Minding the Stop-gap: Attending to the "Temporary," Unplanned, and Added Labor of Human-Robot Collaboration in Context

Hee Rin Lee
Media & Information
Michigan State University
East Lansing, MI, USA
heerin@msu.edu

Sarah Fox
Human-Comp Interaction Institute
Carnegie Mellon University
Pittsburgh, PA, USA
sarahf@andrew.cmu.edu

EunJeong Cheon
School of Information Studies
Syracuse University
Syracuse, NY, USA
echeon@syr.edu

Samantha Shorey
Department of Communication
University of Pittsburgh
Pittsburgh, PA, USA
samshorey@pitt.edu

***Abstract*—HRI scholars envision a future of work where human-robot collaboration brings mutual gains: organizations benefit from increased efficiency and productivity, and laborers benefit when tasks are redistributed between humans and robots based on their respective strengths. Yet, ironically, this collaboration in real-world contexts can lead to the opposite effect—workers' efficiency may decrease due to the additional tasks they must undertake to manage unexpected errors caused by robots. This "stop-gap" labor, often viewed as temporary and naturally manageable over time, can have significant and persistent impacts on workers. Drawing from observations across multiple robot deployment sites, this paper highlights the overlooked burden of this labor, challenging idealized visions of seamless human-robot collaboration. We argue that attending to stop-gap labor presents an opportunity for the HRI community to make genuine improvements for workers as primary stakeholders within complex socio-economic networks.**

***Index Terms*—labor, workers, case study, social justice, human-robot collaboration, stop-gap labor, wage gap, inequality**

Fig. 1. Robots from case studies: cobot in a manufacturing plant [6] (left); delivery robot in public space [7] (right)

I. Introduction

In *More Work for Mother*, Ruth Schwartz Cowan examines the history of household labor in America, focusing on the technological changes that were supposed to ease domestic chores but, in reality, increased women's workload [1]. Cowan argues that while new appliances like washing machines, vacuum cleaners, and stoves made housework less physically taxing, they also led to higher expectations of cleanliness, more frequent tasks, and little change in the division of labor. As men's involvement in housework did not increase proportionally, women were left to manage more work. The book highlights how technological advances inadvertently reinforced existing gender dynamics and kept domestic labor largely feminized.

Similarly, while robots and automation are designed to take over repetitive or labor-intensive jobs, they do not always lead to less work overall. Instead, they can shift labor to other areas, increase productivity expectations, or lead to new types of tasks requiring human oversight, management, or adaptation [2]. Additionally, just as technological changes in the household often reinforced traditional gender roles, automation in the broader economy risks reinforcing class inequality if its benefits aren't evenly distributed [2]–[4]. For example, while workplace automation has increased over several decades, workers' wages have not kept pace with this growth [3]–[5]. This phenomenon is observed worldwide, with the US experiencing some of the sharpest disparities.

In this paper, we examine the effects of newly added tasks that workers must take on to manage unexpected errors caused by robots. In multiple field sites, we found this labor to be considered a "stop-gap:" a temporary fix to problems that will become more manageable and eventually be addressed in the future as the technology improves. Yet, as our research demonstrates, stop-gap labor has significant and persistent impacts on workers in the present. The seemingly ironic effects of this labor—where technologies designed to replace tasks create additional work—highlight problems in the existing relations between workers and automation technologies. However, we argue, they also present a unique lens for HRI researchers to examine the labor issues associated with robotic technologies and identify opportunities to address this important yet understudied social justice issue in robotics.

The contributions of this paper are threefold: First, drawing on three case studies across production and delivery, we highlight the significance of stop-gap labor within distinct empirical settings. Building on HRI's existing interest in unexpected errors during human-robot interaction, we reframe issues of error and recovery as stop-gap labor based on the findings from these different work settings. Second, we bridge the existing literature in HRI regarding human-robot collaboration with labor automation literature that examines similar issues in more nuanced ways, viewing workers not merely as individuals performing tasks but as socioeconomic actors who utilize their labor within a complex network of relationships in a capitalist society. Third, we propose practical solutions for HRI researchers to address stop-gap labor issues, creating new research directions that could benefit workers and allow researchers to engage with the inequalities involved in robotics research.

II. Background

A. Stop-gap Labor in the HRI Community

Stop-gap labor and other labor-related issues of workers have not been explicitly studied in the HRI community [8]. However, individuals working with robots have been investigated in human-robot collaboration studies. As robots have gained increased sensing capabilities and intelligence, they are now able to perform tasks in close proximity to humans, which has led to greater attention to human-robot collaboration research in the HRI community. One of the primary goals of this research is to streamline tasks and increase productivity [9]. To measure the efficiency and productivity of human-robot collaboration, studies have typically been conducted in lab settings using convenience samples (e.g., undergraduate students), employing metrics such as accuracy [10], completion time [11]–[13], and fluency [14]. To enhance the efficiency of collaboration, studies have also examined the suitable behaviors of robots (e.g., gestures [15], sounds [13], and gaze [15]) as well as robots' learning strategies [16]–[18].

A subset of human-robot collaboration studies investigates how to manage robot errors. While both stop-gap labor and the existing body of work on error management in HRI examine ways to addresss robot errors, stop-gap labor emphasizes how error management is treated as workers' labor—often undervalued and neglected. In contrast, error management studies focus on maintaining human trust in robots. Assuming that robot errors are inevitable [19], HRI researchers have explored how humans perceive errors made by robots and how trust, damaged by these errors, can be repaired [19]–[26]. Certain factors, such as task type (e.g., risk level [27]) and user characteristics (e.g., personality [28]), influence human perceptions of robot errors, while recovery strategies (e.g., apologies [29]) can help restore trust in robots. Similar to broader human-robot collaboration studies, the error management studies have mostly been conducted in lab settings [20].

Ethnographic studies have also uncovered the unexpected labor performed by various stakeholders to manage errors and other unforeseen situations after the adoption of robots in real-world settings [30]–[33]. These studies are not necessarily focused on human-robot collaboration and are conducted in actual settings. For example, observational research on delivery robots in public spaces documents the "considerable interactional work" performed by construction workers, delivery drivers, and window washers, who halt their activities and adjust their positions to accommodate a robot's path [34]. While ethnographic studies highlight the importance of addressing unforeseen issues that emerge in real-world settings [35], they did not explicitly focus on stop-gap labor or its implications for labor relations in workplaces.

While all these lines of research are relevant to stop-gap labor, these studies rarely consider stakeholders beyond direct users of robots and the complex social relationships (except for [6], [36]), including managers and other co-workers. In this paper, we will investigate the meaning of stop-gap labor in the context of workplace automation from the perspectives of workers. Robots in this study will be examined not only on an individual level but also from a broader societal perspective (e.g., organizational/economic levels).

B. Stop-gap Labor Outside the HRI Community

The importance of newly added human labor resulting from automation—what we refer to as stop-gap labor—has been identified as a significant issue outside the HRI community. In her article *Ironies of Automation*, Bainbridge points out that workplace automation, intended to increase efficiency and solve problems, can ironically lead to the opposite effects [37]. She argues that after automation, human workers still bear the 'responsibility' of monitoring these technologies and managing abnormal situations caused by unexpected errors. Despite the added responsibility of overseeing technology and handling errors, the competitiveness of human labor diminishes, as workers now perform smaller portions of their original tasks that are expected to require less skill. Decreasing control of the work process, stemming from the need to manage random errors in automation technology, has also been discussed as a factor contributing to high stress and negatively impacting workers' well-being.

Studies have highlighted that the 'Fitts-list' approach to automation, which assigns tasks to humans and machines based on their respective strengths, could exacerbate the issue of stop-gap labor [37], [38]. This simplified method of task distribution may lead workers to lose important responsibilities that showcase their skills or to retain only the more challenging aspects of their work, ultimately resulting in dissatisfaction and lower productivity. More dynamic and situational approaches have been proposed as promising alternatives, emphasizing the importance of human autonomy in deciding when to increase the role of automation technology (e.g., using auto-pilot mode when a pilot has multiple tasks queued).

If the studies discussed above focus on the negative effects of stop-gap labor in terms of workers' task performance, Acemoglu and Restrepo emphasize the importance of newly generated tasks after automation [2], [39]–[41]. Historically, automation exhibits two types of effects: the displacement effect and the reinstatement effect. While robots inevitably decrease the number of tasks allocated to humans, they also generate new tasks that require human labor. For example, when the textile industry was automated, new types of pro-

TABLE I
THREE CASE STUDIES

	Case study 1	Case study 2	Case study 3
Labor type	Production labor	Production labor	Service labor (Delivery)
Field site	Car manufacturing factory	Manufacturing factories	Public area
Region	United States	Denmark	United States
Robotic platform	FANUC cobot	Collaborative robots	Autonomous delivery robot
Primary point of contact	A member of the United Auto Workers (UAW)	An industry network on cobots, the company's cobot partners, and the company's project engineer	City official and Robotics company deployment manager
Data collection methods	Interviews	Contextual inquiry fieldwork	Ethnographic observation, interviews
Duration	January - July 2021	February - May 2021	July 2021 - February 2022

duction jobs were created. However, Acemoglu and Restrepo found that in the past decade, reinstatement effects have diminished. Their economic model, based on a task-based framework, was developed using US government data and quantified the negative impact of robots on workers (e.g., decreasing wages) by calculating the newly generated tasks for humans and those that have been removed [2].

One of the main concerns in this line of work is the increasing economic inequality at the national level, as workers who lose tasks to robots are often those whose labor is already undervalued [3], [4]. The impact of automation technology on the wage gap has also been addressed in a recent OECD report, which identified the US as one of the worst cases across the globe [3]. The scholars emphasize that researchers should investigate how to create new tasks for human workers in studies of automation technology. This was similarly discussed in HRI as well. For example, Winkle et al. [42] argue: "currently, no human activity can be perfectly and seamlessly carried out by a robot. Instead of glossing over the important technical and design work that is behind the translation, turning and framing of an interaction to make it robot-compatible [...] it [should] be documented and reported fully" (p. 78). Stop-gap labor can serve as a starting point to explore the new tasks generated as part of automation research.

Building on scholarship that examines the evolving labor issues of automation for workers, this paper discusses how stop-gap labor is commonly observed in three case studies of robot adoption. It investigates the missed opportunities to benefit workers not only as individuals seeking to enhance their productivity but also as members of the labor market who need to maintain their competitiveness to earn a livelihood.

III. Three Case Studies

Here we present our observations of stop-gap labor across three distinct field sites within two different industries: production and service (delivery) (See Table I for detailed information on each field site). This paper focuses on these two domains because both are known for their rapid adoption of robots. Manufacturing is the industry where more than 80% of robots are deployed in the US, while logistics is a field experiencing a fast-growing number of robots—162% increase in 2016 [43]. Additionally, cobots and autonomous mobile robots, which have been widely adopted in these two industries, are two platforms that have seen robust real-world adoption in recent years [44].

The main arguments of this paper are developed through an approach inspired by meta-ethnography [45], a qualitative research method used to synthesize findings from multiple field sites and gain a deeper understanding of social and cultural phenomena. It involves comparing and translating themes across studies, while preserving the meanings and contexts of the original data. Over the course of roughly 5 months, the authors met weekly to discuss details of each of their analyses, with particular focus on the undervalued labor related to human-robot collaboration observed in each site.

In each case study, we address 1) relevant previous work both within and beyond HRI, 2) the case study settings, 3) instances of stop-gap labor at each site, and 4) the significance of stop-gap labor in their respective context. All three case studies were conducted by the authors, and we will describe each case from a first-person perspective.

Production Labor

Recent HRI studies in manufacturing settings investigate how humans and collaborative robots (cobots) can work together, implicitly exploring production labor. Unlike traditional robots, cobots with advanced sensors and intelligence can operate near humans without barriers. Researchers suggest these robots may assign tasks to humans, potentially mitigating worker displacement due to automation [14]. Most cobot studies focus on productivity from three perspectives: 1) human, 2) robot, and 3) team. For example, human perspective studies examine workload perception [46] and robot usability [47], [48]; robot perspective studies explore human awareness [9] and appropriate behaviors [14]; and team studies assess collaboration efficiency and shared autonomy [47]. Additionally, research on workers' willingness to collaborate with robots shows that features like trust [49] and sociability [50] can increase cooperation and reduce displacement concerns.

While HRI research focuses on production workers as individuals who could be users (or co-workers) of robots, perspectives outside HRI examine production labor within complex social, economic, and political contexts [6], [51], [52]. Workers and their labor are clearly differentiated, as workers use their labor to earn a livelihood [53]. They are perceived as socioeconomic actors whose labor value is determined by the significance of their skill sets through negotiation with their employers (or management). In this sense, production labor in the US is critical, as it enables workers without formal higher education to remain in the middle class. At a national scale, the decline in employment in manufacturing sectors contributes to wage inequity and polarization in employment [2], [54], [55]. Due to its importance, the US Congress has paid special attention to this labor [56]. These studies have revealed that automation technology, which performs labor, has decreased the value of human labor, as automation technology owned by employers reduces the need for human labor [53], [57], [58]. Additionally, automation technology results in less autonomy for workers, as they must work alongside automated machines that operate at a pace determined by employers [53]. Overall, scholarly discourses outside of HRI place greater emphasis on the meaning of labor within the complex socioeconomic power dynamics of organizations and broader society.

A. Case study 1: Production Labor in Car Manufacturing in the US

Setting: The first case study of production labor is based upon interviews with eight participants from the United Auto Workers (UAW) who are employed at a large car manufacturing factory in the US. The data were collected between January and July 2021. The recruitment process involved collaboration with a UAW member and an on-call program presenter from the School of Human Resources and Labor Relations at the first author' university. The school has strong ties to labor unions, with union officials actively engaged to facilitate academic-union partnerships. Participants were categorized into two groups: 1) union officials, including one president and three UAW Local shop committee members, and 2) production workers, including one material handling team leader, one zone leader, one assembly line worker, and one core team member. Among the participants in their 30s, four individuals had 8 to 14 years of experience, while the four participants in their 50s and 60s had 20 to 26 years of experience in production work. All participants were male.

This study was conducted online via Zoom due to COVID-19 restrictions in 2021. Additionally, the UAW Local that I collaborated with did not have the authority to allow me to visit the manufacturing site. While building connections through the trade union does not guarantee access to the field site, I intentionally established primary relationships with the workers. I made this decision because, in my previous workplace automation research [51], [59], I found that researchers were expected to conduct research that aligned with management's agenda if they were the primary point of contact. As the interviews were conducted online, I used the Google Slides platform to conduct the map-making activity [60]. During the interviews, participants were asked to write 15 words they felt were relevant to three keywords: 'your work,' 'your workplace,' and 'future work.' When participants finished writing, they were asked to categorize the words and add the word 'robot' to the word map to understand the relationship between robots and their work context (See [59]–[61] for examples of the map-making process.).

Stop-gap Labor: The stop-gap labor identified in this study arose after FANUC cobots were adopted to install body plugs in various parts of the car body along the seal line. This installation work was originally completed by human workers; however, the new robots are now performing the tasks. The stop-gap labor in this plant refers to the extra work that workers must handle due to the robots missing multiple plugs. This issue was more complex than just a problem with the robots. A zone leader of a seal line who supervised roughly ten workers and had a deep understanding of this issue (both individually and organizationally), explained:

"We have had robots (FANUC cobots) that, where people used to manually install body plugs to put various holes in the body, the robots are doing it now. Since the robots took over, we have missed more plugs due to the robots missing them than when we had people doing it. So that takes up more time to have somebody else go back and have to install them because you don't have the time... when they added all the extra work to your job. So that's one of the things that everybody talks about what's the difference in price between paying somebody, a person to keep doing it, like what we have for years and we didn't have the issue with the missing plugs compared to the robot missing them and then everybody's tied up and doesn't have time. Then you see, we have to get a team leader or you have to stop the line to get that in there. - Zone leader (57 years old, M, 22 yr of production work experience).

Issues of Stop-gap Labor: The stop-gap labor was interpreted in different ways among the stakeholders in the manufacturing plant, indicating that the primary beneficiaries of the cobots are not necessarily the primary users—the workers. From the production workers' perspective, the extra work generated by the robots was a significant issue that lowered productivity and efficiency, which are crucial in a time-sensitive manufacturing environment. Production workers are closely monitored, and the fast pace of their work usually does not allow them extra time to manage unexpected tasks. Often, individual workers had to pause their tasks to perform the stop-gap labor, which sometimes caused the entire seal line to stop. Halting the assembly line can cost between $1 million and $7 million per hour [62], [63]. Since the benefits of robot adoption were not shared with the workers, they wondered about the financial advantages for leadership in removing tasks from workers and hiring fewer human workers. However, this cost analysis was not accessible to the workers or their unions.

The leadership interpreted stop-gap labor differently. Though I was unable to interview the managers directly to understand their views on this new type of labor, I gathered insights on how the benefits of the robots are calculated in this plant from union representatives who have long observed the rationale behind the adoption of automation technology. As the zone leader mentioned, decisions regarding the robots may result from cost analysis, since leadership can own the robots, which do not incur additional human labor costs for both performing tasks and managing them. Due to decreasing productivity, the zone leader and the union representatives have argued for the need for extra human workers to handle stop-gap labor. However, leadership considered this a temporary and straightforward technical issue that could be easily resolved. The experiences of workers have been neglected.

B. Case study 2: Production Labor in Manufacturing in Denmark

Setting: The second case study of production labor draws on fieldwork from two Danish manufacturing companies, which explored the social and organizational dynamics surrounding the introduction of collaborative robots (cobots) [6]. The research involved two companies—one large (Company A) and one smaller (Company B)—that had recently integrated cobots into their production processes. The fieldwork was conducted between February and May 2021, with regular visits to Company A. Company A is a large manufacturer with over 2,000 employees, producing electronic components and mechanical parts. To remain competitive and retain production within Denmark, Company A invested in automation, transforming one of its fully manual production lines into a semi-autonomous cobot cell. The cell involved two cobots working alongside three operators, reducing the need for additional workers. My interviews focused on operators' evolving roles and their adaptation to technical challenges posed by the new cobot system. Company B is a smaller manufacturer with fewer than 50 employees, specializing in metal profile production for industries like construction and wind energy. Since 2020, Company B has integrated five cobots into its operations for tasks such as metal cutting and welding. Through semi-structured interviews, I explored how operators collaborated with cobots, their adjustments to the new work environment, and the broader social and organizational changes that followed the cobot deployment.

Stop-gap Labor: After robots took over primary tasks that once utilized human (e.g., welding), workers became responsible for peripheral tasks—those "before" and "after" steps like setting up workstations or cleaning residues [64]. A worker from Company B reflected on this shift: *"Before the robot was implemented, I was assigned one process and did manually what the robot does now. But now I rotate between various production steps."* These new responsibilities—though seen as "miscellaneous" or "random"—are essential to keep the system running smoothly, even though they aren't formally defined. Another worker noted, *"[Since we got the robot], I have had more variation in what I do, rotating to different workstations. I'm not just standing with the robot."* Tasks like collecting byproducts from the robot's workstation, while seemingly trivial, were indispensable to the overall process.

When robots malfunctioned, the hidden nature of stop-gap labor became more explicit. One common task involved documenting robot status or errors, often by memoing for the next shift. Workers frequently waited for colleagues from other shifts to exchange this critical information face-to-face: *"For example, today we were told the robot couldn't run normally due to an error. It would have been helpful to know ahead of time how to resolve that issue."* Though formal training programs are offered, workers often pointed out that much of the required knowledge—especially for cobots—was learned on the job. As one worker explained, *"The training program is helpful, but when it comes to these robots, theory and practice don't always align."*

Robot errors required contextual knowledge that workers developed over time. *"We have to learn how the robot runs and how it reacts in each situation. Not all errors are the same. Some take longer to resolve because you have to figure out if it's something we've encountered before,"* one worker shared. These breakdowns not only absorb workers' time but also shift their focus from production to problem-solving—often without reaching management's notice or support. Yet, the expectation remains that production rates will increase, despite the growing burden of stop-gap labor.

Issues of Stop-gap Labor: Workers often find themselves taking on unacknowledged and unpaid tasks when robots malfunction or operate unpredictably—such as passing on error information to the next shift or handling breakdowns. These tasks, often invisible to management, create the impression that the robots are functioning smoothly, leading to a perception that workers have less labor-intensive work and that overall productivity has improved. However, this overlooks the hidden burden placed on workers. This disconnect between perception and reality is further exacerbated by the fact that robot designers and developers may not be aware of the persistent stop-gap labor that surrounds the operation of their machines. Even when they consider workers as the primary users [65]–[67], the focus often remains on usability—how easily and intuitively workers can operate the robots—without fully considering the additional tasks that emerge when robots malfunction. Usability, in practice, only becomes meaningful if robots can function with minimal human intervention. Yet, the ongoing miscellaneous tasks required to keep robots running smoothly, which often fall to workers nearby or directly operating the robots, go unnoticed and unaddressed.

To ensure the benefits of automation are fully realized, both management and designers must broaden their view of labor. For management, it would be needed to recognize the hidden labor performed by workers and incorporate it into their assessments of workload and productivity. This acknowledgment should be followed by fair compensation for the extra tasks. For designers, their focus must be expanded beyond usability to include the broader scope of human-robot interactions. By acknowledging the operational friction, they can design robots that minimize the need for human stop-gap intervention, ensuring that usability benefits workers in practice, not just in theory.

Service Labor

This section focuses on service labor involved in *delivery robots*. As autonomous vehicles — ranging from "robotaxis" to delivery bots — have entered public streets, their potential interaction with pedestrians has become a paramount concern in HRI scholarship. Thus, in recent work, HRI researchers have sought to improve the navigation capabilities of robots to minimize disturbances to pedestrians [68] and improve communication from robots to pedestrians about awareness of their surroundings [69] [70].

The dominant expectation of delivery robots is total automation of the delivery ecosystem, where material goods are transported between locations without the need of human labor. Yet, in reality, various forms of labor are required of the people who also dwell in the public spaces that act as delivery routes. Human robot *interaction* in these spaces often takes the form of human robot *encounters*: they are ”subtle, indirect, unintentional, and yet socially profound” [71] (p. 86). HRI researchers Rosenthal-von Der Pütten’s et al. [36] term the human subject of robot encounters the “incidentally co-present person” (or, InCoP). InCoPs are people who just happen to be in the environment where a robot is deployed, and their interactions are largely observational or artifact-adjacent. However, researchers and journalists document the contributions of helpful human bystanders who uphold robotic operations: clearing space for the robot’s pathway [34], lifting them over curbs [72], and dislodging them from snow [73]. Yet, these forms of interaction occupy a theoretical gray-area in terms of user studies. Pedestrians and bystanders are neither users/operators nor recipients of service.

Cognitive scientist Gary Marcus argues that the complexities of real-world scenarios make it difficult for current AI systems, which depend on machine learning, to fully automate these tasks without human involvement [74]. Correspondingly, one solution roboticsts have pursued to overcome the challenges of social contexts is teleoperation. Teleoperation is a form of ”shared autonomy” [75] in which a remote operator typically provides real-time instructions that are acted upon by the robot. Importantly, Elbeleidy et al. argue, pursuing teleoperation requires roboticists make design decisions that support usability for teleoperators – who are often neglected in evaluations and viewed as a ”short-term solution” [76] (p. 578). Teleoperators may be deliberately concealed to amplify perceptions of technology’s capabilities. For example, despite Amazon’s claims around autonomation, news reports revealed that the ’Just Walk Out’ Technology in their ”cashierless” stores relied on more than 1,000 workers in India to review transactions [77]. Likewise sociologists and information scientists have discussed the ways in which the work of content moderation or matching is performed manually by low-wage workers abroad, rather than algorithmically as users might assume [78], [79]. Scholars and pundits alike question whether it is really automation or outsourcing that is being pursued by firms in these cases [80], [81].

C. Case study 3: Service Labor in a Delivery Robot Pilot in the US

Setting: From July 2021-January 2022, I was a part of a university team studying a trial deployment of delivery robots in Pittsburgh, PA. Rather than an academic enterprise, the pilot originated from a partnership with the local city government and a well-known robotics firm. Two distinct motivations catalyzed their initiative: 1) recent state legislation newly classifying delivery robots as “pedestrians,” giving robots some of the same legal rights to occupy public roadways and pedestrian paths as humans; and 2) a multi-city collaborative grant from a foundation meant to examine public acceptance of autonomous vehicles. On the city-side, there was particular interest in understanding how the new state regulation might affect pedestrian behavior and traffic, as well as what oversight they might be able to wield over operations on the ground. The robotics company, on the other hand, saw the pilot as an opportunity to enter into a new market. At the time of the pilot, the company had largely been deployed on college campuses, but the grant created space to work alongside local governments and hone their business case.

My involvement in the study included participant observation during mapping and regular operations, public town halls, and community oversight board committee meetings. This access allowed me and other members of the research team to gain a nuanced understanding of the dynamics of deployment from multiple perspectives — advocates and opponents, local business owners, robotics company representatives, and city officials. During town hall meetings, in particular, the range of concerns and opinions were often on full display. Local transit advocates, for example, questioned the need to invest in experimental pilot projects when they saw the path to addressing mobility and access issues as clear (e.g., free and reduced bus fare, expanding existing transit options). For the disability rights community present, robots occupying space on the sidewalk represented a regressive move — making public space less accessible to those with mobility impairments. Residents also raised concerns over the labor implications of the technology. What did it mean that, during a time of heightened unemployment and precarity, the city was investing in a robot deployment that would displace delivery drivers? Though the pilot proceeded without engagement with this final question, we seek to address it in earnest here.

Stop-gap Labor: Though initially promoted as a humanless form of delivery, the robots actually relied heavily on the labor performed by (a) a globally distributed network of staff and (b) the public. There were, of course, the field technicians who identified and mapped the most appropriate route for the robots to travel within the two neighborhoods where they were deployed. But long after this first phase, there were also robot wranglers on site to observe the devices at all times and intervene in moments of breakdown. This included stepping in to readjust the robots when they rolled into a ditch or encountered a crack in the sidewalk, a frequent occurrence in a city with aging infrastructure. When staff weren’t present, robots were left to “rely entirely on the curiosity, goodwill or interest of nearby pedestrians” when faced with insurmountable obstacles [7](p.15).

Additionally, on-site staff were in constant contact with remote operators in South America, a workforce that was made up of part-time, low-wage student employees. The robots relied on GPS and camera data for navigation, with operators sending commands every few seconds. This “parallel autonomy” system reduced costs compared to full automation technology, making operations more economically viable but much less autonomous than originally marketed [82]. This remote operations program was presented as a means of skills development in robotics and AI, while providing flexible, part-time work that complemented students' academic schedules — framed as a mutually beneficial arrangement that supported students' growth while helping the company maintain affordable human oversight for its robots. The startup paid these students about $2 an hour, which was far lower than the minimum wage of Pennsylvania (where the deployment unfolded) but higher than the country where the labor was performed.

Issues of Stop-gap Labor: Though the human labor taken on during the pilot was, in fact, plentiful — perhaps even enough to offset the jobs lost by human delivery drivers — none of that work was offered to local residents as paid employment. Instead, the parallel autonomy we witnessed was only economically viable if performed from afar. If the remote operators had been compensated according to local wage standards, the cost would have been too high to maintain profitability or justify to investors (as opposed to relying on traditional, human delivery).

Further, necessary modifications in human behavior (like walking around a robot) might be seen as short-lived inconveniences. Yet, technology designers, including roboticists, hold the belief that users can be "configured" [83] [84]. New technologies achieve functionality and acceptance not just through improvements to the product but the gradual shaping of practices that transforms people into "ideal users." If left unchallenged, overcoming technological limitations can become the responsibility of the people who merely encounter robots – people who have little to gain from incidental interactions, being neither senders of goods nor recipients of service. For members of the disabled community, in particular, navigating around delivery robots is an additional burden upon people already managing the inaccessibly and inequity in city infrastructure [85]. As Dobrosovestnova et al. reflect, helping robots is a practice teeming with ambiguities. It is at once an expression of care (representing an empathetic relationality for non-human actors) and a form of work (representing an uncompensated and unacknowledged contribution) [86].

HRI researchers are increasingly called to conduct studies in-the-wild in order to build scientific knowledge of how robots "fit into and change the social structures at work, at home, and in public settings" [87, p.2]. It is thus reasonable to assume that many future human-robot encounters may be with in-progress prototypes, deployed as part of commercial pilots like the one I observed. And here, people will encounter the technology's limitations. Turner [88] argues that prototypes are far more than a preliminary form of an artifact. They are also social models, making visible technical possibilities and "a larger and presumably better way of organizing society as a whole" (p. 260). Looking forward, it serves us to ask: *what future* is modeled in our deployments and *how is labor organized* in this future?

IV. Discussion

A. Common Characteristics of Stop-gap Labor

Although each field study was conducted by different researchers at different times, locations, and using distinct approaches, we found stop-gap labor in every setting. Stop-gap labor has three common characteristics, the first of which is that it arises from the gap between biased views of robots as flawless technologies and their actual performance within complex social dynamics in the real world, along with ongoing issues. Often, management holds the belief that robots will eventually be fully autonomous, leading to the neglect of current issues until the adjustment period is over. However, the HRI community already knows that this is not always true, as existing error-focused studies show [19]–[26]. More importantly, when robots enter the real world, they are not just located in a specific physical space but are situated within complex social networks involving multiple stakeholders. The existing power dynamics among stakeholders can cause the unexpected errors of robots to create more issues for certain groups than for others [52].

The second characteristic is that stop-gap labor is interpreted differently depending on the level of power each stakeholder group has. Management (or the roboticists at a startup in Case Study 3), with strong authority, views this labor as temporary, trivial, and supplementary, while workers performing stop-gap labor, with limited power, perceive it as unfairly compensated and underappreciated. Due to this characteristic, although production workers have been studied as primary users or co-workers of robots in HRI research, they are not necessarily the primary *beneficiaries* of robots. Instead, they struggle with performing stop-gap labor without additional compensation. Moreover, due to this devalued extra work, workers' performance in their main tasks can suffer.

The third characteristic is that stop-gap labor is decoupled from skills, which could be the most problematic issue. Generally, as workers engage in certain tasks, they gain knowledge that enhances their competitiveness in the labor market. However, because management sees the value of this labor as low, temporary workers would be hired without the chance to further use their skills, similar to the student workers in Case Study 3. Full-time workers may also not have the opportunity to leverage the skills they acquire to improve their relative position. This decoupling of skills from labor is significant, as workers' skills directly relate to job security and potential wage increases, both now and in the future. This finding aligns with insights from classic workplace automation literature, which defines workers as socioeconomic actors within a capitalistic society [53], [57], [89].

Although the three characteristics highlight the dark side of stop-gap labor, we believe that acknowledging and addressing stop-gap labor with care can actually empower human workers and strengthen their role in workplace automation. In the following discussion, we will explore how this approach can benefit workers within the HRI community.

B. Formalizing Stop-gap Labor

Automation has long been viewed as a process that decreases the number of tasks humans can perform. In previous eras, these displacement effects were accompanied by reinstatement effects, balancing the two. However, recent studies show that current robots tend to displace more tasks than they generate [2], [5], [41]. In human-robot collaboration studies, a certain portion of work is allocated to humans; however, from the perspective of human workers, they are losing tasks they originally performed to robots. The problem is that the decreasing number of jobs results in economic inequality, along with employment polarization. According to an OECD report, automation technologies have already contributed to severe wage gaps, particularly in the U.S. [3].

Considering the negative impact of automation on workers, stop-gap labor that introduces new tasks for human workers can be transformed into valuable opportunities for training and upskilling. This would enable the HRI community to benefit workers through automation, as it originally envisioned. Stop-gap labor can be formalized in HRI research to recognize its benefits and to explore practical solutions for this formalization. We suggest three potential ways to achieve this.

First, when investigating robots, HRI researchers should increase their awareness that robots are integrated into existing complex social relationships [6]. Since robots can benefit or harm different people in various ways, it is essential to identify whose labor is most devalued, as these workers are the most vulnerable to automation's negative affects. This group should have more opportunities to share their concerns, and their voices should be reflected in the research process, even if only briefly (e.g., by obtaining feedback from some of the most vulnerable stakeholders after experiments or by conducting participatory design with them). Takayama [90] encourages HRI scholars to look at the activities performed by "robot wranglers" during design and development processes to understand roles or even occupations that might exist in the future. Acts of robotic assistance have been formalized today in commercial pilot programs as guides or chaperons [91]. They may not remain temporary after all.

Second, HRI researchers can more deliberately describe the potential errors of their robots. In HRI, as we explore the advancement of robots, errors or unexpected failure are rarely reported unless they are the main focus of the research. A formal description of potential issues that arise during the research process could open new research directions for exploring how humans might compensate for the weaknesses of robots. This consideration need not be limited to studies in the wild; even controlled experiments can benefit from reporting such evidence-based errors. More importantly, when researchers collaborate with industry partners—typically in leadership or management—who provide access to the field site, it is crucial to share these issues to offer a more grounded perspective on the robots and to underscore the important role of human workers, who will ultimately handle these errors.

Third, HRI researchers can identify the necessary strengths of humans in their studies. Through research on human-robot collaboration, they delineate a new division of labor between humans and robots. Historically, this division of labor, resulting from the emergence of new automation technologies, has been shaped to benefit management rather than workers [53]. Thus, it is important to be cautious about what this new division of labor means for the deskilling and upskilling of workers [64]. Through this process, researchers can advocate for the unique strengths of human workers that are essential for effective collaboration with robots. As robots represent significant scientific achievements and crucial subjects of HRI research, their strengths have been emphasized in this field [92]. On balance then HRI researchers should generate knowledge about the importance of human strengths to ensure that automation benefits workers.

V. Conclusion

The adoption of robotics and automation technologies has often been portrayed as a path to efficiency and enhanced productivity. Yet, our exploration reveals that these innovations frequently introduce unacknowledged and persistent forms of stop-gap labor that burden workers. This labor is neither temporary nor inconsequential, as often assumed, but exposes critical issues in automation practices, including inequities in labor distribution, the undervaluation of human contributions, and the decoupling of labor from skill development.

By situating robots within the complex socio-economic networks they inevitably inhabit, we challenge the narrative that automation solely serves organizational interests. Instead, we argue for an HRI framework that centers workers, not just as operators or co-workers of robots, but as integral stakeholders in the design, deployment, and evaluation of these technologies. Addressing stop-gap labor through participatory approaches, transparent reporting of automation's limitations, and deliberate focus on human strengths can transform this overlooked phenomenon into an opportunity for empowerment and skill enhancement.

The HRI community bears a critical responsibility to attend to the labor dynamics inherent in human-robot collaboration. By prioritizing equity, acknowledging the burden of additional labor, and formalizing strategies to address these challenges, researchers can guide the integration of robotics in ways that respect and enhance the lives of workers. Only by confronting these dynamics can the field ensure that the promises of automation translate into genuine benefits for all stakeholders.

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