The Video Game to Robot Driver Pipeline: Sociability with Humans-in-the-Loop*

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***Abstract*— This paper presents an ethnographic study of the robot drivers at DaxBot in Philomath, Oregon. While the preponderance of current robot food delivery companies look like wheeled coolers, DaxBot claims to prioritize "friendly" integration with the community via a higher-DOF semi-anthropomorphic platform. The robot driver observation period occurred over four weeks in August of 2022. The guiding research questions were: (1) *Robot:* How are the 3-DOF head, eye-animations, and sounds used during robot operations?, (2) *Driver:* What makes for a good robot driver? How do they vary in experience and use of system?, and, (3) *Community:* In what ways has this robot integrated with local people and infrastructure? The resulting analysis triangulates over robot driver observations, employee interviews, and the 30-page DaxBot robot driver instruction manual. Social uses of the platform included playing hide-and-seek with children, cueing automobile drivers when it wants to cross, navigating construction sites, pulling back for people in wheelchairs, and stopping to watch the butterflies. We also discover the value of a robot driver's prior experience with video games, as they can puppeteer the 'aliveness' of the robot well. Thus, robot sociability and expression may continue to benefit from experienced video gamer humans.**

Fig. 1: Robot Crossing a Dangerous Street.

I. Introduction

DAX is a robot used for food delivery that utilizes an expressive head, treads that let it traverse uneven terrain, and a retractable temperature-controlled drawer. During our 4-week observation period, the company was just beginning to roll out its autonomous navigation capabilities [1], thus we captured the robot sociability and cultural integration observations presented here at a time when their robot drivers were most experienced, with 1-2 years of full animation and control of the robot. Attention permitting, the company encouraged its robot drivers to bond with people: (1) at the restaurants for whom they are delivering, (2) along the path to the customer, and, (3) at the point of delivery, where the food drawer will open. To do this, they say they hire 'fun-loving' robot drivers – usually with video gaming experience:

> "The nice part is there are a lot of kids growing up, [for whom] playing video games is second nature. To then operate the robot you just have to explain that you don't get another life, you actually have to go pick it up if you drive it off a cliff, right? But the fact there is already a basis there is kinda neat."

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People in the suburban town where the robots operates support and enjoy the robots. For example, the main drivers knew the owners of the restaurants for whom they deliver, teased them via the robot to socially bond, and called them on the phone if someone did not load the robot quickly. Because of the varied terrain, the robots sometimes fall over, but one driver reported that within five minutes a stranger almost always rights a fallen robot, sometimes even stopping their car to help, so they often wait a few minutes before sending out one of their own team members. Company leadership also reported personality as a key criteria for recruiting new robot drivers:

> "Everyone drives the robot a little differently. Some drivers have their go to, like they're really good with using the eyes for expression. Others are really good with using sound... or the neck. Some are good with all three... it becomes muscle memory. Watching [a good robot driver] is like watching a jazz performer."

However, as with remote warfare or search and rescue, driving robots for food delivery comes with some psychological risks. For example, one DaxBot driver described a hit-and-run with a motorist in October 2021, near the intersection pictured in Fig. 1. The driver reported feeling anxiety for several weeks, particularly near that intersection. Ultimately, the robot and its driver appeared in court and

Fig. 2: The DAXBot software, interfaces, and hardware. Each new deployment location has a custom base station to support communications, including realtime video, audio, GPS, robot status and connectivity. During the robot driver observation period, DAXBot, with an operations team of 5 people (includes driving and maintenance) and 26 robots, was just beginning to test autonomous navigation features after two years of active human-in-the-loop delivery.

the erring motorist was declared liable and fined. Local news declared the robot the "victim," perhaps illustrating the community's perception of the robot as in-group.

II. Research Frame & Related Work

Post-pandemic, human-in-the-loop robot delivery has experienced a massive boom as people sought to socially-distance [2], [3]. Separate works have considered robot social navigation [4]–[6], and tablet-based food ordering systems [3], [7], [8], however, little has been done to mine the rapidly growing knowledge of robot food delivery experts, though early works do clarify their social interpretation [9].

Research questions included "How was the robot received by the community?" and "How did the experience or profile of the driver improve that experience?," expanding upon expressive opportunities (such as light based expression [10], sound based expression [11], and motion [12]–[15]): (1) At the point of client business pickup, (2) In transit to or from the delivery location, (3) At the point of customer delivery, (4) Overall, i.e., for the end-to-end system. We additionally report on robot design and communications implementations that add insights and/or reinforce prior results in Social Robotics. Perhaps there will be broadening needs for '*humans behind the robot*,' e.g., [16], [17], that enable the success of robots that interact with other humans.

This robot-driver centric approach complements past work in expressive robots, e.g., how paths of a robot delivering food impact human attention [18], and how robot motion might legibly communicate a robot's current action, needs or wants [19]–[23]. Gesture, such as back and forth motions, can also be indicatory [20], [21]. Coherent motion expressions from a higher-DOF semi-anthropomorphic robot done well, could logically have more nuance and potential.

Ethnography is well suited for situated, participatory research, as it heralds the use of *reflexivity*, i.e., our innate ability to utilize our own insights, social relationships, and experiences to distill meaning [24], [25]. It is also inclusive, as anthropology is the study of culture, and prioritizes direct connection with communities and effected parties [26], [27]. Technology-centric ethnography, and prior uses in robots further evidence the utility of triangulation across sources [28]–[33]. The produced results utilize exemplars, storytelling, images, and grounded coding [34]. As academic analysis of the use of ethnography [35] described: "*benefits of reflexivity included accountability, trustworthiness, richness, clarity, ethics, support, and personal growth—beneficial for the integrity of the research process, and the quality of the knowledge generated.*"

III. Data Timeline

This paper's findings are triangulated across participant site observations, employee interviews/conversations, and technology artifacts/documentation, which were collected over four weekly observation periods in August 2022. To add background to the typical activities occurring at the company and data collected, we detail each observation day:

- Day 1: Driver1 observations, Operations team communications, War Stories, Ethnographer learns work environment. STATS: Coffeeshop 2 ; Restaurant 4 ; Pizza 1. TESTING: *None*.
- Day 2: Driver2 and Driver1 are in, so there are more instances of driver-driver advise sharing / communication, and joint commentary on stories and experiences. CEO interview. Ethnographer orders coffee to research site. Ethnographer met & followed path of robot. STATS: Coffeeshop 2 ; Restaurant 5 ; Pizza 1. TESTING: *None*.
- Day 3: Ethnographer visited Client1, informal chat with employee and trainee. Driver2 Observations, Stories. Ethnographer visited Client2, informal chat with owner. STATS: Coffeeshop 2 ; Restaurant 3 ; Pizza 1. TESTING: *Map Building for New Deployment Site*.
- Day 4: Observations of remote remote-driving, watching via robot operator screen, while actual driver joy-

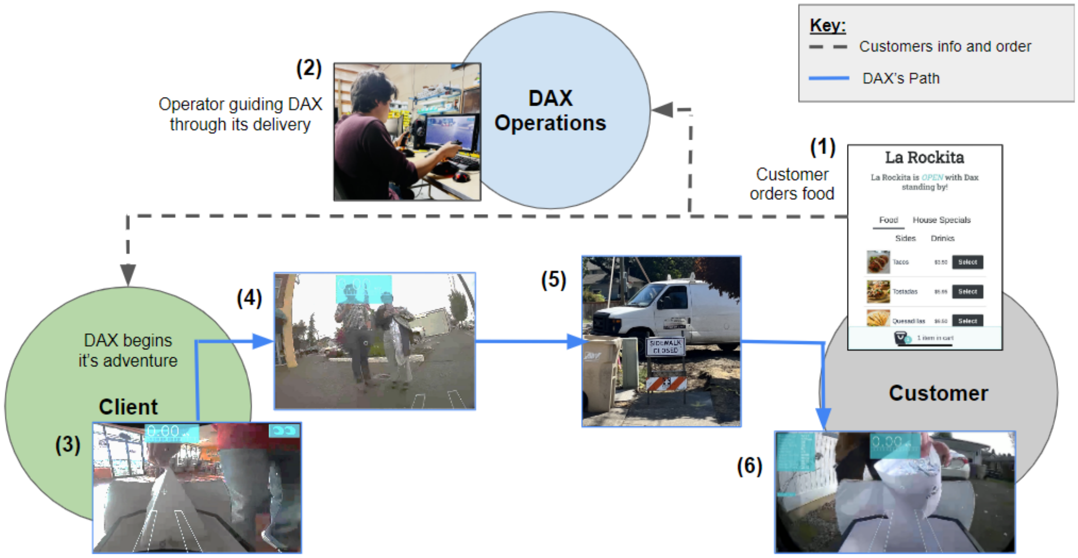

Fig. 3: ORDERING: (1) customer orders (via web), (2) driver receives order, DELIVERY: (3) client loads robot, then along path, (4) robot greets pedestrians (5) navigates roadblocks, and, finally, (6) delivers to customer.

sticks from home. Talked to employee maintaining robots. Driver3 observations and war stories. Interview of Founder. Ethnographer photographs Robot Driver Manual. STATS: Coffeeshop 1 ; Restaurant 3 ; Pizza 1. TESTING: *Remote-Remote Operation of Robots*.

IV. Research Site Operations

This subsection describes relationships between company, client restaurants, and general interaction partners (Fig. 3).

The Company: The Company headquarters is where the robot drivers sit at their command station with two joysticks, a monitor for seeing robot information, and a monitor for viewing general robot operations (Fig. 2). The open plan houses the full operations team including management and maintenance, so they often chat or comment to each other across the space. Located just on the outskirts of town, operators are able to physically retrieve the inoperable robots whether it be due to significant roadblocks, tipped robots, or other accidents.

The Clients: Daxbot defines their clients as the local businesses that both house and utilize the DAX robots. Once an order is received, the clients begin preparing the order before handing it off to the robot in charge of the delivery (Fig. 3). Operators often build direct relationships with the clients through the robots, sometimes interacting with the business's customers and staff while the DAX robot waits for it's cargo. One of the clients in particular formed an interesting relationship with the robots based on dance battles, prank wars, and games of 20 questions.

Customers: The customers are the residents of the town that order food for delivery. Once they submit an order off Daxbot's website they will receive a thread of texts with updates on DAX's progress, a map that shows their DAX's location in real time, and instructions on how to get their food when DAX arrives. The customers that order from DAX tend to fall into three categories: the customer ordered through DAX for the delivery only and do not interact with DAX outside of taking their food, the customer ordered for the main purpose of interacting with DAX upon arrival (Fig. 11), or the customer is a regular. The regular customers tend to enjoy interacting with the robots in a limited scope such as greetings and goodbyes, however they tend to treat the delivery as less of a special event and more of a normal interaction between a living delivery agent and a customer.

Getting Around: The navigation zone of the the robots prioritizes sidewalks and crosswalks, where possible, putting routes through secondary streets to minimize chances of collision. The town of Philomath is an older town with older sidewalks consisting of cracks, potholes, and lampposts directly in the center of the sidewalk (Fig. 14). While town begins to update its infrastructure it has become more common for DAX to encounter sidewalk closures due to construction and change its route (Fig. 3). The operators are also encouraged to stop and interact with other pedestrians that show interest in the robot (Fig. 15).

V. The DAX Robots

Physical Description and Capabilities: The company has twenty-six operational DAX robots, of which they cycle seven throughout the town of Philomath. Each robot weighs around 110 lbs and can move up to speeds of 1.85 m/s. They are powered by transposable batteries that allow each robot to drive around 8.4 kilometers on a single charge. Each DAX is able to fit about 2 gallons of food in its drawer.

The DAX robots have a semi-anthropomorphic design that consists of a head, neck, torso, and two tracks (Fig. 4). The head of DAX houses two cameras in the front of the head, two microphones on the side of the head, an LED array panel that displays different eye expressions, a temperature sensor, a GPS board, and an LTE modem. The neck of

DAX consists of four servos that allow for rotation around the roll, pitch, and yaw axes of the neck (Fig. 7). The neck also houses a speaker that acts as the robot's larynx, outputting expressive non-verbal soundtracks. The robot's torso consists of a drawer that extends out to accept or present the customer's food (Fig. 6), as well as a heater (or cooler) that can be used to keep items at temperature. The DAX robot is non-holonomic, utilizing two parallel triangle rubber tracks to move forward, backward, or to turn. The tracks also contain amber LED lights that act as hazards for the robot in dangerous situations.

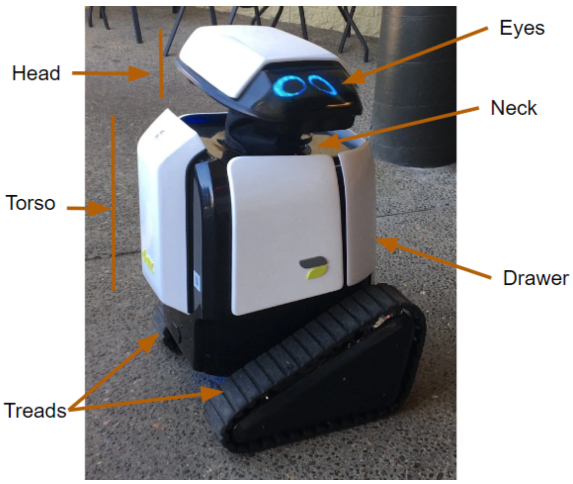

Fig. 4: This is the DAX robot.

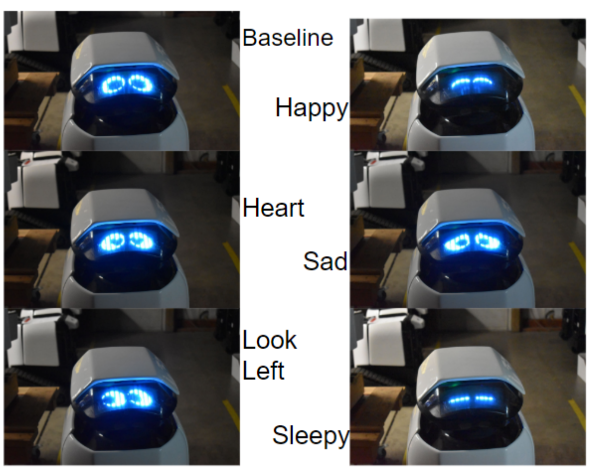

Fig. 5: Sample Eye Expressions.

Expressive Modalities: The DAX robots incorporate five different expressive modalities that can work in conjunction with one another or independently in order to non-verbally communicate different states, needs, or intentions. The most versatile of these modalities is the use of different eye expressions to indicate the robot's intention or state . There are 8 different eye expressions that operators are able to utilize when driving DAX: happy, sad, grumpy, look left, look right, asleep, heart eyes, and the default neutral eyes (Fig. 5).

Fig. 6: A DAX robot opening its drawer.

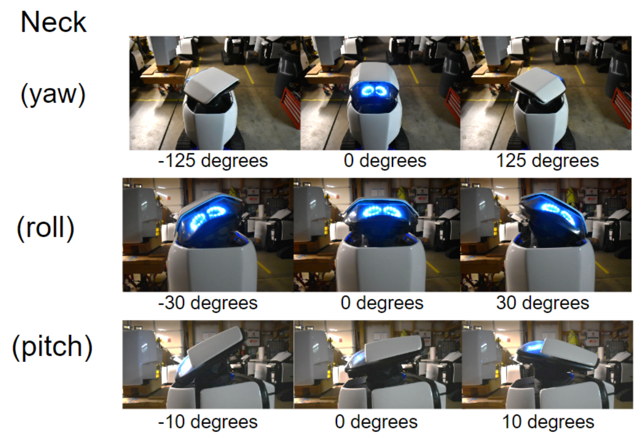

Fig. 7: Neck DOFs.

Operators have found creative ways to use a string of these expressions to convey more complex messages such as looking rapidly left and right before switching to happy eyes to make it clear to an individual that the robot is communicating with them. More often though, the eyes are used in conjunction with other modalities such as sounds and head motions. The DAX robots use five non-verbal soundtracks that communicate "yes," "no," "uh-oh," as well as sounds that indicate confusion and exuberance. The DAX robots have two programmed head animations: a head shake and a nod; however, operators often use other head motions such as tilting the head to the side or looking both ways before crossing the street.

Operator Control: The DAX robots achieve the highest level of social functionality when controlled by an operator. Operators are able to perceive the environment surrounding the robot through the use of a POV interface and act on the environment using two thrust joysticks. The POV interface provides the operator with the specific DAX robot the operator is interfacing with, the expression that the robot currently has, a live visual and audio feed of the robot's environment, and other relative sensor readings such as drawer temperature and speed. The operator can control the robot using two thrust joysticks: one utilized for moving the robot and one utilized for moving the head (Fig. 8). In addition to numerous buttons for different functions such as opening and closing the drawer, the joysticks each feature a hat switch at top of the joysticks that control the eye expressions (left) and the sound output (right) (Fig. 9).

VI. Elicited Themes and Insights

Our ethnographic insights are organized into seven thematic categories that emerged from the open and axial coding [36]: (1) Keeping Robots Functional, (2) Early Autonomy Features, (3) Experience of Research Site, (4) Robot Driver Stories, (5) Community Integration, (6) So You Think You Can Robot Company, and, (7) Robot Driver Meta-Skills. As introduced in Sec 2, the goal of this grounded theory approach was to discover and construct theory via comparative analysis of our systematically collected data.

A. Keeping Robots Functional

Sometimes robots fall over or fault. Thus, the company has a van available to switch out robots, or go perform minor fixes. Drivers say, "People help pick it up when it has fallen. Saying things like, 'we're regulars.' We've even had people stop their cars and get out to help the robot." So now, they often wait a few minutes before sending the van.

In terms of hardware, we learned that the Operations team had particular observations of the joysticks, hardware failure likelihoods, and drawer hardware maintenance – which sometimes required client-side participation. Drivers mentally categorized the Left Joystick as related to Expression, e.g., hazard lights, head, eye, interaction/automation toggle, whereas, they related the Right Joystick to functional motion, e.g., navigation, drawer.

The founder dubbed their robot decision-making software *sudo-organic*: "You can think of it as a public body or board of directors, where all the decision makers have a say. For example, we can put weight on 'safety' + 'looking at butterflies.' An early example is at the crosswalk, where the way it is looking around can decrease driver anxiety." Weighted sums are no stranger to computer algorithms, so this metaphor would be highly reusable.

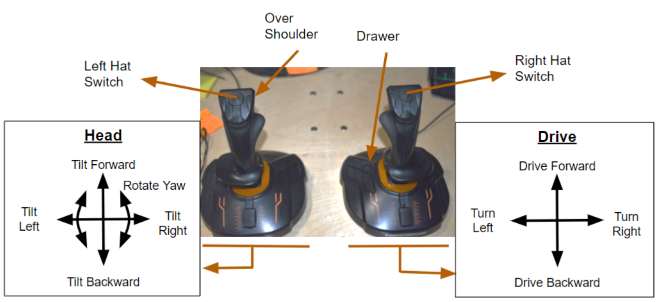

Fig. 8: The two thrust Joysticks used to control DAX.

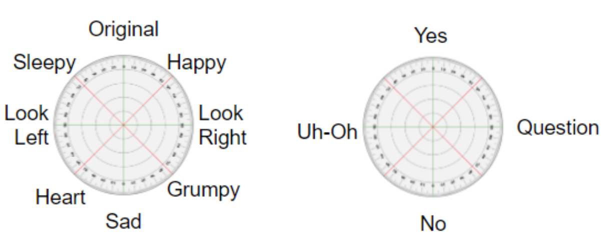

Fig. 9: Breakout Diagram for Joystick Hat Switches.

Fig. 10: Robots at Client Site Awaiting Orders.

B. Early Autonomy Features

During the observation period, they had just begun integrating autonomy features. For example, "There is some built in HRI [when driver isn't available for expressive animations], e.g., at the start of a crosswalk, it will move and look around based on sound. You have to give some kind of cue." They further explained, "Movement is very helpful when things get hectic. Won't be as meaningful [as a human driver], still gives people something."

The autonomous navigation interface was both simple and functional, allowing a map-building operator to record paths directly from an operator example, as segments of lines between nodes. During operations, these recorded lines were visually overlaid on the live operator view, thus could be used as guides during human-in-the-loop operations, or be triggerable as outlined by the line time specified in the original recording. Our favorite feature, however, was the ability to rerecord any segment of the map, should new features appear (more examples in next subsection). We present ASCII version of two similar looking autonomy mode interface overlays:

- ⋙ Sidewalks (full autonomy fine) *full speed ahead
- ||| Crosswalk or Driveway (fire&forget) *give it an okay

C. Experience of Research Site

The first tongue-in-cheek finding from the robot drivers related to their home deployment location: "One of the reasons we use [home town] is the infrastructure is so bad. Haven't been to another place that is as bad as this. It's good training." They clarified that because the city had a somewhat lenient sidewalk maintenance, it allowed them to encounter the obstacles that might occur in any deployment location at a higher training rate.

Next, they described their clients, all local stores within a mile or so of each other. The vendors included 5 clients at the observation time: coffee, restaurant, sandwiches, pizza, and a small neighborhood grocer/bodega. They said it was the small grocer that was most difficult support, as managing the changing inventory across clients/customers/interface was effortful. In terms of lessons learned they said, "if their[a client's] system is too complicated to order, or making adjustments is too complicated, we can't work with you."

They described their vendor order communication interaction goals as the "least common denominator problem: we need to be able to work with the 15-year-old barista, so we wrote the API as simple as possible." In terms of information flow, there are software notifications, but the company also provides each vendor site with a networked printer. "If you go to these places, they get phone orders but hate being on the phone. So we send them printed orders."

D. Robot Driver Stories

First-person reports illustrating interaction breadth.

CASE STUDY: HIDE & SEEK: We did a deployment at the Fairgrounds for an event and there were lots of kids. My boss said, "go play with them." One asks me, "You don't know how to play hide & seek do you?" I put the head down and had an animation of closed eyes. Then I had it look up and act oblivious (though I could see them in the robot's camera). I went the opposite way and did a little whistle.

CASE STUDY: TAG: "You don't play tag do you?" a kid asks, adding, "How fast can you go?" I was laughing and zooming around, trying to catch up but they can do sharp terms. Later, one got possessive when others were trying to play with it: "This is actually our robot." Amazing how easy and fast it is for DAX to get on someone's good side. I'm smiling the whole time. 21 years old and having a great time.

CASE STUDY: MAKING A NEW MAP: 1st step, GPS station: drop it, 2nd step: do route, very time consuming, 3rd: you have to check the route also. To do the 2nd, I have to do interactions along the way to kinda imply that I won't stop. [otherwise the recording map line would have extra wiggles]. For example, I had to delete a line to go around a car that would park in the same spot everyday, so we just remapped that line.

CASE STUDY: HIT BY A CAR: It was a hit and run. Said he thought it was a trash can, and got out of his car and kicked the robot to move it out of the steet… going 70 in 30mph zone... I had anxiety driving for the next couple weeks. Especially at the crossing. A head-on collision is a traumatic experience. I had nightmares... If it goes above a certain amount of damages to the robot it is a felony.

CASE STUDY: FROGS: : Two kids put a frog on my head today. I rocked the robot's head gently back and forth, as if in confusion. They tried to get me to put it in the drawer. Every time we come here, they come out. I used the left

Fig. 11: Two Children Interact with A Robot

Fig. 12: Sidewalk Construction en Route

Fig. 13: DAX looking both ways before crossing the entrance to a parking lot, behavior could be driver or autonomy.

joystick to shake the robot's head in response. [aside to me] We carry food there, that wouldn't be sanitary. (*Otherwise, I think he would have said yes*)

E. Community Integration

Driver relationships with the clients: "Me and [owner] at [site2] are really close, he and his sister own it. Used to go over there every morning at 10am. You start to build a relationship with the clients. Their daughter is often there, she'll often want to play for like 10 minutes, before I'm like, 'I gotta get off the robot.' " During one of my driver observations, for example, said owner opened the door to welcome the robot into their restaurant, just to be courteous, gesturing with his arm to hurry the robot in.

Driver relationships with regulars: "I never assumed I'd make relationships with the robot. There are regulars that I treat differently. I can be more playful with people I know."

F. So You Think You Can Robot Company

The background of the research site was previously telecommunications, which seems to have placed them in a good position to set up reliable robot networking systems. The technological setup of the company is to first register a GPS Base Station (rendering as a robot icon on their local map representation). When asked about communications challenges, they say,"GPS Station is working real well. It's basically point (0,0). 20 mile radius."

Fig. 14: DAX attempting to navigate around an awkwardly placed lamp post. Please note the vertical falloff on the left.

While their parent company is as a local internet services provider, the management's prior projects also included software for fire emergency services. In that work, they had designed technology and interfaces to supply where the location of a signal (cellphone, generally) was coming from so emergency services could respond promptly to alerts, saying, "gets tricky, you know, the curvature of the earth." This experience has probably aided the reliability of their current system, and gave them experience working with clients, who would then offer services to customers.

Clearly the applications were also distinct, however. The CEO said he appreciated that robot delivery was lower adrenaline, saying, "Emergency services was stressful because there are lives on the line. Here: 20 minutes of downtime because you can't get a burrito? It's a little different."

G. Robot Driver Meta-Skills

Meta skills are the base of a person's knowledge, abilities, and experience upon which all soft and hard life skills get built. The quotes and examples below illustrate reusable robot driving skills. Most important of all: interface fluency.

Orienting to Navigation: "This is the busiest road." Much like a new taxi driver might seek to learn the ins and out of a city, robot drivers highlight to me (and each other) helpful navigation tidbits, sharing or asking for help from those in the area before:"They have a steep driveway but if you hit it on the right hand side it's the best."

Robot Animation Skills: "Can always tell when it's [special driver] driving because it's so fluent."

Social Interaction Assessment: "Have to pick and choose who to spend your time interacting with... one of the hardest things in the world is having knowledge of one's surroundings and knowing when to interact. A lot is having to assess the situation. A lot!"

Fig. 15: Pedestrian Takes Selfie with Posing Robot.

Kids vs. Adults: "There's so much more that I do when I interact with a kid than with an adult. With an adult, I might turn the head and do a little nod, if they say "Did he just nod?" I am successful. But with a kid, I'll use 360 degrees, do all the sounds. There are so many different ways to interact based on the situation you are in."

Control Software & Automation: "With autonomy, one person can manage 3-4 robots at once. Everyone's capable but it's about the efficiency." Even without multi-tasking, drivers find themselves immersed in the screen-based experience, saying, "When we have to pick up the robot, the world looks so different."

VII. Discussion

When asked about future opportunities for research in interaction, the research site company suggests dogs, humans, and cars, saying, "dogs mind the robot a lot or not at all." A related area seems to be cellphone-robot interaction, as many of the locals documented the occasion (Fig. 15).

And of course there is much to learn about the continuing roles of robot drivers in HRI. What's your favorite thing about working here? 1: "Cool to portray a personality. Be a friendly DAX. Just to make people step out of reality." 2: "A lot is the wow factor." 3: "Flexibility. I don't like driving[navigation] but it's fun interacting with people." 4: "Not very often that people are mean to me as a robot." In annexing Robot Drivers as a future HRI research topic, perhaps these diverse social grids impacting robot delivery will inspire technology innovations, expanded applications, and expressive possibilities that consider longstanding impacts – on society and our everyday lives. Certainly, the robots are here to stay.

Limitations of this work could be that this paper captures an epoch of time that is transitory, in which humans seek to retain the full flexibility of everyday public interactions. It might be that society instead adjusts infrastructure to robot navigation and asks humans to adjust to robot limitations. The former is expensive, but sometimes tractable with government buy-in – as highways were once laid so robot-readable crosswalk paints might be in the future selected or similar. The latter premise is already present to some degree in other robot delivery companies in their low expressivity. Or perhaps it will be a bit of everything, and the humans-behind-the-robots will be here to stay too. Time will tell.

VIII. Conclusion

This paper involved a four week observation of a robot delivery company that prioritizes 'friendly' interactions in the community, business relationships, and the robot operations team themselves. Such analysis reveals what robots are capable of with full human flexibility.

Robot form, community integration, expression and bonding played a strong role in the DaxBot human-robot ecosystem. Neck, eyes, and sound effects aided aided street crossing, bonding, and indication. The human-in-the-loop aspect helped the remote robots succeed despite the unexpected, e.g., awkwardly placed street lamps and dangerous vertical drops (Fig. 14). Like prior collaborative robotics in industry [14], [37], [38], human-robot systems benefit each other.

Finally, it was pervasive for DAX drivers to cite the benefit of experience with video game interfaces in supporting effective mediation of robot sociability and expression. For example, their star robot driver is also an avid Mindcraft player. Use of system features vary with driver, and many potentials remain for continued investigation, but it is clear that human-in-the-loop sociability is valuable and effective.

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