Title
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Abstract — **This paper explains conflict over technological process innovation in cultural terms, drawing primarily on a case study of electric power distribution and strategies to automate its operation. The paper shows how different occupational cultures, "operators" and "engineers," use different mental models or cognitive representations of technology that are adaptive to their particular work contexts, but give rise to conflicting evaluations of technological innovation. While these cultural groups may be motivated by a common interest in the successful performance of the technical system, they value different sets of criteria for system design and promising modifications. Despite the apparent contradiction, each perspective is internally consistent and rational. The paper argues that it is beneficial for management to consider these diverse perspectives carefully when planning technological innovation.**

I. INTRODUCTION

It is not uncommon for organizations to experience difficulties when implementing technological process innovations. New techniques for production or operation, aimed at increasing efficiency, may fail to generate the anticipated savings in time or monetary terms, or the extent of their implementation may fall short of the full potential. In some cases, initially promising innovation programs are abandoned altogether. Often, the failure of such programs is not due to any shortcoming of the physical devices or technical schemes employed, but rather to conflict and lacking acceptance within the organization attempting to implement the change.

The problem of innovation failure has been recognized in the literature [4], [42], [46], [51], and numerous individual cases have been reported [5], [36], [56], [63], [65], [87]. Some research points to the importance of employee motivation toward technological change [74] and specifically identifies employee resistance as a significant reason for failed innovation [19] [51], [55].

When resistance to process innovation occurs, it typically manifests along occupational or cultural sub-groups within an organization. Because such groups tend to have different goals relating to their own performance and rewards within the organization, their varying degrees of enthusiasm for innovation programs can often be related to competing interests in control, authority, and recognition of skills. This aspect of intra-organizational conflict has been explored extensively in previous work [29], [38], [43] and perhaps most pointedly in the context of labor process theory [12], [50]. Resistance to innovation has also been attributed to information asymmetries between technology advocates and users [41], leading to misunderstandings or disagreements about the expected benefits of innovations [51].

This research examines conflict over technological innovation from a point of view that may be characterized as *cultural*. It aims to explore the origins of different judgments of technology in the area of cognitive phenomena, i.e., how people *think about* technology. A central claim is that when it comes to implementing innovations, occupational groups are not motivated exclusively by self-interest, but also by their sense of what is good for the organization or the technical system as a whole. This sense is informed by a distinct mental model or mode of reasoning about the system, which in turn is adaptive to a particular work context. While each model may be internally consistent and rational, different models yield different answers to questions about specific innovations and their promise. Thus, conflicting values and judgments can arise not only from conflicting interests, but from differences of *interpretation*.

Cultural or perceptual differences among organizational subgroups have been previously identified and discussed [9], [32], [78], [85], [10], [11]. For instance, Van Maanen and Barley [78] define occupational communities in terms of their associated work engagement, identity, values, norms, and perspectives independent of organizational boundaries, and Boland and Tenkasi [11] explore how multiple communities with specialized expertise can communicate their perspectives to each other. But, with few exceptions [21], [73], [88], little work has been done on relating what is known about cultural groups to the problem of technological innovation. The challenge, recognized by some organizational research [6], [7], [11], [14], [52], is to examine process technologies from the perspectives of those choosing and using them.

The present work strives to illuminate conflict around technology adoption and implementation by characterizing the diverse perspectives of the participants involved. This paper focuses on the case of two cultural groups, "operators" and "engineers," within electric utility companies. It examines how their respective models or cognitive representations of electric power systems give rise to conflicting evaluations of new automation technology for power distribution systems. The mechanism of dissensus uncovered here may well be generalizable to other technical settings.

"Distribution automation" is a buzzword in the electric power industry today. It refers to a variety of techniques for increasing the speed and scope of operations through electronic, computer-driven equipment in place of manual procedures. Most utilities in the U.S. are involved at some level in the process of evaluating their options in this area and, in many cases, implementing them [15], [17], [22], [28], [34], [47], [66], [83]. As in other industries, the main motivation for automating operation and control processes is to increase operational efficiency and thereby achieve enhanced performance at lower cost. But, as might be expected, not all experiences with distribution automation to date have been successes. Specifically, automation schemes may remain limited in their application because of doubts as to their reliability or practicality, resistance to utilizing the new technology, or even outright sabotage on the part of some workers. Typically in such scenarios, a division emerges between the groups labeled here as "engineers" and "operators," with the former holding a more optimistic and the latter a more pessimistic view of automation.

Rather than trying to determine who may be right or wrong under given circumstances, this paper aims to explain the diverse perspectives *functionally*, recognizing the internal logic and rationality of each position. It begins by characterizing the two cultures in terms of their relationship to the technology and the types of cognitive representations they tend to construct and use. It then examines the values and judgments arising from these models, and how they apply to specific examples of distribution automation technologies. The emphasis is on the operator perspective because, from an academic standpoint, it is the more esoteric. Finally, the paper discusses some theoretical ramifications of this work and practical implications for management, particularly with regard to possibilities for improved, constructive resolution of conflicts surrounding technological innovation.

II. METHOD

The core of the research reported here consists of interviews with employees of electric utility companies, as well as some participant observation. I conducted 56 interviews with 71 individuals in six utilities: three in California, one in New York, one in New Jersey, and one in Germany. They were selected primarily based on convenience and access, but they also represented a satisfactory cross-section of the spectrum among U.S. utilities in terms of commitment to and experience with distribution automation. All of the U.S. utilities were investor-owned.

The people I spoke with included predominantly operators and engineers engaged with distribution in various ways (e.g. planning, computer systems, design, analysis, and management), as well as several "troublemen" who work in the field. For the most part, I found my informants through "snowball sampling" [11].

The interviews were semi-structured, focused, and non-directive [48], allowing informants to introduce new issues and identify matters of interest and significance to them. The ability of questions to elicit unanticipated responses is crucial, because in this way the research design allows for surprises and can alert the researcher to re-examine underlying premises and assumptions [37]. The evaluation of responses was exclusively qualitative, not statistical.

A previous phase of this research entailed visits to one fossil-fuel and six nuclear power plants, with two of these visits extending over several weeks [62]. Here, the emphasis was on observing people at work, though dozens of similar interviews were also conducted. In generalizing some of my conclusions to other technical systems, I also draw on similar research on U.S. Navy nuclear aircraft carriers and civilian air traffic control [40], [59], [60].

The theoretical foundation for the research methodology is given by principles of in-depth case study in the *Verstehen* tradition [26], grounded theory [27], [45], [71], and thick description [25], which uses ethnographic and interpretive methods [2], [35], [77] to study culture as a frame that establishes mental attitudes and guides action. This type of research is inductive in nature, aiming at hypothesis development rather than hypothesis testing.

Constant comparative analysis, as used in the construction of grounded theory, provides a way of dealing with the multiple realities encountered in a setting such as this, where both action and discourse (i.e., accounts of actions by various actors) are important. The goal is ultimately to arrive at theories that are grounded in empirical observations and meaningful to the people whose actions and accounts they explain, rather than derived from abstract categories that are superimposed on the reality of the setting in the hope of finding some agreement.

III. ORGANIZATIONAL SUBCULTURES

The term "culture" is loaded with multiple and ambiguous meanings [35], [49], [86]. In this paper, I claim "culture" as an operational and heuristic term for the purpose of categorizing a specific set of empirical phenomena. As has been done elsewhere [75], [76], "culture" is used here to describe those cognitive phenomena — perceptions, experience, beliefs and values — that are nurtured within occupational groups and guide behavior, judgment, and aesthetics. Culture thus characterizes ways of understanding how a technical system works, interpreting its purpose and goals, defining problems, generating solutions, and identifying general rules for action. In this sense, culture can be understood as an adaptation to the problems and pressures faced when working in a particular context.

Clearly, every industry has its own collective culture, and one could describe the "culture of electric utilities" as compared to other industries or types of organizations. For example, utilities in general might be characterized as risk-averse and dedicated to serving their customers. But for the present purpose, I adopt a differentiation perspective [44], focusing on the distinct identifiable cultures *within* the industry and within individual firms. These cultures are distinguished by the different relationships people have to power system technology: how they interact with the system, what problems they are responsible to address, what type of expertise they depend on, and how, as a result, they interpret the individual technologies and the power system as a whole.

The two major subcultures that have been observed in the settings of power plants [62], [72] and power distribution can be labeled as "operators" and "engineers." These terms are used here to typify two distinct ways of relating to the technology. Operators generally work more closely and hands-on with the hardware, engaging with it in practice and real-time, while engineers generally work in the more theoretical areas of design and analysis. Based on this typification, I will distinguish "operator" and "engineering" views of power systems and automation technology. Though my characterization draws primarily upon interviews with utility engineers and operators, some evidence suggests that the operator-engineer distinction is, in fact, a more general phenomenon that is not unique to the utility industry, but occurs in other technical settings such as manufacturing [73], [88] or aviation [3], [33].

It is important to emphasize that the boundaries of these cultural groups may not coincide perfectly with departmental boundaries or formal occupational titles held by individuals. The present definition of operator and engineering cultures primarily has to do with how a person *thinks*, which is functionally related to their job, but not by definition congruent with it. For example, an individual might hold an engineering degree but, as a result of their particular experience, identify to a greater or lesser extent with operator culture.

Although the distinction of operating versus engineering cultures is necessarily somewhat simplified, it retains the critical aspects of their identity and their substantive conflict. Most important, it continued to be validated empirically: there is sufficient coincidence of the cognitive aspects with the labels that the categorization was immediately meaningful to every organizational participant who was presented with it.[1]

IV. ENGINEERING CULTURE

Many readers will be intimately familiar with the activities and modeling frameworks of engineering. Obviously, "engineering" encompasses a great variety of specific job tasks. Engineers make design drawings, calculate specifications, select components, evaluate performance, and analyze problems. Their work has an important idealistic aspect, finding innovative solutions and always striving to improve things [24], [39], [73]. Some utility engineers are directly engaged with the physical hardware (for example, overseeing its

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[1] For example, when confronted with a statement such as, "It seems that engineers see it like this…," informants would nod in agreement or elaborate on the viewpoint in question, rather than question the category or the generalization.

installation); others work with abstract models of the power system (for example, power flow analysis) or on its indirect aspects (for example, instrumentation or computer systems). Those engineers whose work is more remote from the field and of a more academic nature best match the archetype of this description.

A. *Cognitive Representation*

In the engineering framework, "the system" is considered as a composite of individual pieces, since these are the units that are readily described, understood and manipulated. The functioning of the system as a whole is understood as the result of the functioning of these individual components: should the system not work, the obvious first step is to ask which component failed. Engineering is therefore analytic, not only in the colloquial sense of investigating a complex thing, but analytic in the very literal sense of "taking apart," or treating something in terms of its separate elements.

Like any analytic process, engineering requires modeling, or representing the actual physical system in abstracted and appropriately simplified terms that can be understood and manipulated. Abstraction and simplification also requires that the system elements be somehow idealized: each element is represented with its most important characteristics, and only those characteristics, intact. An engineering model will thus tend to consider system components in terms of their specified design parameters and functions. Each component is assumed to work as it should; components with identical specifications are assumed to be identical. Similarly, the relationships among components are idealized in that only the most important or obvious paths of interaction (generally the *intended* paths) are incorporated into the model. The parameters describing components and their interactions are thought of as essentially time-invariant, and invariant with respect to conditions not explicitly linked to these parameters [79].

The behavior of the system is thus abstracted and described in terms of formal rules, derived from the idealized component characteristics and interactions. These rules, combined with information about initial conditions, make the system predictable: from the engineering point of view, it should be possible in principle to know exactly what the system will do at any point in the future, as long as all rules and boundary conditions are known with sufficient accuracy. These rules also imply a well-understood causality: it is assumed that things happen if and only if there is a reason for them to happen. Of course, engineers know that there are random and unpredictable events, but in order to design and build a technical system, it is essential to be able to understand and interpret its behavior in terms of cause-and-effect relationships. Chains of causality are generally hierarchical, as in if-then decision-making systems. Stochasticity is relegated to well-delimited problem areas that are approached with probabilistic analysis [31].

In summary, then, the classic engineering representation of a technical system can be characterized as *abstract, analytic, formal, and deterministic.*

B. *Criteria and Expectations*

The most important, overarching performance criteria of technical systems in general can be summarized as *efficiency, reliability*, and *safety*. These general goals tend to be shared widely and across sub-cultures throughout an organization managing such a system. However, individuals or groups may hold different *interpretations* of what these general goals mean in practice, or how they can best be realized. Accordingly, they will also have different expectations regarding the promise of particular innovations.

When there are trade-offs among safety, reliability, and efficiency, cultural groups may also emphasize different concerns, not only because they have different priorities, but because they have different perceptions of how well various criteria are currently being met. In the academic engineering context, it is often assumed that certain standards of safety and reliability have already been achieved, and the creative emphasis is placed on improving efficiency. In the case of power systems, safety and reliability are problems that were academically solved a long time ago, whereas new approaches to increase efficiency offer continuing intellectual challenge.

The efficiency criterion thus takes a special place in engineering. Efficiency here can be taken in its specific energy-related sense as the ratio of energy or kilowatt-hour output to energy input, or in a more general sense as the relationship of output, production or benefit to input, materials, effort or cost. Efficiency is often a direct performance criterion in that its numerator and denominator are crucial variables of interest that appear on the company's "bottom line" (for example, electric generation and revenues). Even where efficiency measures something more limited or obscure (for example, how many man-hours are required for service restoration), a more efficient system will generally be able to deliver higher performance at less cost while meeting the applicable constraints. Conversely, low efficiency indicates waste, or the presence of imperfections that motivate further engineering. A more efficient system will also be considered more elegant: beyond all its practical implications, efficiency is an aesthetic criterion.

In addition, there is a set of indirect or supporting criteria which, according to the cognitive framework of engineering, advance efficiency as well as safety and reliability. While these criteria may be taken as qualitative standards for the system as a whole, they also apply in evaluating technological innovations and judging their promise. One such criterion is *speed*. It is an indirect criterion because it does not represent an actual need or an immediate, measurable benefit. However, the speed of various system functions offers some indication of how well the system is theoretically able or likely to succeed in being efficient. Generally, a system that operates faster will involve less waste. For example, restoring service more quickly means less waste of time, man-hours, and potential revenues. Responding and adapting to changes faster can also mean higher efficiency in terms of improved service quality or saved energy. Given the choice between a slow and a fast-operating device, all else being equal, most engineers would tend to prefer the faster one.

Similarly, *precision* is generally considered desirable in engineering culture. Actually, the desired criterion is *accuracy*: not only should information be given with a high level of detail, but it should be known to be correct to that level. Accurate measurements of system variables allow for less waste and thus support efficiency; they also further safe and reliable operation. However, the accuracy of a given piece of data is not known *a priori* and is subject to external disturbances, while its degree of precision is obvious and inherent in design (e.g. the number of significant figures on a digital readout). Precision can be chosen; accuracy cannot. Though precision does not guarantee accuracy, it at least provides for the possibility of accuracy and is therefore often taken in its place (and sometimes confused). Given the choice between a less and a more precise indicator of system parameters or variables, most engineers would prefer the more precise one.

More fundamentally, *information* in and of itself is desirable. Generally, the more information is available, the better the system can be optimized, and information can in many ways advance safety and reliability as well. In the event that there are excess data that cannot be used for the purpose at hand, the cost to an engineer of discarding these data is typically very low: skipping a page, scrolling down a screen or ignoring a number is no trouble in most engineering work. In selecting hardware or software applications, all else being equal, most engineers would prefer those offering more information.

Finally, the ability to *control* a system and its parts is another indication of how successfully the system can be engineered, managed, and optimized. This is because any variable that can be manipulated can also, in principle, be improved. As with information, in the engineering context, there is hardly such a thing as too much control. If the ability to control something is available but not needed, the engineer can simply ignore it. Most engineers would prefer to design systems and choose components that are controllable to a higher degree.

This set of criteria suggests a general direction for technological innovations that would be considered desirable and expected to perform well. Specifically, from the viewpoint of engineering, innovations that offer increased operational speed, precision, information and control appear as likely candidates to further the overall system goals of efficiency, reliability, and safety. While such expectations are quite logical given the representational framework of engineering, we will see that the perspective of operations yields a different picture.

V. OPERATOR CULTURE

Operators of technical systems, be they power plants, airplanes or air traffic control, must keep the system working in real-time. In electric power distribution, operators monitor and direct ongoing reconfigurations of their system of interconnected power lines and components from switching stations and in the field. Unlike engineering, where the object is to optimize performance, the goal in operations is to maintain the system in a state of equilibrium or homœostasis in the face of external disturbances, steering clear of calamities. An operating success is to operate without incident. Depending on the particular system, maintaining such an equilibrium may be more or less difficult, and the consequences of failure more or less severe.

Three types of challenges are generally characteristic of the operations job: external influences, clustering of events, and uncertainties in real-time system status. In the case of distribution systems, a large part of the hardware is physically accessible and vulnerable to all kinds of disturbances, whether they are automobiles crashing into poles or foxes electrocuting themselves on substation circuit breakers. Events like heavy storms or extreme loading conditions entail cascading effects in the system and require a large number of switching, diagnostic and repair operations to be coordinated and carried out under time pressure. At the same time, system parameters such as loading status for certain areas or even hardware capabilities are often not exactly known in real-time. Distribution operators are quite accustomed to working in this sort of situation, and the cognitive representation they favor, as well as their values and criteria for system performance, can be seen as specific adaptations to these challenges.

A. *Cognitive Representation*

In contrast to the engineering representation, which was described as abstract, analytical, formal, and deterministic, the operator representation of a technical system can be typified as *physical, holistic, empirical*, and *fuzzy*. This representation is instrumental to operators in two important ways: it lends itself to maintaining an acute situational awareness, and it supports the use of intuitive reasoning.

Because operations involve much more immediate contact with the hardware, system components are imagined as the real, physical artifacts in the way that they are perceived through all the senses [8], [84]. For example, a particular overhead distribution switch has a certain dimension, offers a certain resistance to being moved, makes a certain noise and shakes the pole in a certain way as it closes. Even when looking at abstract depictions of these artifacts on a drawing or a computer screen, operators "see" the real thing behind the picture. With all its physical properties considered, each artifact has much more of a unique individuality than its abstract representation would suggest: one transformer may overheat more than another of the same rating, or one relay may trip slightly faster than another at the same setting. Thus, components that look the same on a drawing aren't necessarily identical to an operator.

To be sure, operators must also work with abstract representations. For distribution operators, this means primarily circuit maps and schematic diagrams for switching. It is interesting to note, though, that the abstractions they find useful and transparent are, to them, significantly different from those abstractions preferred by engineers. For example, some operators were presented with a wall map of their jurisdiction designed by the company's engineering department. They found it unusable, saying it resembled "a piping diagram of [a nuclear power plant]."[2] While good maps for engineers are those that do a thorough job of depicting selected objects and their formal relationships, the most useful maps for experienced operators are those that most effectively recall their physical image of the territory.

Another aspect of operators' cognitive representation is that they conceptualize the system more as a whole than in terms of individual pieces. Rather than considering the interactions among components as individual pathways that can be isolated, the classic operator model is of one entire network phenomenon. Every action taken somewhere must be assumed to have repercussions elsewhere in the system, even if no direct interaction mechanism is known or understood. This is consistent with operators' experience, where they are often confronted with unanticipated or unexplained interactions throughout the system.

Rather than using formal rules to predict system behavior, operators rely primarily on a phenomenological understanding of the system, based on empirical observation. The underlying notion is that no amount of rules and data can completely and reliably capture the actual complexity of the system. Therefore, though one can make some good guesses, one cannot really know what will happen until one has seen it happen. No component can be expected to function according to its specifications until it has been proven to do so, and the effect of any modification has to be demonstrated to be believed. While engineers would tend to assume that something will work according to the rules, even if it didn't in the past, operators expect that it will work the way it did in the past, even if analysis suggests otherwise. Many arguments between engineers and operators can be traced to this fundamental difference in reasoning.

Finally, the operator representation is one that expects uncertainty rather than deterministic outcomes. Whether due to the physical characteristics of the system, insufficiency of available data, lack of a complete understanding of the system, or simply external influences, uncertainty or "fuzziness" is taken to be inevitable and, to some degree, omnipresent.

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[2] The comparison is noteworthy because an analogous difference in cognitive representations was found among nuclear engineers and operators who refer to different mental maps when explaining or trouble-shooting a power plant [62]. While nuclear operators would find a piping diagram comprehensible and informative, they prefer to visualize the physical plant as they have come to know it through inspection up-close, which for some meant actually crawling through the pipes before their plant was first brought on-line.

Ambiguity, rather than being subject to confinement, is seen to pervade the entire system, and operators suspect the unsuspected at every turn.

Overall, this cognitive representation was poignantly summarized by an operator who described his distribution system as a "live, undulating organism" that must somehow be managed. This physical, holistic, empirical and fuzzy view of the system is adaptive to the challenge of operating the system in real-time in that it allows one to quickly condense a vast spectrum of information, including gaps and data pieces with different degrees of uncertainty, into an overall impression or *gestalt* that can be consulted with relative confidence to guide immediate action.

The cultivation of a reference map of a complex set of events in real-time has been recognized as a key aspect of operation in other settings. In the cognitive literature, the phenomenon is called "situational awareness" [23], [30]. On Navy aircraft carriers, it is referred to as "having the bubble" [59], [60]. Here the combat duty officer must visualize what is going on in the multiple operational sectors he coordinates — undersea, surface ships, aircraft and missile operations — and integrate these diverse inputs into a single picture of the ship's overall situation. In this case, it is literally a three-dimensional bubble of awareness that the officer is responsible for comprehending. The concept is also recognized by civilian air traffic controllers, who must keep in mind every aircraft present in the airspace, its speed, and trajectory. In distribution systems, the status of the system with all its open and closed switches and the loading conditions on various components must be kept in mind and continuously updated by the operator. In all of these cases, maintaining a "bubble" of spatial and temporal awareness enables the operator to anticipate the consequences of operating actions and recognize imminent failures. Though the consequences of errors in distribution switching tend to be of smaller proportion than airplane crashes, the safety and reliability of the system still critically depends on operators "having the bubble."

Finally, operators tend to draw on intuitive reasoning, especially when data are insufficient but action is required nonetheless. Though there are manuals specifying operating procedures, many situations occur that could not have been foreseen in detail and courses of action recommended. To deal with the problem at hand, analytic tools may not be able to provide answers quickly enough. Worse yet, information on the books may be found untrustworthy under the circumstances — for example, if recent data appear to contradict what was thought to be known about the system. In order to come to a quick decision, the operator's main recourse then is to recall past experience with similar situations. How did the system behave then? Were people surprised? How did the particular equipment respond? Based on such experience, an operator will have an intuitive "feel" for the likelihood of success of a given procedure.

This experience-based approach is intuitive not because it is irrational, but because it is non-algorithmic. An operator might have difficulty articulating all the factors taken into consideration for such a decision, and how, precisely, they were mentally weighed and combined. He or she might not be able to cite the reasons for feeling that something will work, or not work. Nonetheless, the decision makes use of factual data and logical cause-effect relationships, as they have been empirically observed.

The use of intuitive processes is so deeply embodied in the culture of operations that they are often chosen over analytic approaches by preference rather than necessity. Obviously, both methods can fail; the question is about relative degrees of confidence. While engineers may frown on operator justifications that seem based on intractable, obscure logic or even superstition, operators delight in offering accounts of situations where their intuition turned out to be more accurate than an engineer's prediction. In fact, both approaches are adaptive to the work contexts of their proponents, and while both have a certain validity, either approach may turn out to yield better results in a given situation. The important point here is that substantive differences in cognitive representations and reasoning modes underlie what may appear to be trivial conflicts or petty competition between cultural groups, and that these differences will also have specific implications for the evaluation of technological innovations.

B. *Criteria and Expectations*

Of the three general system criteria — safety, reliability, and efficiency — safety takes a special priority in operations, while efficiency is less of a tangible concern. From the point of view of managing the system in real-time, efficiency is an artifact of analysis and evaluation: a number tagged on after the fact, having little to do with reality as it presents itself here and now. Though it may indicate operating success, efficiency more directly measures the performance of engineers. Most operators would agree that having an efficient system is nice, as long as it doesn't interfere with their job.

Safety, on the other hand, takes on a profoundly tangible meaning for operators because the consequences of errors face them with such immediacy. In power distribution, any single operation, performed at the wrong time, has the potential to cause customers to lose power. Immediately, telephones will ring, voices on the other end will shout and complain, and the control room may even fill with anxious supervisors. Because of the interdependence of power system components, the consequences may occur on a much larger scale than the initial error. Aside from causing power outages, incorrect switching operations can damage utility and customer equipment.

But even more serious is the risk of injury or electrocution, whether of utility crews or others who are accidentally in contact with equipment (for example, people in a car under downed lines). The one action operators dread most is to energize a piece of equipment in the course of switching operations that is still touching a person. Like operators of other technical systems, distribution operators carry a personal burden of responsibility for injuries or fatalities during their shift that goes far beyond their legal or procedural accountability. The difference between an intellectual recognition and the direct experience of the hazards cannot be overemphasized: hearing an accident described is not the same as watching one's buddy die in a flash of sparks a few feet away. Such incidents are sufficiently frequent that in every shift of distribution operators interviewed during this research, at least one individual had either witnessed or been partially responsible for a death or severe injury. The awareness of the life-taking potential of distribution system operation is thus in some sense omnipresent in the control room and implicitly or explicitly enters any decision made there, whether about day-to-day operations or about implementing new technology.

Their acute perception of safety colors operators' interpretation of other system goals and helps define their criteria for good system design and performance. The set of criteria — speed, precision, information, and control — which, from the engineering perspective, support not only efficiency but also safety and reliability may be seen by operators as less important or even counterproductive. Instead, operators value a different set of criteria that specifically support their ability to operate the system safely.

Speed, generally advantageous in engineering, is more problematic in operations because one is working in real-time. Speed is desired by operators in the context of obtaining information. They may also wish for their actions to be executable quickly, so as to gain flexibility in coordinating operations. However, a system of fast-responding components and quickly-executed operating procedures, where effects of actions propagate faster and perhaps farther, also introduces problems: it will tend to be less tractable for the operator, provide less time to observe and evaluate events and think in between actions, and allow problems to become more severe before they can be corrected. Power systems are inherently fast in that electric effects and disturbances propagate at the speed of light, making cascades of trips and blackouts almost instantaneous. Any delays or buffering of such effects work toward the operator's benefit. Thus, from the perspective of operations, *stability* is generally more desirable than speed. Operators would prefer a system that predictably remains in its state, or moves from equilibrium only slowly, allowing for a greater chance to intervene and bring it back into balance.

Information can also be problematic in the context of operations. To be sure, there are many examples of information that distribution operators say they wish they had, or had more of. But more is not always better. Because one is gathering information and acting upon it in real-time, the cost of discarding irrelevant information is not negligible. Deciding which data are important and which are not costs time and mental effort; superfluous data may distract from what is critical. Specifically, too much data may interfere with “the bubble.”[3] Distribution operators often give examples of information overload: many computer screens that must be scanned for a few relevant messages, or many pages of printout reporting on a single outage event. Generally, instead of greater quantity of information, operators desire *transparency*, meaning that the available information is readily interpreted and placed into context. It is more important for them to maintain an overview of the behavior of the whole system than to have detailed knowledge about its components: in terms of maintaining situational awareness, it is preferable to lack a data point than to be confused about the big picture even for an instant. If more information has the potential to create confusion, then for operators it is bad.

Similarly, more precision is not always better for operators. While engineers can make use of numbers with many significant figures, the last decimal places are probably not useful for guiding operating decisions. In fact, operator culture fosters a certain skepticism of any information, especially quantitative. This skepticism is consistent with their keen awareness of the possibility of foul-ups like mistaking one number for another, misplacing a decimal point, or trusting a faulty instrument, and the grave potential consequences.[4] Therefore, operators' primary and explicit concern about any given numerical datum is whether it basically tells the true story, not how well it tells it. Moreover, precision can be distracting or even misleading, suggesting greater accuracy than is in fact given. Thus, in operations, *veracity* of information is emphasized over precision. Rather than trusting a precise piece of information and running the chance of it being wrong, operators would generally prefer to base decisions on a reliable confidence interval, even if it is wide.

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[3] An interesting example from a different setting is Perby's account of weather forecasters in Sweden [53], who rely largely on experience and intuitive, “operator-type” reasoning. It was found that augmenting the forecasters' intuitive approach with computer data and processing *lowered* the quality of the forecasts. Perby concludes that “increased information … does not mean greater reliability in decision-making.”

[4] The events leading up to the nuclear accident at Three Mile Island are a classic example [69].

Finally, more control is not always better. Of course, there may be variables over which operators wish they had more control. But the crucial difference is that in engineering, control always represents an *option*, whereas in operations there may be an associated responsibility to exercise this control: the ability to control a variable can create the expectation that it *should* be controlled, and produce pressure to act. Operators tend to be wary of such pressure, primarily because it runs counter to a basic attitude of conservatism fostered by their culture: "When in doubt, don't touch anything."[5] Their reluctance to take any action unless it is clearly necessary arises from the awareness that any operation represents a potential error, with potentially severe consequences. An interventionist approach that may allow greater optimization and fine-tuning thus inherently threatens what they see as their mission, namely, to avoid calamities.

In pragmatic terms, more controlling options may mean that operators have more to do and keep in mind, and thereby increase stress levels. Alternatively, they may not have time to exercise the control at all, in which case their performance will be implicitly devalued by the increased expectation. Because time and attention are limited resources in operations, and because of the potential for error associated with any action, the option not to control can be more desirable than the ability to control. This option is provided by a system's *robustness*, or its tendency to stay in a viable equilibrium by itself.

In summary, then, the system qualities that are most important for operators are stability, transparency, veracity, and robustness, which support them in their task of keeping the system in homœostasis. Not coincidentally, these criteria are generally associated with older technologies, designed and built in an era where operability was viewed as more of a firm constraint than material resources. In the case of power distribution systems, stability and robustness have been provided largely by oversized equipment and redundancy of components, while transparency and veracity were furnished through simple mechanical and analog instrumentation and controls. From the viewpoint of increasing the efficiency of such systems in today's world, process innovations guided by engineering criteria may be desirable indeed. From the operations perspective, however, such innovations may be expected to adversely affect performance reliability and especially safety. Thus, when steps are proposed toward more refined and sophisticated system operation, operators may identify potential backlash effects, in which opportunities for system improvement also introduce new vulnerabilities.

VI. THE CASE OF DISTRIBUTION AUTOMATION

This research focused primarily on two specific approaches to automating power distribution systems. The first involves the remote operation of switches to reconfigure the topology of distribution circuits, along with increased monitoring of circuit data. This technology is known as Supervisory Control and Data Acquisition (SCADA). It implies a transition from operating through field personnel (communicating via telephone or radio) to directly accessing the system via a computer terminal in the control room. This has already been implemented on various scales by U.S. utilities over the past two decades, though it has not reached a majority of distribution systems. The second, more radical or comprehensive approach is operation through expert systems that either recommend actions to the operator (open-loop) or execute them as well (closed-loop). The use of expert systems in power distribution is still experimental and quite limited.

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[5] Different variations of this motto were stated by several operators.

The motivation for distribution automation is a straightforward application of engineering criteria. Remote control vastly increases operational speed, since personnel no longer need to physically travel to sequences of field locations. Aside from the more efficient use of man-hours, increased speed of switching operations implies faster service restoration times after power outages. In addition, SCADA provides more information and greater precision of knowledge about the system status. The shorter time scale of switching, especially if SCADA is augmented with "intelligence," also introduces new options to reconfigure circuits for purposes of increasing efficiency. This can be accomplished by reducing electric losses (through equalizing loads on different circuits), or by enhancing the utilization of assets (through redistributing load at different times so as to get maximal use out of existing equipment). These strategies are known as "load balancing," and along with very rapid automated service restoration, they motivate the development of expert systems for power distribution applications. The engineering literature contains many enthusiastic projections of potential savings and performance improvements by means of these techniques [1], [17], [28], [34], [47], [66], [67].

Among distribution operators, however, the enthusiasm for automation tends to be modest and declines with increasing sophistication of the proposed innovations. While many operators report favorable experiences with SCADA and are quick to point out its advantages, each implementation of SCADA surveyed also met with some degree of resistance, and critiques are still offered by operations staff. The main points of concern relate to safety and the operators' ability to maintain an accurate situational awareness. Without issuing orders over the phone and waiting while they are carried out by someone in the field, time is suddenly compressed. Thus, one operator commented,

> It used to be that you had time to think between switching things. Now you don't have time to think.

and another described an error he had committed recently:

> It was an embarrassing thing – my fingers were faster than my mind. I thought I had opened a switch, but I hadn't...

At the same time, the redundancy of a second person reviewing the steps is eliminated. Less reliance on field crews also means fewer first-hand reports from physical inspection of the equipment that might indicate any abnormalities or developing damage early on. Furthermore, silent interaction with computer terminals reduces the ability of a team of operators in the control room to remain aware of each other's activities and coordinate them. In effect, SCADA imposes on operators an engineering representation of the system that takes components to be readily parameterized and well-behaved, while reducing the opportunity to collectively construct an operator's view of the "beast."

Perhaps most dauntingly, operators have to trust their computer screen to tell them whether a switch is open or closed, potentially a matter of life or death for the field crews. Thus it is not uncommon for operations staff to insist on verifying the operation of SCADA-controlled equipment on location, or even choose to control it manually instead. For example, operators at one utility said,

> We had a guy who, three years after SCADA was installed, sent someone out to the substation to operate the switch.

Finally, given the greater ability to respond to inefficiencies in the system, operators feel pressured at times to take actions that they would prefer to avoid for reasons of safety and minimizing error potential. One supervisor recounted his experience of the first year after SCADA was introduced by his company:

> The data was scrutinized as though one must act on it immediately. The people from [the superior administrative office] called to say, you have to relieve this switch and that... In the second year, I told the staff to ignore them.

As a result of the above concerns, even when SCADA technology is successfully installed, operators often choose not to make full use of the available capabilities, and thereby compromise the anticipated efficiency gains.

With respect to expert systems, operators raise more ardent objections that can be expected to lead to significant conflicts when such technologies are actually installed. The primary contention is that the knowledge required to operate the system well can ultimately not be formalized. One problem is the need to respond flexibly to external influences of an unpredictable nature, or such information as cannot be readily integrated into a computer program. One operator argued,

> What if something goes wrong? What if a line is down, jumping around, and the fault current isn't high enough to trip [a circuit breaker]? The computer has no idea...

and another explained,

> There are so many contingencies that you can't program into a computer – say, the East Bay firestorm. Or I want to test a circuit and there's a van with six kids under it. Or talking to the fire department... You want a person doing these things.

Another, related problem is the accurate maintenance of a vast database on system characteristics, some of which defy formal categorization, such as the actual quality of a particular conductor or splice:

> You may have a piece of wire that's a smaller size, because they ran out. So you know you can't load it the same. But the computer doesn't know that.

Another operator claimed,

> Based on my 25 years of utility experience, I know that a database is never more than 85% accurate and updated. So you can't let the computer do things.

Operators also contend that a system programmed to go "by the book" would be less successful at rescuing seemingly hopeless situations through improvisation. For example, an operator described an action that, he claimed, saved thousands of customers from a power outage:

> One operator recently switched in these two [transformer] banks. A computer would never have done that because it was too risky. It wasn't by the book, but the guy knew that it would be okay.

In the long run, they are concerned about loss of skill and the problem of having to take over in case of a computer failure, without regular practice.[6] Though it is often argued that automating control processes frees up operators' time and attention, systems designed in this way tend to depend on active intervention, and the operators remain responsible to take over this task should any part of the automation fail. As a retired operations supervisor commented,

> If there's an emergency, and you're the guy who's been studying it all year and you have a feeling for it, you probably know how to deal with the emergency. If it's all automated and you have an emergency, you're standing there with your face hanging down wondering what you're supposed to be doing.

Particularly new operators would miss the opportunity to develop an experience-based mental map of the system.

Finally, automation may allow systems to become so complex and demanding in their operation that they are no longer transparent in real-time to any human, in which case the computer must be relied upon completely. Some engineers argue, for instance, that

> ...the restoration task may prove unmanageable for an operator not aided by some kind of tool. Herein lies the importance of an expert system implemented on a computer [1, p.101].

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[6] This problem is well-recognized in the context of aviation [3], [33], [70].

Because of the discrepancies between abstracted models and the physical system they routinely experience, operators fundamentally distrust the notion of computers making real, consequential decisions. Using a popular operator metaphor for the human brain, one supervisor said,

> Don't get me wrong – I love computers. But for these decisions, the old carbon-based unit is still superior.

In U.S. utilities that are implementing distribution automation, these reservations on the part of operators have resulted in delays, reductions of scope, or even abandonment of automation projects. Their resistance can manifest either as verbal or as behavioral opposition to proposed operating techniques. Specifically, operators may choose to execute controls manually rather than remotely, refrain from undertaking certain switching procedures, disregard recommendations by expert systems, or override a closed-loop mode of operation. In one instance, a leading engineer summed up that his company's ambitious demonstration program was essentially abandoned because of "attitude problems" in the operations department. Even in cases where automation is continually being implemented and expanded, it appears that such resistance has led to modified application and thus diminished economic returns compared to initial projections. The evolution of distribution automation is therefore inevitably impacted by cultural conflict.

VII. DISCUSSION

Disagreement between occupational groups as described here tends to be well-recognized among practitioners in technical industries, even if it receives little explicit mention in public forums such as the technical literature or discussions of corporate policy with respect to technological change. In conversation, operators, engineers, and managers alike acknowledge these differences of opinion and even point out their importance for the fate of innovations. Why, then, is cultural conflict not a more common topic?

One might surmise that a fear of what could be seen as corporate embarrassment would motivate managers to minimize these conflicts in public. On a deeper level, though, there are two important misunderstandings that may lead anyone to dismiss the core problem as either intellectually trivial or hopeless to resolve in practice, and therefore not worthy of explicit study. These misunderstandings are (1) that evaluations of technology are determined only by facts, and (2) that cultural groups have inherently subjective or irrational biases.

In the first case, one would argue that differences of opinion arise mainly because people do not have uniform access to the same objective information. This assumption is made, for instance, by those engineers who argue that operators who object to innovations do so mainly because they are unaware or misinformed about the actual capabilities of state-of-the-art technology. In principle, then, conflicts could be resolved by education: once everyone has all the facts straight, they will agree on the most reasonable course of action. However, while education is surely important for fostering cooperation and productive discussions, I would argue that some important perceptual differences will always remain, even in a scenario of perfect information. This is because the root of the differences lies not in *fact*, but in *representation*.

Consider the example of safety in automated distribution switching. An engineer might cite the specifications and performance record of a particular control mechanism and assert that it meets all standards for reliable operation. Yet an operator, having never used the mechanism, might reject the technology based on a hypothetical failure scenario: what if this mechanism closed the switch, but electronically indicated an "open" position? The conflict here is not just about the facts: even if the exact failure probability of the mechanism were known, the conflict would persist. Nor is the argument necessarily about different standards of safety. More fundamentally, the difference lies in the modality of reasoning: the engineer is convinced by abstract analysis, whereas the operator trusts only direct experience. Thus, the operator will remain unimpressed even by superior safety characteristics as shown on paper, until the innovation has been observed under the precise applicable circumstances for a period of time. Specifically, the operator may raise concerns about failure modes that fall outside the scope of analysis, based on other experiences which the engineer, in turn, might argue to be technically unrelated. The essence of the disagreement, therefore, is not about how safe automated switching actually *is*, but about *how one knows* that it is safe.

The second misunderstanding of cultural conflict is to attribute it entirely to pre-existing and irreconcilable differences of a subjective and non-rational nature. Thus, an operator's objections to an innovation might simply be explained by saying that operators are generally old-fashioned, afraid of the unknown, and prejudiced against computers. Conversely, an innovation proposal might be seen as just another product of unrestrained engineering creativity, serving no practical purpose other than to satisfy the engineers' relentless appetite for tinkering and hypothetical optimization games. A related interpretation is that operators and engineers simply act in their own self-interest as occupational groups. Here one would suspect that operators only object to innovation because it threatens their status or job security, whereas engineers advocate innovations only to bolster their own position or self-image. If the above assertions are true, then any attempts to resolve these differences by intellectual argument are bound to fail. Indeed, not few senior practitioners in the utility industry seem to agree with this conclusion and see the retirement of an entire generation of operations staff as the only possible end to the conflict about automation.

Yet I argue that cultural differences can also be understood in a constructive way that unifies the picture, while granting each perspective its own validity. The point is that opinions about technological innovations, however contradictory or self-serving they might appear, can be explained as rational consequences of cognitive representations and reasoning modes appropriate to specific contexts. Thus we might say that a view of technology is *contextually rational* because it follows in a logical and internally consistent manner from certain assumptions, which are in turn logical assumptions to make within a given work context.

Specifically, the respective cognitive representations used by engineers and operators give rise to different ideas about what system modifications may be desirable, and divergent expectations for the performance of innovations. If one imagines a technical system in terms of an abstraction in which interactions among components are governed deterministically by formal and tractable rules, then (1) these formal relationships suggest ways of modifying individual system parameters so as to alter system performance in a predictable fashion according to desired criteria, and (2) it is credible that such modifications will succeed according to *a priori* analysis of their impacts on the system. From this point of view, automation holds positive promise and little risk. On the other hand, if one imagines the system as an animated entity with uncertainties that can never be completely isolated and whose behavior can be only approximately understood through close familiarity, then (1) modifications are inherently less attractive because they may compromise the tractability and predictability of the system, and (2) any innovation must be suspected of having unanticipated and possibly adverse consequences. From this point of view, automation implies the attempt to squeeze the system into a conceptual mold that it may not fit – treating an animal like a simple machine – and thus harbors the potential for disaster.

The notion of contextual rationality not only grants both sides an intellectual legitimacy, it also provides that conflicting views can be motivated not by conflicting interests, but by shared concerns about the fate of the technical system.[7] Thus engineers and operators alike wish for the system to be efficient, safe, and reliable, notwithstanding their different interpretations of what these goals mean in practice and how they can best be achieved. Indeed, the electric utility industry has historically placed great emphasis on cultivating a sense of personal commitment toward the well-being of the system among its employees, shaping what is still generally experienced as “utility culture.” No explanation of behavior and discourse in this setting could be complete without accounting for this phenomenon.

VIII. IMPLICATIONS FOR MANAGEMENT

The problem of cultural conflict as characterized in this paper has two important implications for management, namely (1) that addressing the conflict in some manner is inevitable, and (2) that such conflict can, in some ways, be considered an asset rather than a liability to an organization.

When management deems technological innovation desirable but operations staff resist it, one possible approach is to attempt to minimize the impacts of this resistance. In the short run, this may be done by circumventing operators in the decision-making process. However, if technologies are implemented that conflict with operators' values and concerns, they may compromise the results through selective use or non-use of the installed capabilities [41]. For the long run, then, strategies may be devised that reduce operators' discretion and ability to influence outcomes, or even replace human operators entirely by expert systems.

This approach bears an obvious risk: What if operator knowledge and skills are indeed important to the successful operation of the system? What does it mean to sacrifice the person who “has the bubble”? Typically, the actual contribution of operators toward system performance is not well-known or even measurable for lack of feasible experiment; it can easily be underestimated. It is interesting to note that in the context of nuclear plant safety, where operator actions and their consequences are studied extensively, operators have primarily been considered as possible initiators of failure sequences [57]. Their positive contribution has been recognized only quite recently, sparking a new interest in human factors research [80]. Similarly, distribution operators feel that they receive a disproportionate amount of attention for mishaps as compared to successes. As automation is implemented, one potential problem is that errors and coordination problems are attributed to the control *retained* by human operators, rather than that which they have given up. This may lead managers to conclude that more automation is needed, while in fact events support the validity of operators' warnings.[8]

The model of contextual rationality suggests that when operators assert the importance of their experience and discretion, this may not be a purely self-serving claim. Because their position can be traced through a logical course of reasoning to a common concern for the fate of the system, it is plausible to assume that their arguments have some merit and deserve careful consideration. Depending on the nature of the particular system, the potential consequences of system failures due to neglecting the operator perspective may be severe and life-threatening;

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[7] Here we also draw on an integration perspective of organizational culture, according to Martin [44].

[8] This phenomenon has been reported in aviation, where failures of highly automated aircraft were diagnosed as pilot error, to be remedied by further automation [68].

even if not, they may still exceed the cost of adapting the innovation process in response to their concerns.

Indeed, conflict over innovation could be considered a welcome occasion to explore diverse views and understandings of technology and their positive contributions to an organization's goals. As Van Maanen and Barley have argued [78], deviance from managerial expectations in organizations has traditionally been considered dysfunctional and its sources have been ignored, muted, or attributed to factors not substantively related to the work. Contrary to this conventional wisdom, however, "willful violation of managerial expectations may also correspond to a pervasive logic embedded within the historically developed practices of occupational members doing what they feel they must. ...What is deviant organizationally may be occupationally correct (and vice versa)" (p.291).

The diversity of "occupationally correct" positions can enhance an organization's collective technical knowledge and even offers protection against certain failure modes. Specific support for this claim comes from the nuclear case, where a common characteristic among successful plants (i.e., those with excellent safety records and high availability) was found to be an active and deliberate maintenance and nourishment of cultural diversity among engineers and operators [62], [64]. This was one striking similarity in a cross-national comparison of plants with otherwise quite diverse operational and managerial styles [62]. The nurturing attitude manifested especially in problem-solving situations, where decision-makers drew on the interpretations of both operators and engineers as having equal status but different perspective, with participants negotiating which interpretation was more applicable or useful in a particular situation. It was felt that cultivating both views offered an insurance against shared misconceptions about the plant (for example, misjudging the significance of an instrument reading). In other words, cognitive diversity may protect organizations against errors of rendition [58], [81].

It is plausible to suppose that if cognitive diversity is valuable in the day-to-day problem solving, it is also useful in planning and innovation design. While the scope of the present research did not include a rigorous evaluation of the performance of distribution automation, the projects described as the most successful by those involved were those in which the diversity of views was considered early in the design stage, and where innovations were tailored to the specific needs and concerns of operators.

It is also plausible that the dynamics of cultural conflict described here in detail for the case of power distribution apply in other industries that manage technical systems. This claim is supported by the consistency of some important observations in power plant operation, aviation, air traffic control, and aircraft carrier operations. It is important that, while some characteristics of power distribution were described here for illustrative purposes, the core explanation of the diverse cognitive representations and contextual rationality does not hinge on the particular details of the technical system or the organization managing it. The argument of this paper is also consistent with other authors' accounts of the cultural dynamics surrounding technological innovation in various industries [73], [88]. Finally, anecdotal evidence suggests that practitioners in other technical settings are no strangers to the type of cultural conflict characterized here.

IX. THEORETICAL IMPLICATIONS

Based on the case of distribution automation, this paper has illustrated how diverse cognitive representations of a technological system may give rise to conflicting but contextually rational assessments of technological process innovation. One would expect to find representational diversity in an organization like an electric utility that manages a complex and hazardous technological system because the technology is too complex for any one person to comprehend in its entirety across function, space, and time [11], [13]. Knowledge-intensive firms especially are characterized by

> a process of distributed cognition in which multiple communities of specialized knowledge workers, each dealing with a part of an organizational problem, interact to create the pattern of sense making and behavior displayed by the organization as a whole [10].

The notion that such a differentiation of perspectives represents a functional adaptation to such an organization's task is underscored by findings that the operator-engineer dichotomy in its cognitive aspects[1] is invariant across national cultures [62]. If, as Weick and Roberts [82] suggest, "reliable performance may require a well-developed collective mind in the form of a complex, attentive system tied together by trust," and "normal accidents[2] represent a breakdown of social processes and comprehension rather than a failure of technology" (p.378), then we must further conclude that constructive interaction of diverse occupational cultures within such an organization is vital for its success and, depending on the nature and extent of hazards involved, for employee and public safety.

The distinct competence of each community is taken here to encompass not only the substance of what is known, but a distinct epistemology: a way of knowing things, constructing models, drawing inferences, making predictions, accepting or rejecting courses of action. Such different ways of knowing have been described within another specific technical setting by Orr [52], whose findings about photocopier repair technicians mirror some of those reported here about operators. Orr specifically describes the notion of a unique kind of understanding of a technological system cultivated by repair technicians as opposed to trainers or engineers. His research emphasizes that the nature of the technicians' task demands "tricky interpolations between abstract accounts and situated demands" based on "bountiful conflicting and confusing data" [14] and furthermore explores the function of narrative as a way of fixing and preserving the experiential knowledge needed to deal with this type of situation. Similarly, Boland and Tenkasi [11] recognize the importance of two distinct modes of cognition in the organizational setting, one paradigmatic and one narrative, referring to the distinction introduced by Bruner [16]. Though a discussion of the explicit use of narrative among distribution operators (which was indeed observed) is beyond the scope of this paper, the finding that knowledge of a technical system may be represented in a form that relates to past personal experience on the one hand or abstract quantities with formal relationships and rule-based behavior on the other is in excellent agreement with these authors' propositions.

What the present work further aims to develop, however, is the relationship between such ways of knowing and the process of technological change within an organization. This connection was established by way of the values and criteria that are consistent with the respective representations and that become applied to real, practical choices about work and innovation. The resulting perspective is one that recognizes subjective epistemology applied to

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[1] Other aspects of the dichotomy that vary across national settings include placement within the formal organizational chart, educational requirements, dress, and social status.

[2] See [54].

matters of objective ontology. The technological artifacts and processes in question have objective properties and behaviors, some of them more obvious and others less (say, the failure probability of a switch), but still unarguably real and factual. The literature that analyzes the ramifications of implementing such artifacts and processes, especially with the intention of informing management decisions, generally addresses these matters in terms of an epistemology that is similarly objective, inferring consequences or impacts of technological choices through cause-effect relationships by a method that can be proven right or wrong [1], [15], [17], [34], [46]. But when we acknowledge different yet equally legitimate ways of making such inferences, these epistemologies must be labeled subjective by virtue of their non-uniqueness (there is more than one right way to decide whether the switch is safe). This would be unproblematic if one could therefore simply relegate them to the domain of things irrelevant to rational decision-making (such as whether transformers are beautiful or ugly) and move on. However subjective, though, these ways of knowing and inferring are inextricably linked to the very real process by which people design, fix and operate machines. Thus, in order to gain a thorough understanding of how technology is chosen and used, it is necessary to adopt a framework that can account for diverse perspectives simultaneously.

The need for such an approach is elegantly stated by Czarniawska [20] in the context of anthropological research in organizations:

> The result should be a multifaceted magnifying glass, showing a picture that is wholly visible but fuzzy from a distance, and that becomes sharp but incomplete when viewed through one of the facets. ... The challenge is in presenting the complexity of a situation as it is perceived simultaneously by different actors (and the researcher), in the hope that this same complexity will help both actors and observers to understand the reasons and effects of actions undertaken by actors when they are looking through one facet only. They see a fairly clear picture, yet do not realize that looking through another facet will produce a similarly clear but different picture (p.204).

This work argues for extending such an anthropological perspective to the very specific and applied matters of technology where it has not traditionally had a place.

X. FUTURE RESEARCH

One obvious research task emerging from these findings is to test the categories of operator and engineering culture for their generality across different technical and organizational settings, to ascertain whether an important set of characteristics — particularly the core definitions of the cognitive representations as presented here — remain invariant (as I expect they will). The next task would be to examine whether these two cultural categories are associated with similarly conflicting positions regarding technological innovation in various settings, or in what different ways the cognitive representations and epistemologies come to bear on practical decisions. This approach could also be extended to other occupational or cultural communities. Finally, the view of technological innovation, which has been broadened here to explicitly encompass diversity of perspective at least in a static sense, might be further developed to describe the dynamics of the change process over time and compared with other coherent theories of the dynamics of technological change.

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