Situating Robots in the Organizational Dynamics of the Gas Energy Industry: A Collaborative Design Study

Hee Rin Lee[1], Xiaobo Tan[2], Wenlong Zhang[3], Yiming Deng[4], and Yongming Liu[4]

Abstract—Human-robot collaboration has been an important topic in the HRI communities. In this paper, we explore how robots can contribute to gas pipeline inspection work, and how they can support one of the most important elements of energy transportation infrastructure. To situate robots in the gas energy industry, we conducted a collaborative design study, where our co-designers were diverse stakeholders: from pipeline researchers to utility workers. The contribution of this paper is threefold: First, we explore gas pipeline work setings as a new context where robots can provide significant benefit, considering that public infrastructure is vast but understudied. Second, we collaboratively envisioned the design and use cases together with workers who are not often invited to human-robot collaboration research. Lastly, we address the importance of viewing humans in human-robot collaboration as "workers" whose roles and expertise are shaped within organizational dynamics. This study aims to shed light on the importance of a more nuanced understanding of work contexts and the positionality of robots within organizations.

I. Introduction

Robots have a long history of being part of workplace automation [1], [2]. Initially, they were adopted in factories [3]; more recently, they have been studied as collaborators to human workers in a broader range of industries such as healthcare [4]. To make robots more eficient collaborators to humans, the HRI communities have studied various design elements of collaborative robots. For example, researchers explored trust as an essential element of human-robot collaboration [5], including more specific factors of trust such as transparency [6] or anthropomorphism [7]. The humans in human-robot collaboration are workers who have their own work practices, expertise and organizational setings; however, they have rarely been invited into the design process of collaborative robots as co-designers.

This study invited multiple stakeholders of the gas pipeline industry—from field workers, to researchers and to management—into the design process of gas pipeline inspection robots. Natural gas pipelines are critical to energy transport infrastructure, but the industry has limited technology and human resources to inspect them. The industry uses in-line inspection (ILI) tools with magnetic resonance and ultrasonic waves; a common ILI method deploys a Pipeline Inspection Gauge (PIG) within a pipeline [8]. This process, known as "pigging," detects leak issues caused by corrosion. Despite significant technological advances in pigging over the decades, including the development of robotic or intelligent inspection system called smart PIGs, 70% of pipelines are still "unpiggable" due to their small size and complex geometries [9]. Considering that the US gas pipelines are aging— more than half of which are 60 years or older—we explore how the gas industry could adopt this robot as a collaborator to pipeline workers [10]. To explore robotic solutions for improving pipeline inspection work, we closely worked with multiple stakeholders of the gas pipeline industry to envision potential robot design.

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II. Related Work

A. Importance of Organizational Dynamics in Workplace Automation

Organizational dynamics—especially power dynamics between management and laborers—influence workplace automation and automation technology design [11], [12], [13], [14]. This trend has continued since the successful automation in factories with assembly lines in the 1910s [11]. Although assembly lines are praised for increasing productivity and enabling mass production, they are also known for their negative effects on workers' autonomy. Before assembly lines, workers as craftsmen had stronger autonomy. They would determine when they were finished with a task based on their expertise and when it was time to move on to the next one. With assembly lines, workers were placed at stations and assigned task which they must perform at the speed decided by management. Another negative consequence of assembly lines was the deskilling of workers. Assembly lines allowed management to subdivide tasks to the point where they no longer needed to be done by skilled labor.

The power dynamics between management and laborers continued influencing workplace automation with the emergence of computer-based technologies. Suchman

[1] Hee Rin Lee is with the Department of Media and Information, Michigan State University, East Lansing, MI, USA heerin@msu.edu

[2] Xiaobo Tan and [4]Yiming Deng are with the Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI, USA xbtan@egr.msu.edu (X.T.), dengyimi@egr.msu.edu (Y.D.)

[3] Wenlong Zhang is with the School of Manufacturing Systems and Networks, Arizona State University, Mesa, AZ, USA wenlong.Zhang@asu.edu

[4] Yongming Liu is with the School for Engineering of Matter, Transport and Energy, Arizona State University, Tempe, AZ, USA yongming.liu@asu.edu

reported how management's stereotyped understanding of supportive workers' labor as mindless increased the possibility of displacing these workers with automation technologies [13]. In more recent years, Science and Technology scholars found that the new robot swarms in Amazon in their logistics center—managing product delivery to the packers—weaken worker autonomy [15]. Robots displaced human material delivery workers, and further weakened packers' autonomy by forcing them to work at a speed that was determined by management. These studies show how automation provides management with more power, and does not necessarily strengthen workers' autonomy and existing skills. Overall, the power dynamics between management and laborers are essential to understanding how these automation technologies affect relations with laborers.

B. Invisible Organizational Dynamics in Human-Robot Collaboration Research in HRI

With a few exceptions [16], [17], the majority of work that investigates design elements of robots that facilitate smooth collaboration between humans and robots, seldom considers the organizational dynamics between management and laborers [5], [18].

Although trust-focused studies address socially-oriented research questions about human-robot collaboration [7], [6], [5], these studies are still mostly done without actual stakeholders—actual workers. Organizational studies scholars have found these studies problematic for failing to consider workers, their work contexts, and their organizational dynamics with other workers [19].

Considering the importance of organizational dynamics in workplace automation, this study performed collaborative design studies with multiple stakeholder groups in the gas energy industry, so as to include the stakeholders' voices and envision human-robot collaboration organizational dynamics. Because the gas energy industry involves public infrastructure, it has multiple stakeholders; this allows us to examine human-robot collaborations in more nuanced work contexts. We explored how robots could improve pipeline inspection work by collaboratively envisioning robot design ideas with stakeholders of the gas energy industry.

III. Methods

The method used in this study is inspired by participatory design [20], collaborative ethnography [21], and situated analysis [22]. This approach has been successfully used in the multiple works in HRI and HCI [23], [24], [25], [26], [27]. This method enables participants to explain their contextual knowledge from their own perspectives, with minimal prompting from researchers. Unlike in semi-structured interviews, researchers did not initiate the conversation with their own questions that they are interested in because that could frame participants from researchers' perspectives. Rather, we asked participants to write down any 15 words that relate to "your work," "your workplace," "collaborators," and "future work (see Fig 1 left)." Because this study includes workers with various types of knowledge and power (coming from organizational hierarchy), we wanted to be reflexive regarding our own potential biases towards certain types of knowledge that have gained less attention in our field. For example, throughout the history of automation, body knowledge, accumulated in laborers' bodies through their work experience, has been less valued [11], [12]. Entrylevel workers' views also have been neglected compared to management' views, which could result in displacement of the entry-level workers' labor [13].

The presented four keywords (see Fig 1 left) were chosen based on our interest in worker-robot collaboration in their workplaces. As each interview was done via Zoom, we used Google Slides as a platform to interactively map out participants' work experiences. On the slide, we prepared 15 boxes where participants can add any words (or phrases) related to the four keywords presented by us. After wordwriting was completed (as in Fig 1 middle), we asked participants to categorize 15 words and make a title for each group. We also requested they highlight two to three important words within their words (see the three red keywords in Fig 1 middle). When mapping was completed, participants explained the rationales behind their categorization and choice of the most important words, as well as each word' meaning.

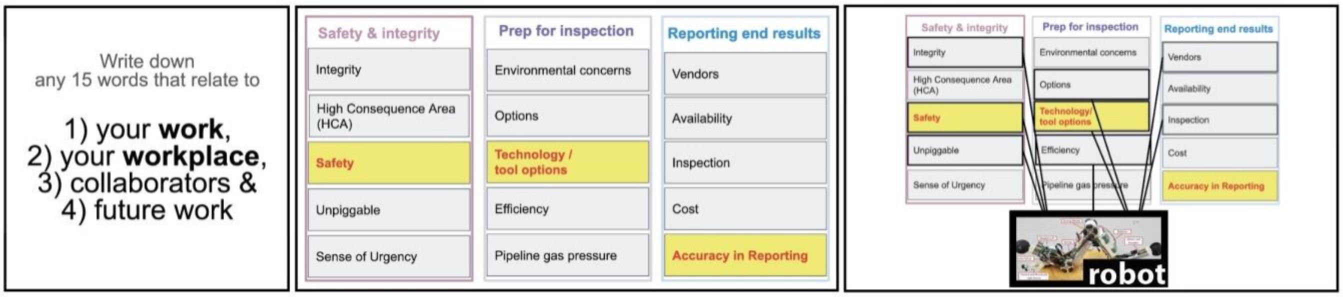

Fig. 1. Study materials. Left: an instruction slide, Middle: P6's map with three groups of words that explains how he interpret the four keywords, Right: P6's map showing how a robot relates to other themes.

Once they had completed their explanation, we showed our robot demo video (a link to the video). After they watched it, we asked them to add the word "robot" to their maps, and show how it relates to the other words (see Fig 1 right). As a final step, we asked questions about robot design: e.g., how can the robot prototype be refined, how would you or your collaborators work with the robot, and what types of functions do you need from it? In addition to individual interviews, we conducted a focus group, in a similar format to our individual interviews, with gas technology researchers at the same institution. Due to their time constraints, the interviews were done as a group in their institution, but the process was similar except that most interaction was done verbally without the Google Slide. We visited their workplace and observed their institution to understand their work practices.

All our conversations with the participants were voicerecorded and transcribed. We performed initial coding following Charmaz' grounded theory [28]. We initially had 270 codes, which were later categorized into five groups— "collaborative work (101 codes)," "current work process and tools (43 codes)", "new robots (101 codes)," "participants' expertise (4 codes)," and miscellaneous (21 codes)." These groups had up to three levels of hierarchy: engineers as planners, which is a subset of engineers as managers, which is a subset of collaborative work in general. These larger themes shaped the structure of the Results section (Section IV). Pipeline inspection and maintenance work as collaborative work (Section IV-A) and Future robot envisioned (Section IV-B). As the only qualitative researcher in a team, the first author performed the analysis and discussed the emerging themes with the other authors, whose background is engineering. Following the practice of social science/humanities studies with critical approaches [29], [30], intercoder reliability was not performed.

A. Participants

We recruited participants through two channels: Utility Workers Union of America (UWUA) and GTI Energy (a gas research institute). We used these two so as to value different types of knowledge: one related to more managerial work (e.g., planning, placing work orders), and one related to field work (e.g., work inside the pipelines). To achieve a holistic understanding of gas pipeline work, we had 10 participants: three utility workers (who were all union members), two engineers, four gas technology researchers, and one former CEO. All had +10 years of experience in their field.

IV. Results

A. Pipeline inspection work as collaborative work

Inspecting and maintaining pipeline infrastructure needs various forms of expertise from multiple stakeholders. In recent years, the number of stakeholders has increased due to the trend of outsourcing much of the work to subcontractors (e.g., smart pigging). According to participants, utility companies have different organizational structures, use different titles for workers, and outsource different parts of their labor.

The general process of inspection and management starts with the regulations developed by regulatory agencies. Based on these regulations, engineers of utility companies generate work orders for either subcontractors or in-house utility workers. Transmission pipelines are required to be inspected once every 7 years. These lines send natural gas from the larger gas companies to the utility companies, where it is distributed to consumers. Because the pressure within these transmission lines is higher than within distribution lines, the gas industry recently adopted smart pigs which collect in-depth data about the pipe conditions (e.g., corrosion). Due to the high cost of smart pigs (in the millions of dollars) and low frequency of use (once every 7 years per pipe), they are owned by 3rd-party companies.

When engineers issue a work order for the inspection of a transmission line, they contact the smart pig owners, and arrange for in-house utility workers to execute the physical labor (e.g., cleaning the pipe before pigging). Those utility workers track the pigging process. When pigging is complete, the pig owner analyzes the collected data and sends a report to engineers of utility companies. Smart pigging is not performed on distribution lines, as the pigs are too large to fit. Instead, the utility workers perform a statistical leak survey on-site with detection tools. More detailed information about each stakeholders and how they envisioned ideal robots will be presented in the following section.

1) Stakeholders and their institutions: There are multiple institutions involved in this type of work, including utility companies, utility worker unions, third-party companies, federal- and state-level regulator agencies, and the Gas Technology Institute (GTI) for gas-related research.

a. Utility companies: In this paper, the name "utility company" applies to both transmission and distribution companies. As do all companies, they have an organizational hierarchy: a *leadership* (e.g., CEO), *engineers* as mid-managers, and *utility workers* as executors.

The leadership decides overall directions of the companies (e.g., salaries of workers, employment of new gas technologies). Engineers called themselves "project managers" because they plan the detailed maintenance and inspection schedules, identify the tools necessary to generate the required data types, generate the specific work procedures that utility workers should follow, communicate with utility workers to check their work process, interpret the data collected through pigging, and decide the future inspection plans. P6 (M, 38, engineer at transmission gas company) explained his role as follows:

> *The engineers, we're the actual project managers, but we aren't on site for most of these. We handle the bidding with the vendors, choosing who the vendors are, geting the actual results, and going through all of that analysis.*

These engineers mostly need bachelor's degrees, and work in ofices. Utility workers are the ones who perform physical labor and act alongside the pipes. They receive work orders from engineers. Their tasks include a leak survey—examining whether gas is detected on the surface in sampled locations, digging the ground if needed, cleaning the transmission pipes, and installing new pipes. Before they touch the pipes, they are required to be certified by a regulatory organization such as Pipeline and Hazardous Materials Safety Administration (PHMSA) or Michigan Public Service Commission. P5 (68, F, former CEO of distribution gas company) explained the unique expertise of utility workers as follows:

> *The federal laws do not allow anyone to touch regulated natural gas infrastructure unless they are operator qualified. Even though I was a vice president, I couldn't physically touch.*

As P5 explained, each worker group has their own expertise within the organizational structure of utility companies.

b. Utility Workers Union of America (UWUA): Many utility workers belong to UWUA. The union has over 50,000 members working in the electric, gas, steam, water, and nuclear industries across the United States. Utility worker participants in this study explicitly value their "body knowledge [11]" and apprenticeship style training through UWUA. Because these workers work inside or near pipelines, their physical interaction with the pipes and tools is crucial. "Body knowledge" cannot be learned via text-based training; as such, the union started its own training program, owned and operated by its members, to replace the company's text-based program. P3 (M, 43, utility worker of distribution company) explained the importance of "hands-on training" as follows:

> *So the goal is to do more hands-on, more in the field and then doing a time and skills based task log is what we call it. Where once you've completed this task so many times and we can sign off on it saying yes, you're capable of doing this task.*

The union workers were excited about this new training program because their experiential knowledge was less appreciated than other worker group's knowledge.

c. 3rd-party companies: More recently, tools and labor that are not needed frequently have been outsourced. Because each utility company has its own organizational structure, size, and resources, they hire different 3rd-party contractors for tasks such as construction and smart pigging. In the case of smart pigs, the utility companies do not want to own them due to their high cost as well as low frequency of use (e.g., needed only once every seven years).

d. Other organizations: Other organizations are involved in the gas industry. As utility workers belong to UWUA, leadership of utility companies have their own organizations, called American Gas Association (AGA) where they decide the industry-wide changes such as adopting new technologies. GTI is a research institution which performs gas-related research and generates training programs mostly for engineers. There are government agencies like PHMSA that establish national policy and enforce standards to protect workers, citizens, and the environment.

2) Safety-focused practices: In the gas energy industry, the most important value is safety. When we asked participants to write the 15 most important words related to their work, "safety" was the most commonly provided word (see Fig 1 middle). Gas is highly explosive, and seemingly small issues could result in a large number of deaths. P6 (M, 38, engineers, transmission gas company) explained the importance of safety as follows:

> *Safety is the number one priority for ourselves and for everybody that lives near our pipeline.*

One utility workers also shared the information that, since the company's founding in 1886, over 200 utility workers had died on the job. This is why regulators impose regulations and enforce policy: to ensure the safety of workers, citizens and the environment.

B. Future robot envisioned

Participants from the various stakeholder groups envisioned how our robot could be re-designed to enhance their safety-focused work practices.

1) The owners and primary users of the future robots: The most dificult design decision was not the robots' functionality, morphology, or behavior (factors which are often prioritized in human-robot collaboration studies); rather, it was who would own the new technology, and who would be its primary users. The most similar pre-existing technology in the gas industry is the smart pig—which, due to its high cost, is typically owned by a subcontractor. However, 5 out of 9 participants envisioned that this new robotic technology, if reasonably priced, could be owned by a utility company. Working from this assumption, participants expected more frequent inspection of not only transmission but also distribution lines. Currently, no smart pigs are available for distribution lines, as those lines are too narrow.

Although pigging distribution lines could have more risk due to their higher pressure, a pipeline researcher (p1, M, 46) explained the necessity of inspecting distribution lines as follows:

> *Because they (distribution lines) have more of the smaller lines that you can't inspect. The other ones (transmission lines) have larger lines, and they could more easily be examined without pigging.*

Distribution lines are never inspected after installation; instead, they are checked via leak surveys, where utility workers pass gas detectors over the ground.

Our utility worker participants expected that, if their company were to own the proposed robot, they could bring it on-site and insert it in the pipes. After the robots collect data from pipes, engineers could analyze the data and use them for the future inspection plans. This means that robots will be used by two user groups.

Our non-utility-worker participants, conversely, envisioned the robot as being owned by an external vendor, similar to current smart pigs—especially if the robot is not used frequently. One of the participants also mentioned that his company does not have enough human resources to analyze this vast amount of collected data from the robots. Engineers also mentioned that their companies do not have enough personnel to analyze all the data the robots provide. Gas researchers and a former CEO also worried if utility companies or 3rd-party vendors would be willing to invest in this technology without a clear expectation of profit.

2) Expected functionality and capabilities of the future robots: Participants reported multiple design ideas to make our initial prototype work in real-world setings.

a. Detect cracks, dents, corrisions and etc: The most frequently discussed element is the robots' detection capability (5 out of 9 participants). They want to examine pipes both internally and externally, using 360-degree scans to locate cracks, dents, corrosion, and variations in wall thickness. Once pipes are buried, digging them out takes too much time, money, and effort; as well, it inconveniences residents.

Participants also mentioned the trend of replacing old wood and metal distribution pipes with plastic ones in the last 40 years. When doing this job, P2 (M, 58, utility worker of distribution company) wanted to make sure that the insides of pipes were correctly welded; he cannot see inside the pipes once the welding is complete, and no method for inspecting inside distribution lines is currently available.

b. Traverse water and gas: The second most discussed design feature (4 of 9 participants) for the robots was the capability to traverse water and liquefied gas. Distribution lines cannot be emptied for inspection without cuting off consumer access to gas. Thus, the robots should be able to function while inside a pipe with gas. The problem is that friction generated by robots can produce sparks and trigger explosions. Because pipelines often contain water mixed in with the gas, participants also wanted the robots to be waterproof. Current smart pigs are not water-resistant, and therefore utility workers need to physically clean the pipelines out before pigging them.

c. Other capabilities: Participants also expected robots to provide real-time data and be able to inspect unppigable pipes. Currently, smart pigs inspect transmission lines for 1.5 months, and reports are ready 6 months later. This means that even urgent problems can go unaddressed for months.

Overall, participants had multiple expectations for robots. Most commonly, they expect that the robots can enhance current safety practices. With increased data collection, our robotic system could calculate appropriate pipe thickness, or more eficiently manage inspection plans. They expected that our system would be an improvement over current sampling approaches such as leak surveys by leting them actually inspect many pipelines. Participants also suggested close collaboration between robots and multiple stakeholders including engineers, gas pipeline researchers, utility workers, policy makers, and leadership of utility companies.

3) Training as important component of the future robot adoption: When discussing robot design ideas, the importance of workforce training was actively discussed (6 out of 9 participants). They wanted to make sure that all stakeholders understand the procedure, and said that the training materials should be developed following new regulations generated by policy makers. The training was expected to involve two different types of knowledge: one for engineers' ofice work and one for utility workers' field work. GTI members expected to generate more text-based materials for engineers, considering their history of generating such materials. P1 (M, 46, gas pipeline researcher) explained his expectations for training materials as follows:

> *Our materials are more from the knowledge side (not necessarily about hands-on activities).*

This quote shows his definition of knowledge primarily includes the knowledge for management and planning rather than the body knowledge of field workers. On the other hand, the UWUA members wanted more apprenticeship-style training by following the rules and codes generated from federal and state-level agencies.

V. Discussion

A. Organizational dynamics is an important element inhuman-robot collaboration not only to make robots functional but also to empower workers.

In this study, we found that organizational dynamics needs to be taken into account, to enable eficient collaboration between robots and humans. Because organizations typically involve multiple worker groups with different needs and issues, the adoption of a new technology does not always make clear who could be the technology's main users. For example, although someone unfamiliar with the field might consider pipeline inspection to be fairly straightforward and conceptually simple, it involves multiple organizations and worker groups who have different views, tasks, and expertise. In order to clarify the functions and interaction modalities of robots, it is helpful to first understand organizational structure and identify the most appropriate user groups.

By understanding organizational dynamics, HRI researchers will be able to not only make robots functional, but also to empower workers, especially those whose knowledge is devalued. In discussion with non-utility workers (e.g., researchers, engineers), most of them addressed the importance of text-based knowledge and neglected the body knowledge of utility workers. Body knowledge has a long history of being devalued despite its importance, weakening the autonomy of manual workers [11]. As robotics researchers get involved in workplaces, they typically interact primarily with managerial workers (as was initially the case in this study). Not all workers have the same power and authority in the workplace; this power differential can lead to certain workers being considered as targets of automation.

The problem is that these workers are already socially and economically marginalized, which has been discussed in economics studies [1]. When working with stakeholders in labor contexts, the voices of those vulnerable populations need more support, and HRI researchers' active engagement with their collective voices could be a way to intervene these power relations. This direction is promising in that the previous study showed how robots could challenge existing power dynamics in workplaces, and how the voice of workers with less power can be supported by robotic systems [31].

B. Human-robot collaboration should accompany trainingof workers for upskilling, not deskilling.

Despite what we as researchers had assumed, participants actively discussed worker training as an essential element for successful human-robot collaboration in their work contexts. All our participants, regardless of which stakeholder group they were in, agreed on the importance of worker training to adopt new robotic technologies. Participants also wanted to make sure the training provides the type of knowledge that aligns with their tasks. For example, utility workers wanted to learn about robots through apprenticeship-style training to strengthen their body knowledge while engineers expected to get trained for their planning work as managerial workers. Training has been rarely investigated in previous humanrobot collaboration studies because most studies focus on robot design and assume that easy-to-use robot design will naturally enable their smooth interaction with humans. These studies aim to enable collaboration between humans and robots, more attention is needed on training workers. Considering the history of automation and its influence on workers' deskilling, the training component will enable HRI researchers to avoid placing workers in a situation where they do not know how to utilize the new technologies, or where the new work process does not align with their existing knowledge, and thereby unintentionally deskilling them.

VI. Conclusion

When human-robot collaboration is studied in the lab, essential elements to consider are the human actor, the robot platform, and the task that they perform together. However, real-world situations are more complicated: the human actors are workers who have their own roles within their employer's organizational dynamics; the robotic platform is owned and maintained by either their employer or a third-party vendor; and the task that workers and robots will perform is defined by how management envisions the robots being used. These complications are socially constructed based on organizational dynamics. By understanding organizational dynamics and various perspectives on the work before developing robots, HRI researchers will be able to not only make functional robots but also address potential social issues involved with automation.. Considering the critical role of robots in the history of workplace automation [1], [2], this paper recommends that future human-robot collaboration studies to be more actively engaged with organizational dynamics and the collective voices of workers—especially those whose body knowledge has long been devalued within workplace automation process.

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