Manufacturing Change: The Impact of Virtual Environments on Real Organizations

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ABSTRACT
Manufacturing workplaces are becoming sites of intense change as technologies like IoT and AR/VR are beginning to make deep inroads into how complex products are engineered and assembled. These categories of technologies are becoming prominent in manufacturing because they offer potential solutions to the problems of unskilled labor and workforce shortages. Technology has the potential to shift manufacturing in both large and small ways, to better understand how a manufacturing organization might appropriate VR, we ran a study with a global aviation manufacturer headquartered the United States. To document the changing nature of work via this class of technologies we conducted a VR study which facilitated access to participant observation and interviews (n=21). Our findings provide initial insights into the organizational impact of VR on human performance augmentation and skill acquisition revealing the larger infrastructural challenges facing the adoption of consumer grade smart technologies in industrial workplace settings.

Author Keywords
Field Studies; Virtual Reality; Qualitative Methods.

CSS Concepts
•Human-centered computing~Human computer interaction (HCI)~Empirical studies in HCI

INTRODUCTION
As we know from over 50 years of computing research in the workplace, reaping the benefit of new technology "requires extensive changes in organizational processes, personal and interpersonal orientations, and attention to information technology" [20]. Foundational studies of groupware implementation revealed the complexity of technology adoption and use impacting both the structure of the organization and the nature of work [30]. The promise of groupware, like electronic calendar applications, was delivering new kinds of tools to help workers better use their time. Calendars were designed to benefit and be use by everyone but ultimately served as tools to track and enforce greater productivity by management [15]. Designers did not understand the social impact of technology on workplace practices [3]. The results of which created new types of work that did not always benefit the worker and reinforced hierarchies of control [15]. Now, the complexities of technology implementation are further compounded as new types of smart technologies designed for consumers permeate into industrial workplace settings.

This new category of smart computing devices includes the Internet of Things (IoT), purpose-built sensor platforms, advanced data capture and analytic capabilities, and Augmented Reality (AR) and Virtual Reality (VR). Examples of how these technologies are changing the nature of work can be found both on the shop floor and in the office. VR is being used for training and troubleshooting for mechanics and technicians and engineers are beginning to explore the use of VR to design products for manufacturability [42]. VR is one example of ongoing initiatives in manufacturing fueled by the digital revolution to enable connected people and connected machines. IoT sensors are being used to track machine vibrations and self-report maintenance issues to dispatch workers for repair [37]. AR is being used in warehousing environments to help employees locate and select the right item [34]. Fleets of Google Glass have even become a required part of the employee work uniform on the assembly line [43]. Taken together, these new smart technologies are rapidly changing the manufacturing landscape and opening up completely new application spaces.

Manufacturing facilities present an opportunity to understand how automation can enhance the worker experience while delivering results. Osborne and Frey predict that approximately 47% of the total U.S. employment will be automated over the next two decades, predominately effecting the blue-collar workforce [13]. As one of the largest industries employing blue-collar workers, manufacturing accounts for 11.6% of U.S. Gross Domestic Product (GDP), and one out of seven private sector jobs, putting 12.75 million people to work every day [24,40]. While it is clear that manufacturing is critical to the United States economic prosperity, significant workforce concerns continue to challenge the industry. Deloitte and the Manufacturing Institute predict 3.2 million jobs will be needed in manufacturing by 2025, however,

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as many as 2 million will be left unfilled due to a shift in required skillsets and an aging workforce [24]. Contrary to popular fears, the jobs challenge is not that automation will replace the labor force, but that it will be necessary in order to fill the gaps left by the lack of qualified workers.

Smart technology is positioned as offering solutions to the problems of increasing complexity and an aging workforce, that are leaving manufacturing jobs unfilled [25]. The dominate narrative encourages manufacturers to implement smart tech to maximize efficiency and productivity to remain relevant in a global economy [24]. However, the assumptions about the benefits of these kinds of technologies are largely unproven in the context of long-term implementation and use and do not account for factors like employee identity or job satisfaction [33]. As has long been the case, it is not always clear what efficiency means in new contexts of work and how these technologies benefit the people tasked with its use rather than supervision [15,22].

VR is one element in a larger class of smart technologies that transcends the shop floor, impacting the entire supply chain including people, processes, and procedures. To document the changing nature of work, we conducted a qualitative study on the implementation of a VR system at a large aviation manufacturer in the United States. We collected participant observation to understand the motivations and expectations of the new VR system across the organization which informed the design of our study. The VR plugin used in our work was a brand-new feature still undergoing development on an existing industry software platform. Our study also acted as a mechanism for understanding the unique design challenges that manifest in the development and implementation stages of new digital technologies like VR and its impact on job skill requirements for engineers, trainers, and mechanics.

DESIGNING VR FOR ORGANIZATIONS

To understand the changing nature of manufacturing work and the types of skills required by the workforce due to the enactment of new computing capabilities, we need to examine the motivations driving smart technology adoption and use, and those impacts on the mechanisms of organizational change.

Opportunities for Immersive Environments

Examining the prior use of immersive environments in organizations exposes the challenges that new VR systems will have to overcome for adoption and implementation to occur. The aviation manufacturer involved in our study had previously experimented with Cave Automatic Virtual Environments (CAVE) systems. Akin to a modern IMAX theater, a CAVE system is a combination of projectors and screens outfitted to three or more walls in a room to create an immersive environment [9]. The focus on these early adaptations of VR were to improve "visual effectiveness" measured across parameters including visual acuity, look around, linearity, progressive refinement, and collaboration [10]. In comparison to other VR head mounted display systems, at the time, the CAVE allowed for the most flexibility to orchestrate group participation which was recognized as a key component "for VR to become an effective complete visualization tool" [10].

Conventionally, CAVE experiences were geared towards individual users. However, large organizations were some of the first entities that could afford to install such expensive systems. Reconfiguring the technology for conference rooms facilitated multiuser interactions where one individual controlled the narrative while others viewed the screens. By creating CAVE conference rooms companies adapted the technology to fit the organization. This aligned with traditional workplace practices that revolved around centralized control and top-down decision making. The organization remained steadfast in its operating procedures and the technology was used as mechanism for reinforcing power and control. But as work permeated outside of office boundaries, in both place and time, CAVE systems quickly became outdated.

Enabling greater mobility, advances in mobile head mounted displays have led to a resurgence of VR for corporations pushing the boundaries of use to entirely new areas of work. Examples of VR's impact on the workplace practices include: providing situational awareness for emergency responders [1]; preplanning the excavation of underwater caves for archeologists [21]; training doctors prior to performing medical surgeries [35,39]; and exchanging classrooms for VR in the cockpit [26]. These VR applications illustrate advanced technical capabilities, yet the experience remains focused on the individual user even though the adoption of VR is expanding to enterprise-wide use.

Within the domain of manufacturing, VR is viewed not only as a one-on-one instructional tool, but as a platform to streamline work and deliver new forms of productivity and efficiency in the manufacturing lifecycle, including design, engineering, and production [41]. Novel VR solutions have been developed including work instruction aids and VR for shop floor layouts [11,38]. However, VR research typically occurs outside the context of use and in controlled environments that do not reveal the kind of integration issues that arise between custom VR software and the deeply entrenched existing organizational platforms and procedures that shape daily operations. For VR to fulfill expectations of efficiency requires a unique and highly skilled workforce to develop, integrate, and use VR tools. These requirements open up completely new domains and disciplines in the manufacturing space where skill specialization has often not been centered around computing technologies.

To realize the potential benefits of VR, we need to understand how to integrate these kinds of technologies into organizations by incorporating lessons learned from past examples of VR use while leveraging the new capacities of smart technologies.

Adoption and Use in Organizations

To understand how to successfully implement VR platforms in manufacturing necessitates comprehending how technology impacts organizational structures. There have been many studies conducted within the field of organizational studies to document the success and failures of technology implementation. The focus has primarily been on software applications or tools designed with the intention of widespread use across traditional corporate environments like electronic calendars. Often leadership mandated technology use and a centralized IT group distributed access across the entire enterprise. Establishing new processes and procedures was essential to achieving critical mass for adoption to occur [18]. From the outcomes of these types of implementation studies we can expect practices and procedures to change for adoption to occur in manufacturing organizations [29].

New smart technologies are being introduced by employees in manufacturing because of the increased affordability to acquire and trial these kinds of devices. Consumer grade products make it easier to circumvent initial bureaucratic hurdles of purchasing new tech but prolong full scale implementation because of the lack of top-down support [17]. These types of pilot projects seek to identify use cases that have been left unstated by technologists because of lack of understanding of workplace practices and the inability of management to envision granular applications [18]. The results of these initial studies claim improvements in efficiency but well below the predicted outcomes [14]. A key part of establishing technology adoption as determined in groupware studies is defining parameters to measure success and creating the same interpretation of use [16,30].

We have seen how previous forms of consumer tech have changed organizational structures with the introduction of mobile devices. Companies had to completely rethink organizational processes and procedures once post-iPhone smart phones became common. There was a shift to bring your own devices and employees expected services to run on their phones creating all kinds of complications for conservative enterprise IT departments. Policies had to be created to allow for personal devices to be used at work and enterprise tech changed as we know it today [27]. In manufacturing, technologies have to contend with even more layers of complexity because of growing global supply chains.

Smart Technology as Boundary Objects

In their foundational work, Star and Griesemer found that for multiple groups to coalesce requires standardization of work and the creation of boundary objects [36]. Boundary objects act as means of translation that are informed by communities of practice and embody the standards upheld by those groups [36]. Navigating the complexities of manufacturing organizations, smart technologies have to be able to adapt and adopt to local practices across multiple disciplines and industries thus becoming boundary objects. In organizational settings, smart technology is used across multiple people and disciplines. Manufacturing environments compound the cross functional use of technology with the complexity of production. At any given time on the manufacturing shop floor, engineering, mechanics, designers, leadership, quality assurance, and training departments all weigh in to make decisions on product design or process improvement. Considering smart technologies as boundary objects allows us to take into account the local practices of individual stakeholders and discipline specific knowledge.

Through Bechky's study of product design in a manufacturing environment, we come to see that through the co-creation of common ground, engineers, technicians, and assemblers bridged their community boundaries to generate a more in-depth understanding of the product and process by referring to a physical product [4]. Each respective work group had their own standards and norms, but the physical product acted as a boundary object creating a collective communication tool that bridged the divide between multiple work groups. The boundary object acted as a common point of reference for conversations [8], illustrating that "the creation and management of boundary objects is a key process in developing and maintaining coherence across intersecting communities" [5]. Smart technologies in organizations must facilitate coordination and alignment across user groups for integration and adoption to occur.

To design smart technologies as boundary objects requires renegotiating the standards of practice in organizations. The lack of standardization has led many forms of technology to be abandoned. As discussed above, previous CAVE systems failed to be adopted by organizations because they were designed for individual users and never got to the point of being standards. Existing workplace practices are entrenched with personal computers and mobile devices, but these practices do not directly translate to smart technologies. Tacit knowledge of systems and practices maybe lost because business processes and standards are not flexible enough to deal with the newness of smart technologies and devalue the invisible work required to make technologies 'smart' [12,19]. Smart technologies have the chance to shape workplace practices by mediating communication between occupational communities and enabling cross functional job training and reskilling.

Bringing boundary object work together with organizational studies, we can begin to analyze the design of smart technologies in organizational settings. These kinds of tools serve as communication platforms for multiple work groups while still having to be flexible enough to respond to the changing demands of workplace environments. Smart tech cannot be treated as plug and play point solutions for organizations. They rely on a system of digital infrastructures for which the standards of practice need to be established. By examining the implementation of one such technology in a manufacturing setting we aim to illuminate current challenges facing VR implementation for large organizations and point to opportunities for design and standardization to realize the potential benefits and reduce further complexity in organizations.

CONTEXT AND RESEARCH METHODS

Our study of the impacts of VR on workplace practices was conducted at a large aviation manufacturer in the United States. The manufacturer was interested in exploring the capabilities of a new VR plugin, recently released on a common industry software platform used for viewing and analyzing 3D models. The company's expressed motivations for using VR were to optimize time and cost spent conducting engineering assessments and reducing human error during product assembly and maintenance. We ran our study to better understand the use cases of VR in the workplace and to situate the technology's impact on workplace practices. This aligned with the goal of the company to understand VR's potential to deliver efficiency gains. The study was developed with the shared understanding that we would provide task-level analysis to the company while also being provided with access to understand organizational factors in how the new system impacted cross-functional collaboration. To begin the study, we conducted participant observation to document existing workplace practices. This initial fieldwork was used to to develop the details of the VR study. Our investigation was the first at the aviation manufacturer to explore the new capabilities of this toolkit in VR for engineering analysis. By using off the shelf VR hardware and a VR plugin on a standard software platform, we were able to understand the organizational gaps of workforce skill and decision making that exist past the concerns of establishing technological feasibility.

The manufacturing company involved in our study was a large global corporation comprised of many business segments. We worked directly with the aviation division and specifically the human factors and maintainability team within that division. A core member of the human factors and maintainability team acted as our main point of contact through the duration of the study. The human factors and maintainability team was comprised of 15 employees and had been recently reorganized to house both human factors engineers and maintainability engineers. The work functions of these two groups aligned in that they were both responsible for bringing the perspective of the mechanic across the phases of product design, development, and service. In terms of work practice, this meant that both groups used the same software platform and could benefit from shifting some tasks into a VR environment.

The role of the existing software platform was critical to ensure that complex engineering models could actually be manufactured and assembled before physical components were produced. Targeting the early design phase, the existing toolkit was used to conduct design reviews, check tolerances, and examine the relationships between major assemblies. The tool was primarily used to inform decision making practices and uphold customer requirements. PowerPoint remained the easiest way to disseminate screenshots of the 3D models and analysis performed using the software. Human factors and maintainability engineers were primary users of the tool for conducting tool sweeps and path planning for part assembly or removal. These analyses ensure there is enough room between parts to insert tools and remove components without obstruction. 3D models of screwdrivers, wrenches, ratchets, and sockets are inserted into the environment as part files to replicate the space required to torque a bolt. Similarly, a removal path creates a designated keep-out zone so that each component has enough clearance to be removed and replaced. Additional platform functionality included conducting human modeling simulations and ergonomic assessments on 3D assemblies and parts. These capabilities rely on a human model to simulate the mechanic or technician's posture, access, and visibility to components on the manufacturing floor and in the field. This class of work is critical because it brings the human worker into the engineering design process, ultimately shaping both engineering and mechanic workplace practices.

We selected a line removable unit (LRU) as the main 3D part file for our usability testing. An LRU is an external component to a larger product assembly that is designed to be easily removed and replaced by mechanics or field technicians to eliminate product downtime for the customer. All LRUs are subject to human factors and maintainability analysis including time studies for component removal and ergonomic assessments. The LRU was chosen based on its ease of access both visually and physically: only four bolts needed to be removed to replace the component. These bolts were subject to tool sweep analysis and a path removal task was required for the entire LRU.

While we worked with the human factors and maintainability team to develop and run the VR study, the focus of our interest was not on the interface of the VR plugin but rather on the impact of VR on routines of work. To run the VR study required extensive knowledge of existing workplace practices across multiple user groups. Current work tasks had to be mapped to the new features enabled by the VR plugin which allowed us access to observe and interview participants to understand how the software platform was being used. These work routines informed the customization of the VR environment. Developing the VR study provided insight into the affordances of VR in the workplace and how VR would shift workplace practices across the organization.

Study Details and Analysis

Over the course of 6 months we collected more than 220 hours of data, including: 21 semi-structured interviews, screen recording of tool use, and participant surveys. Our study was composed of two parts, an initial assessment and then the study itself, both of which transpired over week-long on-site visits to the manufacturer. The assessment was used to document the desired outcomes of the VR usability study, determine the technological capabilities of the company's existing equipment, and document current workplace practices. Our technical evaluation consisted of 40 hours of onsite equipment troubleshooting, meeting with the company's IT organization, and meeting with software developers from the VR platform vendor to configure the tool for the study. We also conducted and transcribed five semi-structured interviews (n=5) as part of the initial technology assessment. These interviews lasted approximately 60 minutes each and were geared toward documenting the motivations behind using VR in their workflow.

The final VR study culminated in an additional 40 hours of user testing over the course of one week. All participants (n=16) successfully completed the study which consisted of completing a demographic survey, a VR training demo followed by the VR usability test itself, concluding with a semi-structured debrief interview. The human factors and maintainability team managed the recruitment of participants from the manufacturer consisting of trainers, engineers, and leaders. No prior experience using the software platform or VR was required. Testing lasted approximately 2 hours per person including interviews which were approximately 1 hour each. Participants first completed a 7-minute electronic survey to collect demographic information on age, gender, race, and education. The survey was also used to gauge experience levels, using a 4-point Likert scale, participants ranked their experience conducting engineering analysis and using VR. Prior to launching the VR test environment all participants completed a generic SteamVR tutorial. OBS screen capture software recorded participant actions while using the VR plugin. The testing equipment provided by our research team included an HTC Vive and custom VR desktop. Internal policy, budget, and IT hurdles prevented the timely acquisition of company-owned VR capable hardware. Immediately following the VR testing, participants were ushered into a semi-structured debrief interview. The focus of the debrief interview was to capture initial reactions to the VR environment and have participants reflect on the ways in which the VR plugin would change their daily work routines.

We used a grounded approach to analyze all 21 interview transcripts and field observations. We coded the interview data inductively, applying Charmaz's method of open coding [7], arriving at an initial set of themes that included accountability, scalability, decision making, productivity, embodiment, and engagement. Three main user groups comprised of engineers, trainers, and management also emerged from our initial coding process. These foundational categories were used to inform the design and testing of the VR environment. Additionally, four participants were part of the company's core team leading the VR implementation investigation and participated in both the technology assessment and the final VR study. Working closely with these core members allowed for focused follow up questioning and provided insight into the organizational hurdles and the types of invisible work being performed by employees in order for VR to be implemented.

During the final VR study (n=16), we integrated data collection methods – surveys and screen recording – and compared these outcomes with our interview themes. We used screen capture as a mechanism to link participants actions to their expressed sentiments about VR. Additionally, the VR completion times collected in screen capture were also compared to the demographic survey information to reveal age and gender disparities. The findings presented here have the most insight to offer given the research question(s) focusing on understanding the changing nature of work as a result of VR implementation and use.

FINDINGS

VR is not as a new technology, but one that is newly encountering long-standing issues in organizational change and technology adoption. Our findings highlight the significance of understanding and identifying the organizational, technological and personal infrastructures when designing and implementing smart technologies like VR in new workplace settings. Based on the dynamics of the participants in the study, we expected to see strong differences about the adoption and use of the VR plugin for engineering analysis along age groups. We anticipated strong support from early career participants but adamant rejection from senior participants. Contrarily, we discovered overall enthusiasm for the use of VR with differences falling along the career paths of management, engineering, and training. These divisions revealed three dominate themes of efficiency, access, and workforce skills. While management's expectations of VR to deliver efficiency set the precedent for technology use across all participants, differing interpretations of access and shifting skill requirements amongst engineers and trainers exposed divisions of labor. Our findings begin to unpack the layers of infrastructural support necessary to implement VR in organizations negating the ease of access and affordability that have become synonymous with consumer grade smart technologies.

Managing Expectations

Management's perspective revealed infrastructural breakdowns between their desire to optimize for cost and the necessary IT investments required to operationalize VR across the organization. Placing emphasis on VR as a tool to improve existing workplace practices actually limited the potential of the technology to result in real savings. The narrow definition of success – time and cost savings – also precluded management from addressing larger organizational hurdles necessary to garner executive level support crucial for tech adoption in a hierarchical organization [18].

The goal expressed by the human factors and maintainability leaders for using VR was to generate a business case that communicated the benefit of VR in terms of operational efficiency. In the traditional sense, efficiency was discussed in terms of time and/or cost savings. As P17 stated, "*One of the factors on our side is that there's gotta be some sort of productivity or cash return on investment*." The goal of showing potential savings would then be used as a justification to ask for more money from higher level executives for large scale implementation. When asked if there were other benefits to consider, P8 stated "*None come to mind that are as easily measurable as time and hence cost.*" These sentiments restricted the application of VR to streamlining existing work tasks and increasing remote work.

The concept from leadership's perspective was that VR would fundamentally change the usability characteristics of certain tasks resulting in significant reductions in time and cost. P19 imagined VR would ultimately be quicker to use because your eliminating steps, "*With Vis VR you're more emulating what you would actually do with real life*." P8 expressed that VR would ultimately be faster because it would eliminate steps stating that VR would *"Cut out some of the very clicky…work that's done and just do it more real-time."* However, 'real-time' relies on the VR platform not only being able to integrate with existing network infrastructures but also workplace practices.

The other predominate notion was that VR would facilitate more remote work, reducing travel costs for the company and their customers. The engineering team discussed reducing travel time by being able to verify their analysis virtually instead. The training team envisioned less customer travel to training centers, as P2 shared, "*Instead of them flying thousands of miles and being here for a week or so, they can stay at home and do it, so you keep those resources locally."* These visions of VR use rely on several assumptions. First, that VR delivers positive results as an engineering and instructional tool. Second, that VR upholds customer requirements and lastly, that customers also have VR capabilities. For VR to increase remote work entails reimagining the customer relationship and how and where work gets accomplished.

By only emphasizing efficiency as the main criteria for success, new and perhaps more beneficial outcomes were not explored. The affordances of VR like realism and scale provided a new perspective for human factors and maintainability engineers and trainers. P15 described it by stating, "*On the desktop I can be looking at an engine which is maybe a few hundred pounds and an engine which is 20,000 pounds, a giant engine. On the desktop they all look the same*." The size differences in products is not communicated on a 2D screen. After putting on the VR headset, P1 exclaimed, "*These bolts really that tight?...Well I'm standing right next to it. The engine is right here*." The realism and scale of the immersive environment gave participants a new outlook, P3 reflected by stating that VR "*opens up your ideas up about different issues or risks with the design that you may not have thought of before*." VR frames the issue differently which could add "*Alot of value in understanding the complexities of an engineering problem*" P4. These benefits were undervalued by management because they are not easily quantified in terms of time and money.

VR was treated as singular problem-solution deemphasizing new kinds of affordances and the infrastructure necessary for adoption and use. P3 described the rejection of a previous business case proposal for Google Glass that demonstrated potential savings in the million-dollar range stating that "*The hardest thing to swallow for the business was that it wouldn't just integrate seamlessly into our existing spaces*." In this case, Google Glass was viewed by management as an all-in-one unit that should be plug and play. VR was subject to similar obstacles. Simple tasks like downloading the free SteamVR application on company hardware took layers of approvals. This approval process was only partially successful because SteamVR was only allowed to run in the offline mode on internal company WIFI. Additionally, the company did not have any VR capable desktops so new hardware had to be approved by IT prior to getting purchasing approval which took more than 6 months. The complexity of institutional tech infrastructure negated the simplicity of the consumer-focused platform and device making it difficult to integrate.

While declining costs have made VR systems like HTC Vive more affordable, they are not necessarily more accessible for organizations. Significant investments in IT infrastructure and hardware need to be made in order for adoption to occur. P17 commented "*One of the biggest boundaries to the model-based enterprise [3D modeling software] is the consumption of the definition"* referring to individual licensing and computer stations. The sheer volume of hardware upgrades and VR headsets alone would require a full organizational transformation. As P18 imagined it, "*You either have 12 sets of goggles or they're sharing one set of goggles and I'm waiting*." This is compounded by the fact that *"The manager is being pressured to keep costs down and we're saying 'hey if you have a million dollars you could do this and two years from now, you'll see your savings'"* P16. Smart technologies are a long-term strategy not a short-term payoff that contradicts the fundamentals of business decision making [25].

Engineering New Work Functions

The engineering perspective upholds management's expectations for efficiency but exposes divisions of labor that are entrenched in the software platform. As expert users, the ownership of the software toolkit primarily lied with human factors and maintainability group. They were concerned with how VR would be operationalized because it was viewed as a way to increase access to the toolkit shifting work away from the human factors and maintainability group. To maintain domain specific knowledge and practices, changes were proposed to both the organizational structure and job function of human factors and maintainability engineers. These ideas reinforced centralized control and authority presenting the same attributes that led to the previous failures of CAVE VR systems.

Management's priority for delivering efficiency manifested in two ways within the human factors and maintainability team. First, reducing their own internal time spent conducting engineering analysis and second, reducing human error in the field caused by mechanics. The emphasis on time stemmed from management's expectations for delivering savings but P1 also recognized the ability of VR to potentially deliver higher quality work. When brainstorming the potential of VR, P1 stated "*I think you could do more in the same time, yes. Same amount of time. You could do it faster if that's what you need to do, if you need an answer quickly. But if you really wanted to study it in more detail I think you could*." However, this perspective was overshadowed by the dominate viewpoint held by engineering participants. P5 summarizes that position best stating, *"That [VR] wrench has to enable that mechanic to get the task done in less time with less error otherwise you're not gonna spend a cent on it or waste his time with it."* Ultimately, traditional expectations for time and cost savings set out by management were prioritized by the engineering team members.

The capacity of the human factors and maintainability team to execute their daily work routines relied on their ability to be subject matter experts using the software platform at the core of our study. Illustrating expert status P1 shared an example of routine use of the 3D analysis platform, "*I had to put Jack in there and show them [design engineers] 'Look he's reaching as far as he can he's still 2 feet away*.'" Design engineers owned the responsibility for conducting tool sweeps and path removal tasks but limited frequency of use and familiarity with the software toolkit placed onus on the human factors and maintainability team to validate and reinforce the execution of these work tasks. Increasingly, the human factors and maintainability team served as internal trainers teaching design engineers how to use the software platform and advocating on behalf of the mechanic. VR was seen as a way to increase awareness and accountability for design engineers and management to foster decisions that were mechanic centric.

By being more intuitive, VR was viewed as an apparatus for increasing access to the engineering analysis toolkit. P4 described the VR setup as a way to "*Enable[s] people that might not be overtly technical to become domain experts in the technical realm*." This would create opportunities for engineering analysis to be performed not only by a highly skilled technical group but also more non-technical roles. VR has the ability to remove software specific knowledge barriers by opening up access to a common toolkit. However, creating a platform that serves different user groups relies on the tacit knowledge of human factors and maintainability engineers being embedded in the VR system.

To maintain their work domain, the human factors and maintainability team was willing to change the nature of their work to encompass VR. P15 went as far as suggesting changes in the job function of human factors and maintainability team sharing that *"We'd basically we would become an assistant or consultant to the design engineers."* Many participants saw the role of IT increasing if VR usage were to become more widespread throughout the organization. P13 stated, "*We would need a lot of IT support because we're not programmers. I have a little bit of a background but we dont have time to I guess learn how to do all of this stuff*." Figuring out how to manipulate VR is not seen as value added work for engineers and that task was placed on IT. Ultimately, VR would change the job functions of the human factors and maintainability team.

The successful adoption of VR across the engineering organization became about having ownership of physical resources. P19 proposed, "*It may almost be better to have it [VR] centralized just because you can train a core group of engineers like maintainability or human factors engineers to go do that activity*." Referring to the layout of the office space, P3 even stated that "*In a perfect world, you would have your engineering space realigned*." P19 stated that "*you've gotta have a specialized workstation...just a converted conference room or something dedicated to that purpose it'd make it easier for the engineers to come in load their hardware, do the analysis*." Creating a centralized VR lab would maintain traditional work boundaries for the human factors and maintainability group.

However, having a dedicated physical space for VR followed the same thinking as previous CAVE conference rooms which failed to be adopted by the organization. P19 recalled that *"In the past we did have like a 3D room for viewing models again that was centralized in one place. I think the issue that we ran into there as it was, it was kind of complex system to operate. You had to have someone dedicated to running it*." The failure of the 3D conference room was contributed to lack of technical prowess and not deliver efficiency gains. P17 supported this concept stating, *"The big problem that I think killed it not only did the cost of it and it being locked down but there wasn't that next step that everybody was feeling might be there*." The next step P17 was referring to was ability of the tool to deliver cost savings. An additional constraint according to P1 was "*Having it not travel with, if it's completely immovable and your people leave, your customers leave, it's gonna become a doorstop."* These sentiments contradict the desire to create a centralized VR installation and should serve as warnings for the appropriation of VR under one work discipline.

Training the Next Generation

Advances in technology have changed the types of skills mechanics in the aviation industry need. However, training has remained largely unchanged relying on lecturing, PowerPoints, and hands-on demonstrations. VR was seen as a way to modernize the training department. The desired use of VR was to create a *"new training experience that would bring more value to the customer"* P2. The 'value' was discussed in terms of access and workforce. Supporting overall efficiency gains, VR was seen as a way to increase access to training materials resulting in greater knowledge retention to save customers time and money. However, to create VR training content requires the development of new workforce skills. As new medium, VR would ultimately serve as a tool to attract and retain new talent for both training department and mechanics.

VR was seen as a mechanism for increasing content availability by delivering 24/7 access to the most up-to-date training materials. The training department primarily serves mechanics and technicians of product owners in the field. Training is often front loaded prior to a new product purchase or launch. However, there are limited training slots per customer resulting in many mechanics not being able to participate. VR would promote remote training. As P2 imagined, the virtual would enable "*Being able to train anytime, anywhere*" for customers located around the world. In classroom training sessions, as P18 described, "*you dont have to have an engine, you can just go sit in a room and start that learning curve*." Increasing content access was also seen as a cost savings opportunity by reducing travel as already discussed. But as P12 stated even "*if I'm doing onsite training, and I can package this stuff up, put it in a case, go to a customer location*" if they don't have the product yet. VR could provide access to digital product models and decrease product downtime.

VR was viewed as a tool to encourage deeper levels of knowledge retention and reinforcement of key concepts for mechanics. According to P2, VR has the potential to *"Grab their [mechanics] attention and really stick it to them."* In sharing his perspective on training the new workforce, P12 stated "*You give em a video game type scenario and they're gonna navigate through it way easier than if you hand them a paper test."* P12 continues by saying that *"It [VR] just adds another level to delivering instruction. It's the lecture based then you could do VR based then you can do hands on so it's just that retention is hopefully hammered home."* However, training based on perfect conditions and models does not accurately portray a mechanic's reality *"there is no damage in a virtual environment" P8.* As P5 stated, *"There is sometimes no replacement to just getting your hands-on things."* Design opportunities exist for VR to be able to provide more haptic feedback to replicate real-world scenarios.

Developing VR content for training relies on the training team being taught how to use the basic software toolkit first. The introduction of the existing software platform has been a recent adaptation for the training group at the aviation manufacturer. The software platform is being used by the training department for content creation for online videos. P12 shared that "*It's been a big shift for me,*" because he had no previous experience using the program. As P2 describes, "*Part of being an engineer of part of [the] stuff they learn once they get on their job, but it's definitely not in our core competency*." Currently, the software platform is learned through on-the-job training. No formal training is even provided to the engineering team. The onus falls on expert users of the software platform to share their knowledge. As previously highlighted, this tacit knowledge secures the human factors and maintainability group's role and importance within the organization.

Increasing access to training materials with VR requires changes in the nature of work for trainers. When reflecting on using VR for training P12 was adamant that *"You're gonna have to have somebody who manages those packages somebody way smarter than me that actually understands the software…It is a full-time job*." Technical development skills were even being incorporated into a new job posting for the training department at the time of our study. However, it is not just the backend content creation that technologies like VR change, but also the public facing role of a trainer changes with the implementation of VR. In the classroom as P2 stated, *"Now you become more of a facilitator instead of being a guy up there trying to push information to them. You lead them to the playground and tell them what is going on, let them do it and then you give them advice."* Fundamentally, the job description and work tasks of a trainer change with the adoption and use of VR.

The training department's vision of VR for increasing access and knowledge retention relies on mechanics reception of the technology. When asked how mechanics would react to VR, P12 responded by stating *"Is it insulting to the intelligence of the mechanics? It probably could be construed as 'Well I don't need this to tell me to take a bolt out.'"* P5 thought "*You saw me fiddling around with those menus. They [mechanics] would do that for 5 seconds and be like, 'This is like a waste of time. I'm going to throw this headset in the garbage*." The importance of the mechanic's perspective for the training department's use of VR cannot be understated. Especially, because VR was discussed as a mechanism for attracting and retaining new talent.

The novelty effect of VR creates an opportunity to reach a younger workforce and re-engage employees in traditional blue-collar industries like manufacturing. As P2 stated, *I think this has a way of energizing a little bit, "Yeah, I want to play with that." It's a new toy, I want to try it."* P12 shared that *"[VR] it could open up doors to people who thought they would never be a mechanic*." This is a double-edged sword because what is attractive to one person may be a turn off to another.

The digital revolution is forcing manufacturing to contend with issues of latency in tech adoption and workplace culture. The two arguably go hand-in-hand. This is propelled by the ready availability of consumer grade smart devices. Participants saw the promise of smart technology in its affordability, but these kinds of technologies may actually create more systemic issues if implemented without any standards of practice. Smart tech has the potential to empower employees, but we must also recognize the potential consequences of the technology to reinforcing hierarchies of control further limiting innovation. By examining divisions of labor and changes in workplace practices and skill acquisition we can begin to see how technologies like VR are complex tools that need further attention.

DISCUSSION

Clearly there are risks associated with technology adoption and use in organizations. As we saw with CAVE systems, technology can reinforce command and control relationships. It is imperative that we apply these lessons learned to new smart tech as the workplace continues to evolve in many forms due to technology. There are tools being setup across HCI to address these newly emerging contexts and disciplines that are part of larger movements surrounding the Gig economy [19].

The challenge presented in our work is how to bring consumer grade smart technologies into existing industrial workplaces in a way that supports and extends the capabilities of the workforce while responding to the organizations need to compete in a global economy. The VR plugin in this study is a new smart technology enabled on a legacy software platform for viewing 3D models and conducting engineering analysis. Our findings highlight the barriers to implementation and long-term use of the VR plugin. The issues of delivering efficiency, scalability, and reskilling are challenges that are pressing for the large-scale adoption and use of smart technologies across organizations. Without an understanding of the organizational structure and divisions of labor, consumer grade smart technologies stand to reinforce structures of control and increase the complexity of organizational processes missing the opportunity to reimagine a future of work that is more worker centric.

Changing Organizational Practices

Workplace practices recreate and uphold organizational structure [28], the expectation of smart tech like VR is that they will adapt to fit into these existing structures. However, as discussed previously, smart phone integration in the workplace revealed that consumer technologies can shape organizational practices. This is consistent with early groupware studies that showed that once a technology reaches critical mass organizations are forced to confront change [16]. Treating smart technologies as boundary objects is one way to reveal the impact of these kinds of devices on organizational structures.

The developers of the VR plugin stressed that the VR tool was created as a collaborative tool for design reviews meant to extend the capabilities of the existing software. This suggests that the platform upholds current work place practices. However, the aviation manufacturing company's design reviews entailed deeply entrenched processes and required multiple approvals by different occupational groups. To share information amongst stakeholders, the platform was only enacted in the form of PowerPoint screen shots. The developers imagined VR serving one user group like the human factors and maintainability team, but they didn't consider how the platform was actually being used in practice which revealed multiple stakeholders. Without understanding the decision-making process, the VR developers were creating a tool for a nonexistent use case at the aviation manufacturer.

To contend with all the stakeholders viewing and using the software platform requires developers and designers to understand the breakdowns in work tasks and domains. Boundary objects serve as a way to tease out the jurisdictions of work [3,6,23,36], the provide legible points of transit between different standardized organizational practices. The software platform at our field site served this role: multiple teams used the models for different purposes and had developed unique but related work practices around those models, software capabilities, and workflows. By shifting some of those practices to VR, had the potential to shift how the organization shared information and negotiated work via the common software platform.

As came out in the findings, the concept of creating a centralized VR lab is an example of the human factors and maintainability group remaining tethered to their existing work domain. For the human factors and maintainability group, VR immediately became about centralized control of VR hardware and knowledge resources. The human factors and maintainability group was willing to change organizational structures and their nature of work to maintain ownership of the software toolkit to conduct engineering analysis. Boundary objects are especially relevant as smart technologies like VR enable more remote telework settings. The virtual environment has to be able to adapt across multiple disciplines and industries that are more fluid.

Standardization remains a critical task because occupational communities share and develop specialized local knowledge and understanding of their work and the organization through the tools that they use [28,36]. Even our relatively small-scale study required overcoming institutional barriers like purchasing approval for hardware and gaining WIFI access for SteamVR. These approvals required buy-in from top-level leadership to circumvent standards of practice for the study. Recognizing the implications of technology on organizational structure and practices, we need to consider smart technologies as boundary objects to develop workplace practices that inform new processes and procedures in conjunction with smart technology design.

Creating Context of Use

The lack of practical applications of VR in industry settings is contributing to limited adoption and use [41]. It is critical that smart technologies are designed within the context of use because these kinds of devices have the ability augment human performance providing an alternative to traditional automation and job loss. Without a properly defined use case the VR platform falls into the same predicament as previous groupware applications that failed to be adopted because there was no clear benefit to users [18].

Manufacturing's focus on the use of smart technologies to deliver efficiency derives from the narrative surrounding Industry 4.0 and a vision of a fully automated future. The reality of manufacturing is much more complex and reliant on human cognitive abilities to mediate decision making and multitask – as we saw with the human factors and maintainability group who acted as a middle-man between design engineers and management. VR has the ability to extend these skills, especially if we consider the potential of VR to make work fun again as a way to increase employee satisfaction and thus productivity [31].

An alternative approach to smart technology implementation is selecting complex test cases. This runs counter to proof of concept projects, like this one, where simplistic scenarios demonstrate the potential capacities of the technology. The LRU in our study was selected for its' simplicity but this made it more difficult for participants to think about using VR in place of existing methods because their work tasks were much more in-depth. This also limited participants' ability to see other benefits aside from time and cost savings because we were not taking advantage of the full affordances of VR like scale and realism since the LRU only exposed the outside of the product.

Selecting complex work tasks rather than simplistic models would also make clear systemic challenges smart technologies would have to overcome for full scale implementation. The failure of the Google Glass proposal because "it didn't integrate" is an example of the complexities and costs of large-scale infrastructure overshadowing efficiency gains P15. A more complex task and real-world test environment would have exposed these hurdles early on because infrastructural support from entities like IT and production would have been required rather than creating an isolated use case.

Reskilling the Workforce

Manufacturing has shifted away from manual labor towards knowledge-based labor. Many participants recognized that the nature of manufacturing has changed from being hands-on to being more service oriented. Implementing smart technologies in manufacturing would increase the emphasis on knowledge-based work and requires reconfiguring the value placed on certain types of invisible knowledge work. These changes would result in shifting workforce skills to align with the adoption and use of new smart technology in the workplace.

Feminist HCI has started to consider invisible work in other contexts but manufacturing workplaces offers another setting to understand how these perspectives become a part of practice [2]. In our study both trainers and human factors and maintainability engineers expressed that IT would have to become more involved in their daily practices to facilitate the use of VR. IT in this sense refers to a category of work that involves negotiating between multiple stakeholders [32]. Navigating infrastructural IT hurdles was not seen as work, it was viewed as what had to be done to get the tool to perform. As previously stated by P13, human factors and maintainability engineers "don't have time" to figure out the VR toolkit because understanding VR was not seen as a part of their job. In engineering and training jobs, success is measured by delivering results that effect the bottom line. Even during our study, the human factors and maintainability engineers, struggled to prioritize the VR project over daily work tasks. To integrate VR requires organizations reprioritizing the value placed on the invisible work necessary to overcome infrastructural complexities.

Secondary to mentioning IT support, participants also acknowledged that they too would have to learn new systems and technologies. VR would change the type of work trainers and human factors and maintainability engineers carry out. They become more like "assistants" and "facilitators" as mentioned by participants in our study. The types of skills required by these new job descriptions change who is qualified to perform the job, what type of work is being performed, as well as how a job well done is measured. How we engage with these new kinds of smart technologies will shape human cognitive abilities.

While VR has the potential expand skills for certain categories of workers it can constrict others. We have to consider that mechanics and technicians would have no choice but to adapt to VR. As training content transitions to the virtual environment access to traditional materials may be lost excluding a portion of the workforce not able to adapt. The concerns for access brought up by study participants in our work did not consider VR's ability to exclude rather than include whole categories of workers.

CONCLUSION

The study presented here reveals the complex infrastructures between technology, organizations, and the people they employ. These barriers coincide with the implementation and use of consumer grade smart technologies and their expanding domain applications in organizational settings. Manufacturing is only one industry that exemplifies the ongoing struggle to incorporate smart technology to remain relevant in an increasingly digital and global economy. The fear of being left behind gives rise to the desire to be seen as an innovative company spurring the implementation of smart technologies which necessitates the revitalization of organizational studies.

Predominately, these technological implementations are occurring in large organizations that have the financial means to explore new digital tools. There is a need to understand how these types of technologies manifest in small sized companies as well because they represent the majority of businesses in the United States [44]. Developing a clear understanding of the impact of smart technologies across different size organizations will help inform design and implementation practices to create a future of work that is worker centric.

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