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Mediation and Maintenance in Engineering Professional Work Practices: Findings from a Utility Company

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Mediation and Maintenance in Engineering Professional Work Practices

There has been an ongoing call for engineering education to contribute more directly to the development of a strong STEM workforce. This assumes that a strong STEM workforce is essential to meet the future challenges of our societal, national, and global economies [1]. Recognizing there are different positions regarding the preparation of engineering professionals, we agree with the position that learning about the actual practices of engineering is important, if not essential for students—and will help them be more successful transitioning into their future careers [2]-[7].

Work has been studied from different perspectives, such as the psychology of individual actors, the gendered sociology of the workplace, identification and development of competencies, work group diversity, identity issues, innovation, and design, and so on [4], [5]. For this study, we focused on the work practices as activities reported by a sample of practicing engineers working in the power transmission division of an electrical utility. We chose the perspective of work as activity systems and framed this study based on Cultural-Historical Activity Theory (CHAT), which has been recognized as a robust and holistic theory for the study of work and technology [8], [9], [10]. It is through activities that we create, innovate, and accomplish our goals in work. Also, through activities we develop and maintain our organizations, systems, communities, and societies [8].

Many studies of technology and work have focused on novel contexts of work, such as innovation and disruption [6], [11]. Against this trend in work studies, Russell and Vinsel [12] advocated for more attention to the workers and work in routine maintenance jobs that are far more prevalent in societies around the world. They claimed this attention to maintenance included most of the work done in technology industries. An important focus of their argument was to shift our focus toward maintenance because a focus on innovation is limited and overlooks most of the work that maintains relatively orderly physical environments and social structures.

The following is a study of one of those industries that works around the clock to maintain the provision of electric power to thousands of customers in a midwestern region of the U.S. In contrast to the current obsession with innovation [12] we examine the work of engineers in a utility company following established routines mediated by the tools and knowledge that characterize the sociotechnical practices of this industry. Maintaining a stable provision of electricity is an important requirement of our society that is often taken-for-granted—until it fails. This study examined the complexity of this work as reported by the engineers working to maintain the system that transmits electric power. This information and its details of the practices in this organization can inform engineering educators and students about the variety of experiences and practices that make up the real-world work of energy engineers.

Theoretical Framework

Cultural-Historical Activity Theory (CHAT or Activity Theory) presumes that human activity is object oriented [13], [14], [15]—meaning that people do things to achieve or accomplish something. That something is the object or objective of their activity. Activity is an interdisciplinary construct grounded in psychology, sociology, anthropology, organizational, linguistic, and historical perspectives. Activity is also an abstract, theoretical idea used to describe and explain basic units of human life [8].

Another key idea is that what people do is always mediated by something, such as the tools, ideas, beliefs, norms, and practices that influence or mediate their work [15]. The model of an activity system describes the interrelations among people taking action to achieve some object mediated by the tools, rules, communities, and the division of labor involved in the system (see Figure 1). Objects can be tangible, concrete things such as products or services, or they can be abstract ideas such as learning, development, and knowledge.

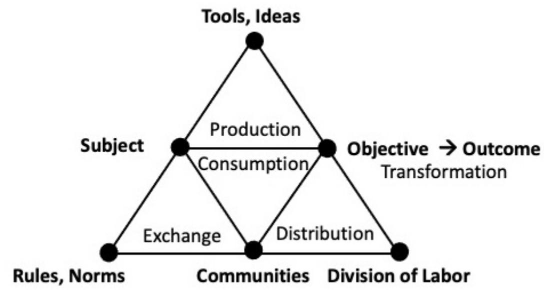

Figure 1: The structure of human activity (based on Engeström, 2015 [9])

Specific elements of the activity theory framework include (see Figure 1): a *Subject* (the focal person, subgroup, or organization taking action to accomplish what is labeled the *Object* (the objective or purpose of the activity), which then leads to an *Outcome*. The actions performed are mediated by various *Tools* (machines, formulas, ideas) and *Rules* (norms, regulations, habits), as well as *Communities* (e.g., stakeholders/collaborators with shared interests in the object) and the *Division of Labor* (the distribution of the work related to the object). Thus, work is not perceived of as a linear progression of tasks, or even the collective collaboration of tasks in a team, but rather more holistically as a complex system of culturally and historically influenced and interdependent factors and activities done by people who work toward some desired outcome.

Activity systems are abstract models of human activity. They can range from smaller, localized, and specialized activities to larger, generalized activities. Several smaller systems focused on a similar outcome form 'constellations' of systems that can be characterized as a larger system [16]. In this way work can be holistically modeled at different levels of analysis—horizontally and vertically. This systems modeling provides a comprehensive way to identify and understand the dynamic complexities of work in context. Context is not merely the background for work, but rather an interdependent element interacting with workers and their work, including the objectives, tools, rules, communities, divisions of labor, and the cultural and historical influences that comprise the system.

It is the analysis of actual, contextualized empirical data of engineering and technology work that is emphasized in this paper based on interviews with participants in the system. The empirical data will also help to identify the phenomenological characteristics of the systems, its structures, and the current ideas and models guiding work of this engineering- and technology-driven system.

Research Design

Russell and Vinsel [12] argued that despite society's fascination with novelty (e.g., entrepreneurs, start-up companies, break-through technologies), many of our organizations are involved in the important work of maintaining current systems. They called for more research to better understand questions such as, *what are the routines and practices that are maintaining the system? Who are the people doing the maintenance? How did these routines, practices and practitioners evolve into the work of maintaining and maintenance?* To address some of these questions the purpose of this study was to better understand engineering work in a sociocultural context that is not often studied. The overall research question for this study was *What is the nature of engineering work in an established electrical utility company?*

Methods

For this study, we conducted IRB-approved, semi-structured interviews with nine engineers about the work they do as employees of the regional electrical utility company (UtilityCo as a pseudonym) in the Midwestern U.S. The interviewer asked participants about their work, who they worked with, and the processes and tools with which they worked. These questions also included deeper questioning of particular experiences and ideas. From the reported experiences of their work, we were able to identify various themes that captured the nature of engineering work in this context. An overall model of the work as an activity system perceives the *outcome* of this work to be the delivery of electrical power to the region's customers. To achieve this outcome there are different *objectives* (or objects) to accomplish, such as installing transmission lines, designing electrical power infrastructures, and generating plants, coordinating contractors, obtaining regulatory approvals/permits, and working with the local communities, etc. Achieving these *objectives* requires subgroups/teams of workers (*division of labor*) to collaboratively produce the components of the power grid. They do this work using specialized *tools* (computers, plans, knowledge, and skills) according to existing *rules* (regulations, norms, 'best practices') to achieve their *objectives* and ultimately deliver the *outcome*, that is power service to customers (see Figure 2).

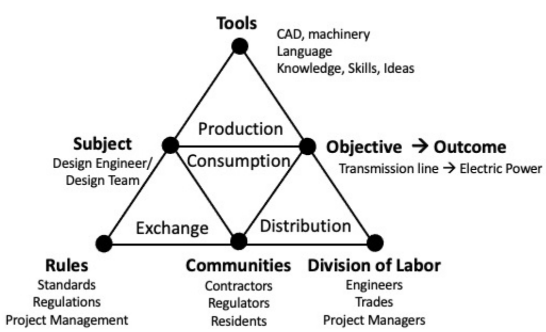

Figure 2: Example of an engineering activity system in this study

Data Analysis

The interviews were transcribed and analyzed using a *thematic analysis* approach [17], in which the data were analyzed to find patterns and themes in the texts. Braun and Clarke formulated a thematic analysis process comprised of six general phases: 1) Getting familiar with the data; 2) Generating initial codes; 3) Searching for themes; 4) Reviewing the themes; 5) Defining and naming themes; and 6) Producing the report. Thematic analysis is a common method for interpreting and understanding qualitative data. It is a method that is flexible, not bound to a particular theoretical framework, and provides inductive and deductive analyses, as well as illuminating both manifest and latent meanings in the data [17]. From a constructionist and interpretivist position, we believe that the perceptions of individuals in context are meaningful to the actions (work) done in context. Thus, we believe that a thematic analysis of the perceptions and experiences of individuals at work is meaningful to the way the work is done in this company as a research site.

Our analysis began by carefully reading the transcripts and coding which statements/phrases reflected particular components of the activity theory model, such as subjects, objects, tools, rules, communities, and divisions of labor (see Appendix 1: Table 2 for initial codes and definitions used). Next, we gathered all statements into the categories according to how they were coded. This resulted in 138 statements for the category *Subjects,* 77 for *Objectives,* 31 for *Tools*, 63 for *Rules*, 119 for *Communities*, 75 for *Division of Labor*. For each category, the statements were carefully read again, looking for patterns that represented subcategories. We labeled each subcategory with a thematic description (see Appendix 2; Tables 3.1 – 3.6). This was a process of constant comparison, going back and forth between the data (texts) and the development of thematic categories. The findings are followed by a discussion and conclusion of the results.

Participants

We interviewed nine engineers working on the transmission side of the company. They were responsible for designing, building, and maintaining the transmission lines that delivered electric power in the region.

Table 1: Participants in the study

	Role/position in UtilityCo	Education/training
P-1	Engineer IV; Geotech, Civil group	BS-Civil Engineering
P-2	Distribution Systems Operator, Design	BS-Masters-electrical engineering
P-3	Design Engineer	BS-Civil Engineering
P-4	Engineer, Transmission Design Dept.	BS-Civil Engineering
P-5	Structural Engineer	BSE-General Engineering (Civil, Structural)
P-6	Design Engineer	BS-Mechanical Engineering
P-7	Design Engineer	BS-Civil Engineering
P-8	Energy Management Dept.	BS-Electrical Engineering
P-9	Plant Engineer	BS-Mechanical Engineering

Analysis

This investigation of the work reported by the engineers we interviewed at UtilityCo illuminated the nature of engineering work activity in an organization that was considered an established organization with a relatively stable system of work being maintained. Following the theoretical framework of an Activity System [16], we organized our analyses based on the components of an activity system and conducted a thematic analysis of each component—Subjects, Objectives, Tools, Rules, Communities, and Division of Labor (see Figure 2).

Subjects of the Study. Participants described occupational and organizational roles and positions in various activity systems in the organization. We identified two categories of subjects—individual roles and teams/groups. Within those categories we identified five subcategories of individuals: *engineers* (structural, design, plant), *systems operator*, *supervisor of engineering* teams, construction site coordinators (CSC), and project managers (PM). In addition, there were three subcategories of subjects that were teams and groups: design teams, project teams, and other organizations and groups (see Appendix 2, Table 3.1). The participants in this study were engineers working on the transmission side of the business. Their experience level ranged from early career engineers working in small groups as design engineers to mid-level managers in the company serving as project managers or supervisors of teams, "*Because of the role I have, which at this point is an unofficial supervisor role, I lead my group*" *(P-1)*; or as operators of the distribution system, *"I would receive first call of an outage and I would be in charge of the line crews, (P-2)*; or coordinators for construction sites *"from day one to the last day, I coordinate all activities, as best I can, to make the project successful" (P-8)*. Others fit in between these two experience levels and largely did engineering and technical work with few, if any, supervisory responsibilities.

Many of the participants reported that although their education in school gave them some valuable foundational knowledge and skills, learning the specifics and procedures of their job roles was largely an on-the-job experience—often beginning under the supervision and guidance of a more experienced engineer as a mentor; "*I worked under the direction of a senior engineer who would give tasks and oversee projects" (P-4)*. In addition to typical job roles and responsibilities of doing engineering work, many described their interactional roles with others in their teams and with others beyond their teams. These interactional activities required sensitivity to the interpersonal expectations of the ways that people were treated in the organization, "*As long as you're willing to learn and you showed initiative, people were very willing to help out" (P-6)*.

Overall, participants described a strong sense of responsibility they had for their engineering work. This meant getting the job done correctly by meeting expectations and needs of others in the workflow, in their teams and outside of their teams. There were also comments by some about being responsible for safety and for keeping the power system operating with minimal disruptions. Responsibilities were codified in many of the important tasks by having supervisors and other experts explicitly review and sign off on designs and decisions, *"I would come up with a plan, because it was my area, then I would have two other people verify it's the right plan. They would sign off on it. Actual wet signature" (P-2).*

In addition to individual roles, there were different teams, groups, and organizations. Teams ranged from relatively homogeneous groups of engineers (e.g., design teams), to more heterogeneous groups, such as project teams. Beyond UtilityCo there were other organizations that were considered stakeholders in the work of building and maintaining transmission lines. These were organizations such as regulators, suppliers, contractors, and municipal, utility, and environmental agencies.

Objectives of the Work. Participants described the objective(s) of their work in ways that we categorized as externally or internally focused objectives. Externally we identified five subcategories of objectives: *complete a project successfully*, *design structures*, *restore power*, *supervise contractors' performance*, and *control energy costs*. Internally, we identified four subcategories: *improve equipment performance*, *develop standards*, *support and develop the team*, and *manage and develop career* (see Appendix 2, Table 3.2). For example, one of the major objectives of the work was designing, building, and maintaining a regional energy infrastructure for the purpose or outcome of delivering power to that regions group of customers. This objective was presented on the company's website, although no one in this study explicitly described their objectives at this high level. The closest description to the provision of power was one participant who described their work as that of keeping the power in service (maintenance tasks) and restoring power during an outage (repair tasks). For example, "*If a transformer was damaged, I'd work with that and then I was responsible for restoring power*" *(P-2)*.

Participants described their individual or team objectives as responsible for specific aspects of successfully completing their work on a project and all the meetings and administrative work that go into completing a project.

> *As I became full time, I wasn't prepared for how many meetings and phone calls and so much coordination. Project management usually handles managing the entire project but as the design engineer, you kind of manage a lot of the parts as well. There are certain things the PM [Project Manager] oversees, but being responsible for the design and materials, drawings, there's a lot of coordination and meetings you have to have. I was kind of surprised or just unaware of how much coordination it would take. You think as a design engineer you're just issuing prints but . . . I wasn't ready for all the extra non-technical things I would have to do (P-6).*

Related to their part in completing a project, participants described their various job objectives focused externally, for example, designing structures, restoring power, supervising contractors, and auditing customers' energy costs. *"I'm responsible for the design of projects which include pole and tower placement along with the transmission lines that run from substation to substation" (P-2).* In contrast to the external focus of these objectives, there were other objectives that were internally focused to improve the performance of the company by improving the performance of specific equipment, tools, or standards, as well as improving the performance of teams and individuals. *"It's really trying to balance out supporting my team of engineers/designers/drafters with their questions, supporting their development . . ." (P-3).*

In many cases, multiple objectives were the focus. Depending on the role of the participant the objectives of their work differed largely related to their particular job assignments (e.g., design, project management, site coordination, construction, etc.). Collectively these various objectives formed and maintained a relatively coherent and collaborative activity system of systems across the organization to design, build, and maintain the regional electrical utility company's services.

Tools. The work of the participants (i.e., achieving the objectives) was mediated (influenced) and facilitated by various tools. Participants described these tools, and we identified seven subcategories of mediators: <u>*Knowledge and skills*</u>, a <u>*model of engineering*</u>, <u>*training and continuing education*</u>, <u>*mentoring*</u>, <u>*computers and software*</u>, <u>*design standards*</u>, and <u>*projects*</u> (see Appendix 2, Table 3.3).

The concept of tools included the knowledge and skills held by employees and codified in the organization and industry. Participants reported that an important tool learned in school was their mental model of engineering—the engineering way of doing things. This was typically characterized by most as problem solving and described as a method of decomposing a problem into smaller problems. Additionally, there was the knowledge for how power is produced, exchanged, and distributed from the company to its customers. On the job, participants also talked about solving problems in other ways, most commonly by getting help from more experienced colleagues in the organization or technicians/contractors in the field. Knowledge and skills also included the more abstract concepts such as theories, models, engineering science formulas, along with organizational and business ideas and practices.

One of the most common tools used was computers/software, *"We have a pretty specific industry software" (P-4),* and the design standards sourced from other utilities and industry organizations. Software tools helped design the layout and structures of transmission lines, as well as manage projects to completion. Projects included the design and construction of transmission lines, as well as processes for optimizing energy use in customer organizations, *"I moved up and took over one of our customers [accounts] to redesign their [energy management] software and I also had to be able to read their blueprints about their electrical system" (P-8).*

Participants referred to their education (a tool) in various ways, from learning foundational engineering knowledge applicable to work, to learning little that was applicable to the job; *"For the most part, you'll learn most of your skills on the job rather than in school. (P-6).* Training and continuous learning (as tools) were also reported as ways of developing new knowledge and skills. There were various opportunities for training, as well as information learned from reports and manuals. There were industry resources for learning provided by IEEE and the Electrical Power Research Institute (EPRI). In addition, the organization provided mentoring for newly hired engineers to help learn the details of their jobs, *"Working with the mentor, that's who we went to with any questions. That's how we worked 'til we completed the project" (P-5).*

Rules. Participants described numerous rules mediating their work of maintaining the transmission system, from which we identified three categories based on three levels of analysis: individual, organization, and industry. At the individual level we identified two subcategories: Task-oriented work and interactions and relations. At the organization level, we identified six subcategories: Standard operating procedures, norms of interaction in the workplace, supportive management, concern for safety, legal contracts, and financial norms. At the industry level we identified one subcategory: Government regulations and technical standards (see Appendix 2: Table 3.4). These rules regulated the work activities and relations among engineers and others in the company. The things that regulate activities and relations are also known as norms, policies/procedures, beliefs, guidelines, etc. They can be viewed as formal and explicit or more informal and implicit.

At the individual level, there were rules for doing one's task-oriented work and rules for the interactions and relations among those working together. Several participants reported their personal rules for continuous learning and taking responsibility for doing their best work, *"The way I take it is that as the engineer, you're taking responsibility for something" (P-3).* Other individual norms and beliefs were more informal and/or implicit having been internalized from their education and other work experiences.

> *I try not to talk about work right away when I go to the site. I try to ask how it's going, try to relate to them, figure out their interests so it's not always talking shop the whole time. . . If you find out some guy's kid is in band or playing sports, you ask how the team is looking this week, things like that. If things are going well, maybe stop and bring in donuts and coffee one day – things like that go a long way (P-7).*

At the organization level there were rules that governed how the company organized and managed the work. There were many standard operating procedures that regulated and informed people about how things should be done in the company—especially those supporting an explicit concern for safety mentioned by several participants. Another important rule guided the norms of interaction that emphasized maintaining a collaborative and friendly workplace, "*You have to collaborate and work together to accomplish things and find solutions that work across the board for everybody" (P-9)*. One participant described different rules between the culture of working in an office compared to working on a construction site. Another participant described experiences with tensions between generations and occupations (e.g., some distrust/disrespect between construction crews and engineers).

Related to the norms of interaction in the workplace was the norm of a supportive management. Managers were expected to be supportive and collaborative, as well as being available to help anytime as needed. There was support for training and development evident in the practice of assigning senior/experienced engineers to be mentors to newcomers, as well as continuous support for training.

> *if you had less than 2 years of experience, you had to go . . . and sit in this training program and you learned about the industry, kind of the basics. I do feel like they tried to get us involved and learning and up to speed*, *(P-4).*

Participants also referred to the power of legal contracts regulating the work of vendors and other parties (communities) involved in work. There were also financial norms that governed how projects were managed emphasizing the expectation of staying on budget.

At the industry level there were government regulations and standards for how transmission lines were designed, constructed, and operated such as the standards provided by the Electrical Power Research Institute (EPRI) and other governmental agencies (local, state, and federal). For example, the company was currently collaborating with another utility in a neighboring state. Different states had different rules and there was a steep learning curve reported by those working on this project to learn a different set of rules and regulations of the state in which the new project was located.

Communities. Descriptions of communities from the participants were categorized as either external to UtilityCo or internal. Furthermore, three subcategories were identified for this analysis; two subcategories were externally focused—*Industry groups and organizations* and *non-industry communities and work groups*. A third subcategory was identified that was internally focused—*Work groups and project teams* (see Appendix 2, Table 3.5).

Externally, there were industry groups and organizations interacting with utilities and other organizations. These groups ranged from local, regional agencies and municipal and residential groups to national and international groups. Two main objectives of these groups were to develop and regulate safe practices in the industry and facilitate learning and sharing knowledge across the utilities and related organizations regionally and nationally—all for the purpose of maintaining a reliable and safe power transmission system. For example, one group mentioned by several participants was the *Energy Power Research Institute (EPRI),* an international organization that is *"a non-profit energy research, development, and deployment organization . . . collaborates with scientists, engineers, government, and experts from academia and industry to shape and drive technology advancement by pushing the frontier of innovation from concept, pilot, operation to end-of-life."* [18].

At the local level, there were different non-industry communities and work groups that were involved with the utility in various ways—customers, residents, businesses, and other stakeholders. Interacting with these groups meant working with people with different perspectives and views. A common conflict was between the utility and various outside municipal agencies and residents' communities that sometimes contested development plans affecting that community. Contractors, such as construction companies also brought different perspectives to the work, *"I always like to have a kickoff meeting in person with the construction crews . . . at the site so you can walk away with what you need to do and how you need to design it" (P-6).*

Internally, work groups and project teams varied in their composition from rather homogenous teams of design engineers to project teams with members representing various organizational functions (e.g., finance, legal, regulatory, etc.). Participants described the importance of interactions among different people on the team, understanding different points of view, and the effects of collaboration on a design. The quality of interpersonal relations was an important factor in the work of the organization, as well as outside of the organization.

In addition, participants were part of multiple communities (professional, occupational, organizational), some that were internal to the organization, such as project teams. The various contexts of work also influenced the ways of working within the group. Not only were work activities embedded in different contexts, but they were also influenced (mediated) and changed by the context, and this sometimes led to confusion and friction. At times there was a breakdown in the workflow between internal groups. For example,

> *If you're asking is the work streamlined? Not necessarily. Outside our department, there are processes and procedures that are across multiple departments, and it becomes a little bit more of a rat's nest to figure out who's responsible for what. You get who you think needs to sign off and inevitably someone else jumps out and says they never saw it. In my career, this transmission side of the business is the most complex, convoluted reporting structure I've ever seen. (P-5)*

Division of Labor. Participants described how their work was divided into various responsibilities and roles distributed among jobs and positions in the company. We identified two subcategories of statements from participants referring to how the work was divided and assigned—the subcategories were labeled (themed) *distribution of work responsibilities and roles* and the *managing distributed work* (see Appendix 2, Table 3.6). The distribution of work responsibilities and roles mostly followed a functional logic of assigning work tasks. The various jobs that made up the organization comprised an overall, complex activity system of the company.

Like many organizations, UtilityCo was project based and included numerous project teams, each responsible for particular aspects of the work—contractors, suppliers, vendors, customers, project managers, schedulers, engineers, and so on, *"Typically we started with a job briefing in the morning for the whole group. We all had different areas of responsibility to report out on based on stuff from the previous day or over the weekend" (P-7)*.

Also, nested within the teams, individuals' roles and responsibilities differed across the team, *"We also have drafters that support us with the drawings" (P-6).* The work at the organizational level was divided up among the design engineers, in which there was a relatively focused objective, in this example—one line to design, "*there are ten different lines, but they're split up – each line is assigned to one design engineer" (P-6)*.

Individual roles and responsibilities also changed over time with experience, as well as with transfers or promotions to new positions in the company, *". . . and then where I'm at now,* [shifting from] *the technical side to the supervisory side, it's more managerial tasks and also the design." (P-3)*. The nature of one's responsibilities and roles also reflected a level of experience and competence in the company. For example, the following quotes describe first an experienced individual's role and responsibilities compared to the second quote from someone relatively less experienced in the organization.

> [experienced] *I work with everybody. I'm like the top of the triangle for the project in the field. I work with the project manager and all my contractors, suppliers, vendors, customers, etc. They all go through me and then I work with project management and my management, anybody else above that who needs updates on what I do. . . . A nice part of my position is dealing with quite a few entities at the same time . . . (P-8)*
>
> [new] *For the most part, you just hang out at your desk. You get up and chitchat or talk with your drafter to ask if they can change how something is called out, rerun a cross-section, detail changes, etc. There are still conversations you have. And if I don't know how to do something, it's talk with another engineer and learn (P-3)*.

Managing distributed work was the second theme in this category and included not only decisions about the assignments of work to teams and individuals, but also making decisions that might relate to outside stakeholders. Understanding the special issues that might alter how the work is divided and assigned takes experience and is the responsibility of managers. Participants in this study described the management of distributed work as one of assigning projects and tasks and keeping the organization stable and running smoothly. Any difficulties in the organization seemed to arise from the interfaces between teams/groups and this was another area requiring managers' attention.

Identifying Activity Systems. After a detailed analysis of the components of activity systems in the company, we identified several different forms of activity systems that can modeled from the analyses of the components. Based on the data analyzed above, five activity systems can be modeled representing the different activities reported by participants (see Appendix 3, Table 4). There were activities related to *designing and planning* often done by engineers responsible for developing the design of a new transmission line, as well as the design of the components of the line. Other work was focused on *maintaining and repairing* the existing infrastructure—especially in the cases of power outages. *Managing and supervising* the work were mediating and maintaining activities and were reported to occur at different levels across the organization, from the specific assignments and job tasks of an individual to the management of teams/groups, to managing entire projects. *Coordinating and communicating* were also reported across the work done in the organization at all levels. These activities included internal as well as external coordination and communication tasks. Participants also described some of their *learning and personal development* in the form of training, self-study, and other ways of continuous learning to enhance their knowledge and skills.

Summary of Analysis

Analyzing the work of participants (engineers) from the perspective of activity systems emphasized the complex and varied nature of the work and its interdependence with multiple activity systems in the organization and environment. Most of the participants interacted with others beyond their work teams and departments to include the various communities and groups within and outside of the company. This also included collaborating with other groups to deliver their part of larger, multi-faceted projects, in which the work was divided among different teams of specialists and outside contractors. There was noticeable overlap of experiences and descriptions across the components of an activity system indicating the complex nature of this work and the multiple interpretations possible among the engineers, managers of the company, as well as the researchers of this study. This complexity is addressed more fully in the discussion below.

Discussion

We analyzed the reports of engineering practice in this organization through the interviews of participants describing their experiences/activities as practicing engineers at UtilityCo. Overall, the practice of engineering in this organization has a strong historical and cultural foundation supporting a rather traditional view of engineering as a process of designing, building, and maintaining technology related to the production and distribution of electrical power in a particular region of the U.S.

The value of examining engineering work as an activity system was found in illuminating the variety of activities and the interactions among those activities that make up the complex system of work across different levels of organization. In this study, engineering activities are comprised of actions and operations, mediated by tools, and focused on an object or multiple objects (objectives). Tools include a range of things from simple paper and pencil to discursive expectations and explanations to abstract paradigms, ideologies, and visions used to solve problems, achieve objectives, and maintain the system [19]. The mediational characteristics of work factors (tools, rules, communities, and divisions of labor) both enable and constrain activities between the subject and the object (objective). Mediated action requires two things—an agent and an artifact. Agents mediate the work by the nature of their education and training, capabilities, predispositions, perspectives, and the contexts in which they work. Artifacts mediate work by the way they have been designed and how they are used. Agents and artifacts both enable and constrain activities in various ways that affect the objectives, and the ways objectives are achieved.

In this study, tools that mediate the work are the obvious computer-based tools, as well as organizational processes such as project management, and disciplinary concepts, such as the equations, formulas, and decompositional ways of problem solving described by many of the participants. The engineers' activities of designing, building, and maintaining the technological systems are mediated by the tools in use, as well as the rules regulating the work, how the work is distributed and the communities taking an interest in the work [2].

Russell and Vinsel [12] argued that maintenance is one of the most common forms of technical expertise, which they define as "all of the *work* that goes into preserving technical and physical orders." (p. 7). Maintaining the technical, physical, and social order of a regional electrical utility is a major objective of the work for engineers in this study, which they reported as the more concrete, daily work tasks of their jobs and teams. We focused on what the participants said they did as these are the ways in which their engineering work was is done.

Studying engineering practices in UtilityCo perceived as activity systems helps understand the dynamic, complex, and interdependencies of work in the organization—work that is historically and socioculturally influenced. In many ways the structure of the power system has changed little over the past century. The object of the system's activity was and still is to deliver electric service that is affordable and reliable. The lines through which electricity is delivered have not changed much, and generally, the solution to increasing transmission and reliability has been to build more and better lines [20]. This solution was evident in the engineering work of UtilityCo.

Another key characteristic of the electrical power industry is the formation of regional monopolies by the states beginning over a century ago. This effort was thought to be more efficient at serving the needs of the market [20]. It also led to the development of a strong state and federal regulatory environment. These historical and cultural conditions are evident in the current state of the nation's electrical grid, which is largely built on 50-year-old technology and equipment that was not created for today's power needs. However, the work on the transmission side of UtilityCo, in which their primary purpose is to build and maintain safe, affordable, and reliable transmission of electricity is based on dated infrastructure and the historical practices for maintaining that infrastructure. The ways in which things are done often have a strong legacy of activity that has changed little since the middle of the 20th century.

Despite incremental, routine innovations in work patterns and technologies, the work depends on engineers and the trades to solve typical problems in design and construction to maintain the electrical power transmission lines. A common experience reported by participants was to learn how things were done and thereby design and build structures based on tried-and-true experience. For example, one participant recalled how the field workers reacted to his design, *"Some of the field guys* [sic]*, if they've been doing it a long time, they're quick to tell you they don't think it should be done this way. . . They're the ones doing the work. If they have any concerns - a lot of times, they may say there's an easier way to do it or have their own opinion about how to do it" (P-6).*

New engineers entering this part of the company were trained to follow specific ways of designing and building the transmission lines by more experienced coworkers, as well as the construction crews in the field. Learning to do this work appropriately was the goal of their work whether they did the actual designing and building themselves or managed teams/crews of others assigned to doing the work. Designs were also carefully produced within narrow constraints of federal, regional, and/or state regulations, as well as the constraints from the organization for safety, feasibility, and performance. Maintaining the order of the industry was the overriding objective of the work of these engineers [12].

Developing knowledge and appreciation of the complexities of engineering work as practiced in engineering organizations is one of the important competencies supporting successful transitions of students from school to work [21]. The findings of this study can help educators and students develop their knowledge and understanding real-world applications of many of the concepts and ideas learned in the classroom and labs. From previous research on engineering practice, we know that many of the details of engineering work are often unique to particular work groups, organizations, and industries [2], [6], [7]. This study can add to the body of knowledge of engineering practice with the practices that are more or less unique to this organization and industry. It also provides a more holistic look at engineering practice by using the analytical framework of Activity Theory, which includes the social and organizational mediators of work in the form of tools, rules, communities, and distribution of labor. This view goes beyond the focus on technical experiences to include the social and cultural factors that mediate the work of engineers.

Limitations

This paper presents an early analysis to document the work activity systems experienced by a group of engineers working for an electrical utility company. It is by no means comprehensive. Further analyses, as well as additional data would certainly enrich the initial information collected from these engineers and would deepen the insights about the actual work practices in this organization. Braun and Clarke [17] described thematic analysis as flexible method for different kinds of qualitative research, more likely to provide deeper insights into a phenomenon, and is never finished. Activity systems are process oriented and evolve over time. The retrospective reflections of the participants in this study provide some information of the historical and processual nature of their practices, however more information from additional data would help supplement these analyses. Despite these limitations, these data provide insights into the everyday work of practicing engineers in a kind of organization that is seldom portrayed in the literature.

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Appendix 1

Table 2: Initial codes and definitions used in this study.

Category	**Code Frequency**	**Definitions** [15], [22]
Subject	SB 138	Focal person or team/group doing work (activity) to achieve an objective.
Objective	OB 77	The object of human activity, described as the objective, motivation, or purpose for the activity. Human activity is a purposeful activity. We use the term objective rather than object for clarity.
Tools	TL 31	Resources/artifacts/ideas (physical and conceptual) that participants use to achieve a particular purpose or objective. *Physical tools* include computers/software, wrenches, cranes, meetings; *conceptual tools* include equations, theories, language, management, collaboration/contestation, responsibility, knowledge, etc.
Rules	RL 63	Policies, procedures, norms, beliefs, etc. that regulate the actions of and the interactions among people related to an activity.
Community	CM 119	Various contexts (social and cultural) in which work activities were embedded, including collaborators and stakeholders involved in an activity. Communities include occupations, professions, teams, organizations, agencies, residents, etc.
Division of Labor	LB 75	The shared and distributed responsibilities and various job/social roles among members involved in the activity, including collaborators and stakeholders, among others.
Other	OT 188	A code to note items, ideas, and concepts that do not fit neatly into other code categories (many were about learning, previous jobs)

Appendix 2

Table 3.1: Roles related to the concept of the **Subject**— *Focal person or team/group doing work (activity) to achieve an objective.*

Roles	Descriptions from participants
Individual	
Engineers (structural, design, plant)	• Designed structures for transmission equipment infrastructure, supervised construction • Responsible for design and materials, drawings, coordination, and meetings (material deliveries, estimating, etc.); each line is assigned to one design engineer • Doing maintenance and performance testing (generation) • Produce reports on performance • Make recommendations for maintenance or system adjustments • Trained by coworkers and supervisors
Systems Operator	• First contact for a power outage • Manage restoration of power in cases of outages • In charge of line crews, identifying the right crews, providing assistance, • Use Energy Management System to restore power in some cases • I would come up with a plan and then need two others to sign off (actual wet signatures). If there is not agreement, then a new plan is created
Supervisor of engineering teams	• Responsible for design and materials, drawings, coordination, and meetings (material deliveries, estimating, etc.) • Liaison between clients and engineers in the office • Supporting team members, mentoring, and representing team in project meetings • Sharing knowledge, prioritizing tasks
Construction Site Coordinator (CSC)	• Managing Projects, problem solve, team meetings • Technical work and envisioning how things go together (construction skills) • check equipment/deliveries for project, meet/socialize with field workers, • Take training courses, share with/learn from other CSCs •
Project Manager	• Managing projects: scheduling, supervising people, managing financial aspects of projects • Coordinating all the activities across the organization to get a project done (CSCs, Real Estate, Engineering, Environmental, Siting and Regulatory, Forestry/VM folks) • Continuous learning
Teams and Groups	
Design Teams	• I am a supervisor of transmission design; I am one of 5 supervisors who oversee design engineers.
Project Teams	• I would say there's fifteen or so on the entire project team, across environment, project management, construction, the CSCs, siting and permitting, and a couple contractors.
Organizations, Groups	• I work with the project manager and all my contractors, suppliers, vendors, customers, etc. • And then present it to the townships/boroughs/all the different parties and stakeholders and work our way through them to get approval

Appendix 2

Table 3.2: Themes related to the concept of the **Objective**—*The object of human activity, described as the objective, motivation, or purpose for the activity. Human activity is a purposeful activity. We use the term objective rather than object for clarity.*

Themes	Descriptions from participants
External Focus	
Complete a project successfully	• Project Managers (PM), coordinate all activities to get project done • Dealing with real estate, engineering, environmental, siting, and regulatory • Coordinating across the organization and communities to get work done • Manage construction process and crews; coordinate all activities in the field (deal with schedulers, engineers, project managers, and design firms) • Take responsibility, solve problems (e.g., missing materials, etc.) • Doing them [*projects*] quicker, faster, cheaper, safely, and environmentally friendly
Design structures	• Designed variety of structures for equipment (e.g., steel and support, beams, columns, ductwork bracing, plate girders, stiffened plate) • Meet with others for feedback and changes to design • Developed an initial design and then feedback from others changed design
Restore power	• Figuring out ways to restore power • Understand the capacity in the system for moving power around • Responsible for managing crews to restore power
Supervise contractors' performance	• Supervise construction sites • Develop metrics to measure vendors' performance beyond just schedule and budget • Multi-functional team effort
Control energy costs	• Conduct energy audit for commercial customers • Send tech support to fix problems
Internal focus	
Improve equipment performance	• Worked with plant operations • Conduct performance testing • Writing up reports for maintenance and/or system adjustments
Develop standards	• Look at past designs internally and at other standards of other companies externally • Merging past standards and with new technologies and new safety concepts
Supporting and developing team	• Supporting team of engineers, designers, drafters by answering their questions, • Coordinate professional development for internal engineers and consultants • Source training content from specialists, associations, and YouTube videos
Manage and develop career	• Changing positions to keep learning/growing • Shifted responsibilities from managing site crews to understanding how projects are set up (e.g., financials, scheduling, etc.) • Personally work on developing presentation/communication skills • Taking professional development training (e.g., project management, OSHA classes, shadowed design engineers, project engineers, permitting) • Learning through hands-on experiences, reading books, learning what others know • Built up trust quickly to advance to lead engineer sooner than most

Appendix 2

Table 3.3: Themes related to the concept of **Tools**—*Resources/artifacts/ideas (physical and conceptual) that participants use to achieve a particular purpose or objective. Physical tools include computers/software, wrenches, cranes, meetings; conceptual tools include equations, theories, language, management, collaboration/contestation, responsibility, knowledge, etc.*

Themes	**Descriptions from participants**
Knowledge and skills	• Previous coursework in school about engineering science and skills • Additional learning about industry standards and organizational skills • Learned theories, equations, and other conceptual tools (engineering science and business practices)
Model of engineering	• As an engineer, I am responsible for my part of the project • Understand the standards, requirements, and engineering of infrastructure • Problem solving
Training and continuing education	• Courses on technologies, company procedures and tools (software), industry basics and standards • Continuous education, courses from professional organizations, PE credentialing • Meetings with representatives from industry companies • Share information and knowledge among peers and contractors/technicians • Information from analyses, calculations, tests, designs, recommendations • Learning industry basics and standards from reports and manuals • Presenting information to others
Mentoring	• Advising and training co-op students • Getting advice and training from a mentor
Computers and software	• Used to create designs • Used to optimize processes
Design standards	• Standards sourced from past projects • Industry standards shared among utilities and agencies
Projects	• The way work is organized, distributed and the goals accomplished • To manage and coordinate the work to accomplish goals

Appendix 2

Table 3.4: Themes related to the **Rules**— *Policies, procedures, norms, beliefs, etc. that regulate the actions of and the interactions among people related to an activity.*

Themes	Descriptions from Participants
Individual level	
Task-oriented work	• Always do the best job you can, no matter how trivial • You are responsible for everything on your part of the project—even what you might consider to be administrative work • Be proactive and continuously learn
Interactions and relations	• Be approachable and communicate well to coworkers and community residents • Explain projects to residents and be a salesperson for the company • I try not to talk about work right away when I go to the site. I try to relate to them • Learned how to handle conflict and angry people (keep calm and stick to the facts) • The more you work with people the more comfortable they get working with you
Organization level	
Standard Operating Procedures	• For creating standards, we look to the past and to other companies • Fine balance of merging new standards (e.g., safety) with old standards • Step-by-step process for taking equipment out of service (Switching Documents) • Review documents to understand the present conditions of service • Two other people must check and sign off on your work/plans • Look at all the characteristics before making decisions • Making sure processes are followed
Norms of interaction in the workplace	• Must work together (there is no choice), maintain collaborative, friendly workplace • Office environment has a different way of handling yourself (more professional) than on the construction site (less professional) • Some generational and occupational friction between groups (e.g., construction crews and engineers), need to earn/develop trust
Supportive management	• If needed, I could go to my supervisor anytime necessary—24/7 • Management and other coordinators are supportive and collaborative • Visit site at various stages of construction and anytime there is a question • New hires paired up with a senior/experienced engineer for learning/mentoring
Concern for safety	• Greater emphasis on safety now than in the past • Look to improve structures so they can be safely built and maintained
Legal contracts	• Work with legal to ensure vendors perform as required Hold them accountable • Review contract documents, proposals
Financial norms	• Need to balance the budget, by pushing projects back if necessary
Industry level	
Government regulations and technical standards	• Different regulations in different states • Reach out for information before design, rather than get feedback then re-design • Many standards written by Electric Power Research Institute and other utilities • Standards shared among companies in industry • Need to balance merging new technology with existing standards

Appendix 2

Table 3.5: Themes related to the concept of **Communities**—*Various contexts (social and cultural) in which work activities were embedded, including collaborators and stakeholders involved in an activity. Communities include occupations, professions, teams, organizations, agencies, residents, etc.*

Themes	Descriptions from text
External	
Industry groups & organizations	• Industry group with members from different companies focus on different parts of the industry (e.g., transmission lines) • Some groups designed for knowledge sharing among companies • EPRI (Electrical Power Research Institute) provides training workshops and research reports for utilities. They provide standards for utilities in US and Canada; UtilityCo sends a few people to the workshops, and they come back and present what they learned to others • Also, the professions and/or occupations of engineering, business, construction, and the trades.
Non-industry communities & work groups	• There were different technical requirements and approval processes in among states • Working with multiple groups in a new environment is difficult and leads to misunderstanding and rework (learning the requirements of new communities and stakeholders)
Internal	
Work groups and project teams	• As CSC, from day one to the last day, I coordinate all activities to make the project successful. I deal with schedulers, engineers of various types, various project managers and design firms. A nice part of my position is dealing with quite a few entities at the same time. • Project teams (mixed bag of people: e.g., structural/design engineer, construction crews, line supervisors, project managers, construction site coordinators (CSC), siting and permitting, drafters, and contractors • Start with a job briefing and the different areas report out what they're doing • Not clear organizational processes across groups (e.g., difficult to figure out who needs to sign off) • Usually meet with construction crews on site to check in, get feedback, solve problems • Some of the line crews are quick to tell you if they don't think it should be done this way. If they don't agree with you, they say so; it's nice to get this feedback • Just being involved with different teams, you learn different things about whatever is going on with the company • Occupational work groups, functional groups of workers with similar responsibilities (e.g., usually all the engineers have projects assigned to them) • We've got different EBRGs (employee business resource groups). I'm part of one that's the family network, and it's a resource group for helping people to deal with different work situations. • I'm on the vendor performance metrics team. So, we hear from scheduling folks, project managers, stuff like that • Coming from a construction background, to go to an office environment I learned there are different ways of presenting yourself in the different environments

Appendix 2

Table 3.6: Themes related to the concept of the **Division of Labor**—*The shared and distributed responsibilities and various job/social roles among members involved in the activity, including collaborators and stakeholders, among others.*

Themes	Descriptions from text
Distribution of work responsibilities and roles	• We all had different areas of responsibility to report out on • I would receive first call of an outage and I would be in charge of the line crews. • I worked with teams; people would check your work if it was something planned. These are highly technical decisions. • I would come up with a plan because it was my area, then I would have two other people verify it's the right plan. They would sign off on it. Actual wet signature. If there's something they disagree with, you come up with a new plan • Outside our department, there are processes and procedures that are across multiple departments, and it becomes a little bit more of a rat's nest to figure out who's responsible for what. You get who you think needs to sign off and inevitably someone else jumps out and says they never saw it. • She is the one that helps us with engineering support. As a project team, I would say there's fifteen or so on the entire project team, across environment, project management, construction, the CSCs, siting and permitting, and a couple contractors. • Coworkers and supervisors largely were the ones who did the training • There is an HR department, so they cover basics with you about onboarding when you come onto the company. You have someone you were paired with, so you can ask any questions to that person. It was a comfortable environment. I would just take questions to my mentor and talk to them about it. Ma • Whether it's a maintenance project replacing a few structures, or a full line rebuild, day to day I basically work on my assigned projects. • We also have drafters that support us with the drawings. • We all had different areas of responsibility to report out on based on stuff from the previous day or over the weekend.
Managing distributed work	• It's making sure that the structure of the organization is correct. Making sure that processes are being followed • Group supervisor determines if this group should be involved with a project and if so, assigns the correct people to project • I answer to my manager, but I also had two field techs and I scheduled guys in the field to go out and support what I was looking at. • Making sure the right crews got out for the job. • it'll go to the supervisor first, but sometimes they come up to me and I can take it up to the GM if there's something significant. We fully use the chain of command appropriately. We have a very healthy chain of command in this department.

Appendix 3

Table 4: Activity systems based on the analyses of the components of activity systems reported by participants

Activity Systems	Descriptions from participants
Designing, Planning	• Designed structures for transmission equipment infrastructure • Responsible for design and materials, drawings • Technical work and envisioning how things go together • I would come up with a plan and then need two others to sign off (actual wet signatures). If there is not agreement, then a new plan is created
Maintaining, Repairing	• Doing maintenance and performance testing (generation) • Use Energy Management System to restore power in some cases
Managing, Supervising	• Problem solving • Make recommendations for maintenance or system adjustments • Manage restoration of power in cases of outages • In charge of line crews, identifying the right crews, providing assistance • Managing projects, supervising people • Supervised construction, meet/socialize with field workers • Managing financial aspects of projects • Produce reports on performance
Coordinating, Communicating	• First contact for a power outage • Coordinating all the activities across the organization to get a project done • Responsible for coordination, and meetings (material deliveries, estimating, etc.) • Liaison between clients and engineers in the office • Supporting team members, mentoring, and representing team in project meetings • Sharing knowledge, prioritizing tasks • Check equipment/deliveries for project • Scheduling
Learning and personal development	• Take training courses, share with/learn from other CSCs • Continuous learning • Learning from mentors and other experienced personnel • Changing jobs to learn more