. In this article, the added dimension of genre assemblages as instantiations of standing sets of transformations (SSTs) has revealed one of the mechanisms of these causal relationships that are so useful for a project of infrastructural inversion.

The original 8 "dimensions" (Star & Ruhleder, 1996) of infrastructure already resonate

strongly with how we tend to understand genre in Writing Studies: infrastructure is sunk into other structures, social arrangements and technologies; infrastructure is incorporated into tacit practices; infrastructure is learned as part of community membership; and, infrastructure both shapes and is shaped by the conventions of a community of practice (p. 113). In fact, genre is effectively already a theory of infrastructure for writing, although it has not previously been explicitly theorized as such. A genre from Fig. 3 that is useful to consider in light of genre theory is the contract performance report, which is a periodically issued status report on the progress of building a new supercomputer. In technical organizations, reporting documents tend to be viewed as static, after-the-fact documentation of what has already happened rather than as dynamic documents on which future contingencies rely, such as maintaining the trust of the funder and the project funding. In this case genre theory, and by extension a relational theory of infrastructure, is a useful analytical tool for articulating how even reporting documentation continues to enact social action during the complete cycle of authorship, circulation and archiving.

Finally, Star's development of a relational theory of infrastructure within the context of actor-network theory (ANT) has useful ramifications for Writing Studies researchers. In short, ANT focuses the attention of research on the relationships between objects and people (actors) and establishes continuity, rather than division, between technical and social actors by assigning agency to nonhuman actors. ANT affords researchers the opportunity to define documentation processes as mediators involved in the enrollment of stakeholders essential to building and maintaining the socio-technical network of which the supercomputer is an outcome. For example, the reported results of testing a new chip technology function to enroll a working, reliable chip technology to the project (Fig. 1). In Fig. 3, black Gantt chart bars are enrolled if

Control Account Managers (CAMs) are keeping their parts of the project on budget and on-time. Black Gantt chart bars signal that the project is continuing within compliance parameters and can therefore continue to be funded. Without the inscribed enrollment of either working computer chip technology or black Gantt chart bars, the project to build a supercomputer would face significant technical and financial obstacles. Similar to the affordance of genre to make visible causal connections between document form and content and context, actor-network theory makes visible actors, and non-human actors in particular, that may not always be able to speak for themselves but that none the less are essential to the enactment of the socio-technical network.

Conclusion

In this article I have argued that assemblages of genres related to building a new supercomputer function as essential infrastructure for the US national laboratory system and for big science endeavors in general. These genre assemblages, in particular those related to the documentation of financing and project management, function as infrastructure because they mitigate the inherent uncertainties and attendant risks of big science. In other words, for the inquisitive visitor standing in the machine room at the supercomputing center, they are a key answer to the question, "How does one build such a complex and expensive supercomputer?" This finding has implications for researchers in terms of adding to our vocabulary, and ultimately our metaphorical imagination, for the functions that writing has for technical organizations.

This article has drawn on Writing Studies research that uses genre theory and ANT to document various functions of writing in industry. Generally speaking, however, this research

has had little impact outside of academia, especially in terms of affecting professionals' understanding of how writing relates to their professions or in terms of shaping technical and professional writing pedagogy at universities. Almost anyone in technical fields will, if asked, be able to tell you that the value of good writing is its power to enable clear communication, which is essential to advancement in a technical career. This generalized understanding of the value of writing is a demonstrable gain over several decades ago, as evidenced by the support accreditation organizations in technical fields have put behind communication curriculum (e.g., ABET 2000's inclusion of communication outcomes for engineering programs). It would be much more challenging to find, however, a non-Writing Studies researcher who will tell you that technical documentation constitutes social action—that technical writing is not secondary to technical work and organizations, but constitutive of them. The limited scope of how technical writing is construed in classrooms and in industry has consequences, I believe, for how students in technical professions are taught to write and for how time spent writing is valued in the workplace.

In the technical and professional writing classroom, writing teachers often struggle against entrenched notions of what counts as writing in technical organizations and the perceived lack of value in teaching future technical professionals about the world of documentation that will comprise their professions. In general, the function of writing to communicate, as instantiated by the common genres of workplace communication (e.g., memos, letters/emails, short reports, resumes), tend to dominate standard textbooks and commonsense notions of why teaching writing is important. While all writing has at least some communicative function, writing also functions beyond the traditional rhetorical triangle of rhetor-message-audience. This is where a theorized notion of infrastructure is a powerful addition to the theoretical and

methodological repertoire of Writing Studies and an alternative to more abstruse language, such as "constitute," or "translation," sourced directly from genre theory or actor-network theory (ANT).

The powerful commonplace entailments of infrastructure as a metaphor for the many documentation processes that undergird the operations of organizations are accessible to students and teachers of technical and professional writing without deep forays into theory. For example, imagine what might be contained in a textbook section entitled, "Infrastructural Genres in Technical Organizations" (e.g., READMEs, project management matrices, APIs, leases and other legal documentation) as a partner to the more familiar section called "Genres of Workplace Communication" (e.g., email, memos, reports, resumes, websites, etc.). However, if siloing genres into only two functions seems to oversimplify the complex, multi-functional social actions enacted by most genres, students in more advanced technical writing courses could take on a more theorized notion of infrastructural writing and research a genre's multiple functions themselves.

This article has argued that the function of leasing and project management processes to mitigate uncertainty qualifies them as not only part of the US research infrastructure but also as infrastructural in a broader, theoretically defined sense. However, mitigating uncertainty may be only one possible infrastructural function of technical reporting and documentation processes. Work remains to fully document how writing functions infrastructurally across all contexts for writing and to test whether a unified notion of "infrastructural writing" holds. After all, what it means for writing to communicate has evolved over time with successive theories that have evolved from the direct transaction of information to sophisticated models that account for structural power relations, distributed authorship and interpretive variation (Slack et. al, 1993).

This article develops a theory of infrastructure for Writing Studies rooted in genre theory, ANT and Starr's relational theory of infrastructure. Those frameworks, however, may only be relevant to certain contexts and shift over time. Regardless, I believe that like "communication," "infrastructure" can be an enduring framework for how we understand and value the writing and documentation processes that comprise the modern world.

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