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Encountering Autonomous Robots on Public Streets

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ABSTRACT

Robots deployed in public settings enter spaces that humans live and work in. Studies of HRI in public tend to prioritise direct and deliberate interactions. Yet this misses the most common form of response to robots, which ranges from subtle fleeting interactions to virtually ignoring them. Taking an ethnomethodological approach building on video recordings, we show how robots become embedded in urban spaces both from a perspective of the social assembly of the physical environment (the streetscape) and the socially organised nature of everyday street life. We show how such robots are effectively 'granted passage' through these spaces as a result of the practical work of the streets' human inhabitants. We detail the contingent nature of the streetscape, drawing attention to its various members and the accommodation work they are doing. We demonstrate the importance of studying robots during their whole deployment, and approaches that focus on members' interactional work.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in collaborative and social computing**; **Human computer interaction (HCI)**.

KEYWORDS

public space, urban environments, delivery robots, ethnomethodology, conversation analysis, video analysis, bystander

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1 INTRODUCTION

Robots deployed in public settings—such as autonomous delivery robots—operate in spaces that people live and work in. This apparently banal observation has significant implications for robot design and how HRI itself both conceptualises and studies human-robot interactions. As delivery robots get deployed in more and more public spaces—residential streets, university campuses, and shopping areas [15, 46, 90]—it becomes ever more pressing that we understand in detail what happens at street level.

HRI has explored how to design robots for public settings [28, 98], developing algorithms for navigating urban spaces [41], and modes for communicating with other people on the road [45, 53, 61, 99]. This work has also mapped how people react to robots in public, documenting positive responses [15, 49] as well as robot abuse [3, 12]. At the same time, research in HRI has underlined the importance of systematically studying interactions with people who are not primary users—"incidentally co-present persons" [69]—and of designing for "implicit" interactions with these people [34, 53].

What this work has not yet done, however, is present how 'autonomous' technologies become enmeshed within the social organisation of everyday street life. To this end we present a video-ethnographic study [25] of delivery robots and the mundane, everyday encounters with people and objects on the street that ensue. Drawing on video recordings from two field sites in the United Kingdom (as well as observations in Tallinn, Estonia), we demonstrate how delivery robots encounter the socio-materiality of the streetscape, and members of street who work there, or who are passing through. Our study aligns with a strand of interaction-oriented research on how novel technologies meet the streets and roads of cities and towns. This includes e-scooters [85], 'self-driving' cars [11], robotaxis [10], and autonomous buses [50].

The contribution of this paper is threefold: 1) we offer a video-based empirical study of a working robot deployment, focusing on the whole process of a delivery; 2) we provide a nuanced view of the role of people—i.e., 'members of the street'—that a robot encounters during a delivery ride; and 3) we demonstrate how real world studies can deepen our understanding and theorising of HRI, sensitising us to the subtle but nevertheless essential interactions that take place in these spaces.

2 RELATED WORK

Three key areas of research inform our study. We review work on human-robot encounters in public and extant (albeit limited) studies of delivery robots specifically. Then we point to the extensive body of work in human-computer interaction (HCI) on public interactions with technology. Finally, we underpin our methodological approach by examining sociological studies of urban streets.

2.1 Human-Robot Encounters in Public

HRI researchers have repeatedly called for studies in the 'real world' [36, 72]. In public settings robots meet primary *users*, who may often be customers [46, 83, 84]. In addition, they may encounter *passers-by* [15, 90, 91], *bystanders* [3, 13, 30] (people who are "co-existing in the same environment as the robot" [75, p. 9]), or *incidentally*

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copresent persons (InCoPs) [1, 51] (people who simply "happen to be there" [69, p. 656]).

Studies on HRI in public describe two types of behaviours of such users: supportive actions towards robots [15, 91], or conflicts with and abuse of robots [3, 12, 56]. Both categories entail people in focused interaction, closely scrutinising or paying attention to the robot, while some studies also examine how passers-by transition into primary users [24]. In turn, design for co-present interaction with robots in public typically focuses external human-machine interfaces that involve sound, light and movement [45, 53].

Delivery robots specifically have received increased attention in recent work, with studies mapping how potential customers [46] and 'InCoPs' [1] perceive the robots. These describe examples of how non-primary users help the robot by moving obstacles out of the way, pushing robots along, but also how they may block robots' paths [15, 90]. Responding to this, design-oriented work explores how delivery robots might communicate 'intent' [99]. However, other studies touch on more subtle interactions, noticing fewer conflicts than anticipated [89] and that pedestrians and cyclists often alter their trajectories to avoid collisions [21]. It is this vein of HRI research that we will explore and contribute to with this study.

2.2 HCI and Public Interaction

Although studies in public are relatively new for HRI, we note a significant tradition of research on interactive systems in public within HCI. This spans deployments and studies of technology use for a wide variety of situations and settings, from large interactive displays in urban environments [55, 57], video chat [64] and use of interactive wearables [54] in public, mixed reality performances [17] and live video streaming from city streets [68], location-based gaming [58], to social autonomous driving [11].

Informed by such studies, HCI has also developed conceptual apparatuses for thinking about design for interactions in public, from performance-led research approaches [7], to design consideration of bystanders and spectators on public interactions [66, 67, 96] and the fluidity of divisions between spectator and participant [87], designing for the social framing of public interactions [6], as well as frameworks for designing implicit and explicit forms of interaction [35] that grew out of video interaction analysis, HCI, and ubiquitous computing. We point to this research in HCI as it offers HRI an existing conceptual landscape and language for describing public interactions with technology (e.g., bystanders, spectators, 'witting' vs 'unwitting' and 'implicit' interactions, etc.). While the concept of implicit interaction is already applied by some HRI researchers [2, 40, 82], HRI's interest in public robots could have much more to synthesise with HCI's long-standing interests in public interactions.

2.3 Studies of the Street

Finally, we highlight studies of the street as a site of socially organised human action. Interaction-oriented descriptions of behaviour in public often stem from Goffman's work, identifying phenomena like "civil inattention" in maintaining social order in public [22]. Relatedly, ethnomethodological and conversation analytic (EMCA) studies have substantially addressed public settings and their jointly achieved social organisation, the stability of which is easily breached [47]. For instance, De Stefani and Mondada [79] detail different embodied methods that approaching acquaintances and strangers on the street entails. Such work demonstrates the type of fine coordination that is happening on urban streets and roads—the same places in which delivery robots are to be deployed. Members of the street do not only rely on explicit means such as indicators [9] and horns [38] to show where they are going, but they also mutually adjust their movement e.g., when overtaking [14]. Similar methods then are leveraged by people in encounters with autonomous vehicles e.g., shuttle buses [50, 59].

Visual aspects are central to this street order. Sacks [73] describes how police officers' visual assessments of a street scene's appearances can arrange a scene into one of criminality. Relatedly, Hester and Francis [27] discuss the ways the visual availability of categorical order on the street (e.g., turning car, slow pedestrian, etc.) forms and supports organised social action such as in passing others on the street. Forms of mobility also transform the phenomenal experience of urban environments, hence runners apprehend a 'different' street of both possibilities and dangers as they traverse urban scenes [78], while e-scooter riders present challenges to established categories of mobility (car, bicycle, pedestrian) [85].

In sum, our study aims to furnish HRI with a greater empirical grasp of the often subtle and foundationally mundane aspects of interaction with and around delivery robots in public. While it is tempting to focus on the 'highlights' and 'lowlights' such as people helping or hindering robots in public, most of the time far less obvious interactions are actually happening. Understanding this will be crucial for encouraging a close critical reading of existing systems as well as encouraging more expansive forms of design, particularly in urban spaces where theories and methods developed for lab studies may not apply.

3 STUDYING DELIVERY ROBOTS IN PUBLIC

The delivery robots we followed in our field study are run by Starship Technologies, which has deployed services across the United States, UK and Estonia. Similar services and robots are deployed by other companies such as Amazon Scout or Postmates Serve.

3.1 Starship Delivery Robots

Starship's delivery robot (see Fig. 1) is a six-wheeled, knee-height rectanguloid vehicle of ~35kg, equipped with various sensors (ultrasonic, cameras, GPS, etc.) for autonomous navigation. The robot's wheel pairs can be moved separately, helping it to move over curbs. The robot has an orange blinking flag, red rear indicators and white front lights, and a lid that can be opened to reveal its cargo box. The service is accessed via mobile phone apps which provide a front-end to customers and participating vendors. The robots pick up goods from partnered vendor stores (mostly supermarkets and cafés) and deliver to a customer-selected location within a geo-fenced, mapped area (see Fig. 2, left).

3.2 Taking an EMCA Approach

Our approach to studying delivery robots in public is informed by ethnomethodology (EM), which focuses on understanding the ways in which social order is produced by the concerted activities of members of a setting [18, 19]. An EM approach would argue that on the street, people, as members of the scene, work to produce specific orderly activities—queuing [43], crossing a road [48], or stopping to greet a passing friend [79]—whilst simultaneously ensuring those activities are also *recognisable* for other members of the scene. This intertwined aspect of actions and their accounts is crucial to members (of the street) establishing intersubjectivity or mutual understanding. As demonstrated perhaps most extensively by EM's related field, conversation analysis (CA), such actions are sequentially organised, whether it is through turns-at-talk [74] or turns at using a physical space [32, 37]. EM and CA—EMCA—are preoccupied with *describing how* that order comes about, from the perspective of members at the scene who are embroiled in its (ongoing co-)production. It is into this complex socially organised milieu that novel technologies—whether cars, scooters, or delivery robots—are deployed. They must be 'made at home' amidst the minutely organised practical workings of the street's members.

We have two further points to make. Firstly, EMCA-informed research adopts a particular perspective on 'generalisability'. Actions are routinely produced on the street, and the competencies involved in their production are themselves naturally 'generalisable'. People do not constantly have to invent new methods for talking or moving their bodies; and when novel circumstances arise, they tend to reuse and adapt existing methods to fit. Secondly, research adopting an EMCA has a long history within HCI (e.g., [11, 26, 63, 65]) while approaches influenced by EM in particular have been applied previously to study robots [86]. Thus, we build upon this while bolstering an emerging strand of EMCA work in HRI [20, 60, 70].

3.3 Data Collection and Analysis

EMCA research sometimes uses ethnography (e.g., participant-observation) to develop investigators' own competencies in adequately making sense of sites of investigation. It also may use audiovisual recordings to act as an "aid to the sluggish imagination" [18, p. 38]—i.e., as a material for capturing and being able to revisit the organisation of social life (and also exhibit its features to other researchers). The video recordings capture events that cannot be easily recollected or imagined and enable repeated viewing, but they never capture the totality of the scene—they are shaped by the researchers' ethnographic skills [52, 62]. While interaction analytic observations can be made based on relatively little data and experience [33], a detailed EMCA study as presented here is time intensive and requires thorough training.

In our research we did both field observations and video recordings. Reeves and Cantarutti spent three days between August 2022 and March 2023 capturing ~12 hours of video collectively from the streets of Milton Keynes and Northampton, both in the United Kingdom. In addition, further fieldnotes and sense-checking of UK observed phenomena were made by Pelikan during a week's fieldwork in Tallinn, Estonia, enabling researcher triangulation.

During fieldwork in the UK we captured simultaneous recordings from a mobile phone and a GoPro, giving us both focused and wide shots of the action. Capture involved two main strategies: 1) us as researchers creating our own orders and 'shadowing' robots from the start of their journey to the end (i.e., order receipt), sometimes followed by a return to a robot 'hub' (i.e., locations in which idle delivery robots sit); and 2) opportunistically following robots which were either en route to customer orders or returning to a hub. Our capture process also afforded two key elements: firstly, by having to follow the robots we gained insight into their particular machinic patterns of mobility (e.g., speed, ways of stopping, turning, etc.); and secondly, enabling us to capture an ongoing in situ informal 'commentary' between us as researchers, rendering some difficult-to-capture on-street occurrences more comprehensible.

For each day of fieldwork and video capture, we collected field notes. This was important to contextualise, enrich and extend audiovisual capture (not everything socially apparent on the street is easily captured). We synchronised, composited and catalogued our recordings, and annotated and partially transcribed them in ELAN [95]. Following common practice in EMCA research [25], we inductively built collections of similar clips, nuancing and refining the phenomena involving delivery robots and members of the street through joint discussion and by identifying 'illustrative' fragments. We discussed selected video clips from these collections within our group and with other researchers in data sessions [25, 81].

3.4 Ethics

Our study was approved by the University of Nottingham, School of Computer Science ethics committee (#CS-202-R58). We carried information sheets and identification should we be queried by anyone during fieldwork. Although there is no expectation of privacy in the UK when in public, we adhered to a number of principles during data collection. The locus of our capture was the robots and we avoided recording people unnecessarily. We also avoided children in particular, although sometimes they were visible at a distance or in passing. We also ceased capture when following a robot arriving at its destination and delivering to a customer.

4 THE DELIVERY OF GOODS VIA ROBOT

As a way of tutorialising our approach, and by way of beginning, here we describe the most prominent, obvious, visible, gross features of a typical robot delivery as it appears 'on the street', i.e., its publicly witnessable features. We sketch these features as three key stages once an order has been made (since ordering happens as a largely 'private' event on a customer's phone and is therefore not generally accountable to 'the street'). We present a simple data fragment describing the main contours of a delivery as collected via our video recordings (all videos are in the supplementary material).

4.1 Loading and Receiving the Order

Fulfilling the order, the vendor first locates the specific robot—in this case it was the only one present outside a café that we ordered some coffee from (see Fig. 1). They unlock the robot's lid, placing the order in the loading box, and arrange the contents appropriately—in this case liquids needed to be held upright. The vendor shuts the lid, steps away and indicates in the app that the order is ready to go. Subsequently, the robot begins turning and starts its journey to the order destination we specified. The public availability of delivery robot loading work is important here, as a visible extension of the vendor's work at the café; the vendor is 'working on' the robot as part of their shop practice.

Later, as the robot reaches its destination, customers have to be in the delivery location, i.e., that which robot mapping has determined as the point of delivery; see Fig. 2. This is always a public spot either

Figure 1: Loading the robot (Costa Coffee [00:00:00–00:00:36])

in the middle of the pavement or a public court of houses. Once the robot has identifiably stopped (coupled with an in-app indication of the destination being met (Fig. 2.1), we need to unlock via the app (with audible unlocking sound to follow), open the lid (Fig. 2.2), remove the contents (Fig. 2.3), shut the lid and indicate we have retrieved our order (Fig. 2.4). Subsequently, the lid is audibly locked again and after a short period of time the robot moves off. Once again, the public availability of this sequence of actions with the machine is clear—interaction in this way immediately marks one out—to 'any' observer who has even a passing familiarity with delivery robots as a customer receiving goods.

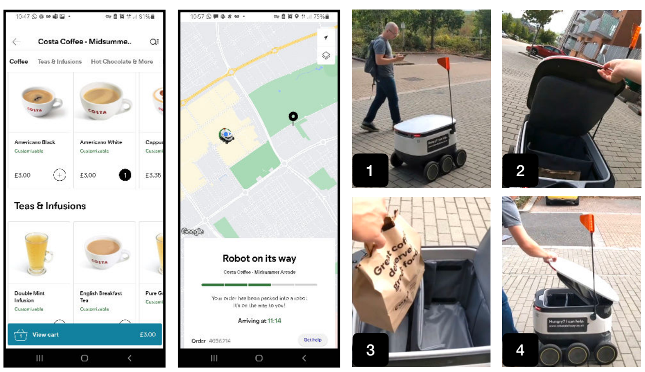

Figure 2: Left: Ordering in the customer app; right, 1-4: receiving the order (Costa Coffee [00:14:05–00:15:52])

4.2 Doing the Delivery

The delivery itself involves the robot passing through streets and over road crossings. During parts of the journey the robot will be alone in the spaces it passes through, moving fast, above walking speed. At other times, direct encounters between people on the streets and roads occur. Members of the street sometimes playfully oriented towards the robots such as waving and saying "oi" as a robot passed. Other times passers-by assisted robots such as interrupting their own journey to press a button on a pedestrian crossing a robot was attempting to cross (see Fig. 3).

We also observed moments when members of the street got involved physically with the robots, either in a more aggressive way such as grabbing the antenna as they passed by, or more playfully such as young children obstructing the path while exploring the 'strange' objects on the street (see Fig. 4).

Figure 3: A person pressing the traffic light for the robot (Barry Road [00:05:21–00:08:42])

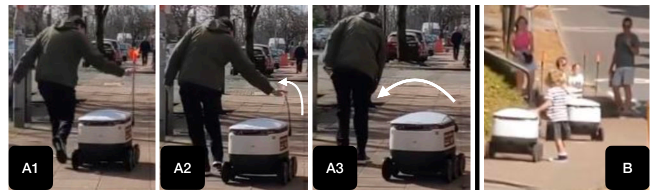

Figure 4: A: Pedestrian grabs the antenna and pulls it (Kingsley Park [00:04:11-00:04:21]). **B: Children block the robots' way as they inspect them excitedly** (Leaving Coop [00:02:45-00:06:00]).

5 AUTONOMOUS DELIVERY: AN UNREMARKABLE ACCOMPLISHMENT OF THE STREET

In the previous section we presented some of the more frequently-noted features of interactions with delivery robots. But our fieldwork and video data suggests instead that such 'obvious' explicit interactions *represent only a small portion of what is actually happening on the street.* Firstly, the 'streetscape' is itself a more complex physical environment than is often described, and critically that physical complexity is formed by its status as *a site of human social life.* Secondly, in fieldwork and reflected by our data, delivery robots themselves were *rarely* attended to; in a sense they are treated as thoroughly unremarkable or even 'invisible'. It is this complexity and unremarkability which we will now unpack. Ultimately, we reveal how autonomous delivery is not just an accomplishment of robots, their designers, and the control room managing them but really also of the street itself and its members.

5.1 Robot Encounters with the Streetscape

The streets that the robots are in a sense 'invading' are living, working places. The streetscape as an environment is of course not lab space nor an empty space—instead we find it has many categories of objects which robots encounter and must negotiate to achieve a successful delivery. By 'streetscape' we thus mean 'the street as we find it': a space of practical contingencies that simultaneously emerge from everyday human (social) activities and gain their meaning and sense from those same activities. For instance, in the UK, a series of wheelie bins present on a street (see Fig. 5.A) would suggest that their contents either are about to or have just been collected, i.e., that it is 'bin day'. On the other hand, a lone bin might offer a categorical implication that bin day has already been, and an occupant of an proximate, implicated house has not been home since collection. Such categories are readily available to 'any' competent member of that particular community. Their situation speaks out to us of the street's social world.

Many phenomena of the streetscape are already anticipated and mapped by delivery robot designers, such as road crossings, pavements (sidewalks) and lamp posts. But much of the streetscape to be navigated remains unmapped. Our data shows how components of the streetscape index—or point to—a particular pattern of different dureés and on-street 'behaviours', whether a weekly somewhat jumbled appearance and removal (bins), or perhaps instead being in place for potentially months at a time (scaffolding, see Fig. 5.B) albeit see-ably temporary whilst also physically very much immovable. These pose potential problems for robots; e.g., the scaffolding caused a 1 minute stop for the robot, while the bins caused repeated stationary periods of 30 to over 60 seconds.

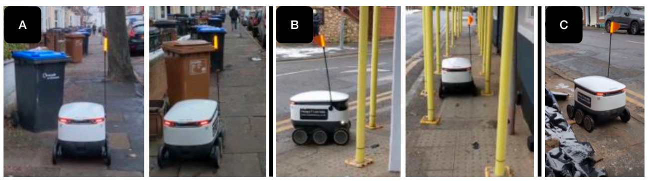

Figure 5: Robot encountering road infrastructure. A: Bin Day. B: Scaffolding. C: Temporarily deposited construction waste.

In contrast, other phenomena of the streetscape may appear at first glance to be more unpredictable; they could appear and disappear at any time for a given location. This category includes parked scooters, parked cars, or construction waste temporarily deposited on the street (Fig. 5.C). In reality, of course, there will always be local reasons at play so they are neither entirely 'unpredictable' nor 'unreasonable'. We also note a further subtlety to all streetscape phenomena which is that they frequently implicate people on the street in different ways: a parked car suggests an owner, whereas a hireable e-scooter will not (i.e. we find 'possessitives' (owned) and 'possessables' (ownable) [19, p. 182]). This has implications for how, when and whether that object will move and where it will go.

We have selected here just a few moments from our data collection that begin to highlight some of the different categorical implications that on-street objects have—in that sense they are not simply 'obstacles' but also situationally meaningful objects, traces of human presence, with different temporalities, permanence, ownership, and so on, all of which index their socially-produced role.

5.2 The Street as a Workplace

We just saw how robots encounter a wide range of streetscape phenomena as a routine matter of delivery. We also pointed out how the circumstances of the many different categories of objects on the street was itself a product of the everyday (social) life of the street. But how do streets gain their coherence and sense from the praxeological 'work' done by people who dwell there or pass through it? And how do delivery robots come to be embedded by members amidst the street's ongoing scenes?

While vendors work on the street to load delivery robots as part of their service, presenting a readily apprehensible visual account of their relation to robot delivery, for many others whose workplace is the street itself, delivery robots are merely passing through their workplace. Such workers are treated by robots in a similar way to other objects on the streetscape. However, this is only half the story. Our data shows that considerable interactional work is done by other service workers, construction workers, etc. to actually embed robots into the organisation of street space.

First we consider temporary zones of activity which can be created via work being done on buildings that line the streets. Passing through may not be possible without some kind of negotiation or rerouting (e.g., stepping off the pavement momentarily, asking to get past, or perhaps a worker anticipating the passing). For delivery robots, there is little possibility of either, but we found people on the street were sensitive to this. In one instance a window cleaner spots an approaching robot (Fig. 6.1), suspends their work and creates a space for a passing as the robot gets closer (Fig. 6.2). But the robot does not speed up (as a competent member of the street would likely do when passing by someone), but instead seems to slow down, maybe due to the narrowed pathway. The window cleaner says "come on, then" possibly to share a moment with the filming researcher. They then say "hurry up" and give the robot a little kick, as if rushing the robot to move along (Fig. 6.3).

Figure 6: A window cleaner makes space for the robot. (Edmund Street [00:48:33 - 00:49:42])

This foot tap is interesting because it offers a physical account to us as observers about *the need for accommodation work* here as well. It also suggests various unfulfilled anticipations of passing 'ability' of the robot that were made by the cleaner during its approach.

In contrast with the example in Fig. 6, portions of the street may be more permanently implicated as 'work sites'. Various businesses lining urban streets may entail a zone of interactional relevance out into the street, for instance a café that provides some seating on the street itself.

In Fig. 7 we show an example of a worker who is delivering food to a restaurant and temporarily places some cones to protect their workspace. The restaurant worker accommodates the approaching delivery robot by repositioning their trolley and delays placing a traffic cone until after the robot has passed. The worker is just placing a red cone in front of an open basement door when the robot is approaching (Fig. 7.1). A colleague seems to be passing a second cone via a hatch in the ground (see Fig. 7.2-3,6). As the robot moves closer, the worker looks at the robot and pulls back the trolley (Fig. 7.2). The robot first stops and then turns right, and the worker continues to gaze at it, adjusting his position (Fig. 7.3). As the robot starts rolling forward in a rightward direction, the worker pulls the trolley closer inwards, yielding more space on the pavement (Fig. 7.4). The robot first makes a brief leftward

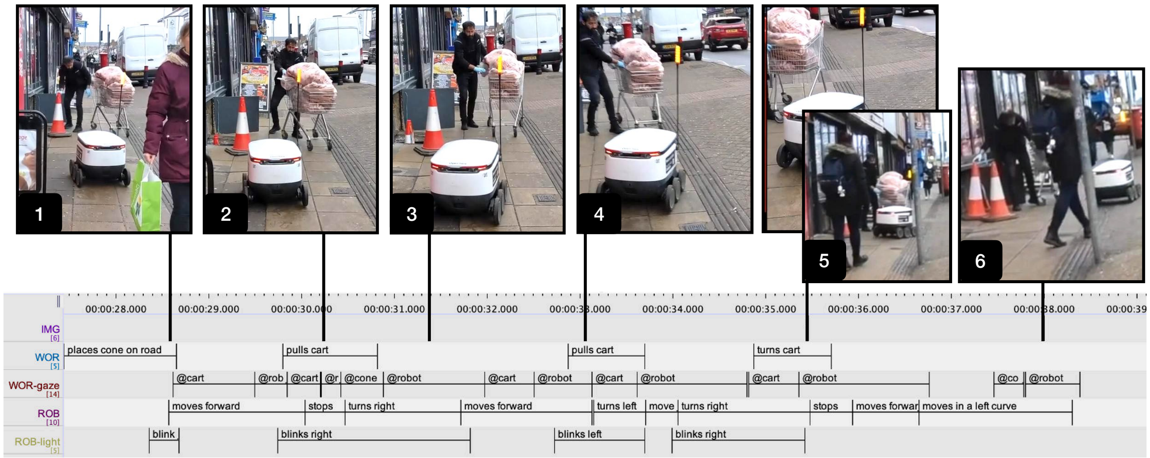

Figure 7: 1-5: A restaurant worker accommodates the robot; 5-6: A passing pedestrian rerouting to avoid the robot (Edmund Street [00:30:00-00:30:11])

movement before finally making a larger right turn. As the robot is starting to make its way towards the trolley, the worker further adjusts and pulls the front part inwards (Fig. 7.5). When the robot has moved enough to pass, the worker returns to the cones but turns their gaze back to the robot, monitoring how it moves past the trolley (Fig. 7.6). During this 10 second sequence we also note that passing pedestrians visible in Fig. 7.1,5&6 design their movement to carefully avoid the robot and its anticipated trajectories.

This single example illustrates what we found across our data: that robots are not somehow alone in performing 'work' on the road doing deliveries, but that the street is *already* home to more or less transient 'work sites'—sites that are there for 'anyone' to see but which robots blithely invade. Workers in these zones then have to manage the fixity of their own space against robot mobility in subtle ways, often 'creating space' for delivery robots to pass through successfully.

5.3 The Street as a Place of Passing-Through

In contrast with the ways streets can be formed as workplaces, many people present on the street are just passing through, like those we noted also in Fig. 7. Their mobility increases the complexity of how members of the street manage the machinic mobility of the robots.

We often saw pedestrians enacting very subtle, fleeting, but fluid changes to their embodied ways of traversing the street to somehow accommodate robot behaviour. Consider Fig. 8.A, in which a pair of pedestrians walking abreast change their trajectory as they approach the robot (A1), lining up behind one another (A2), moving to the outer edge by the pavement kerb and squeezing past a lamppost (A3) as the robot passes. In Fig. 8.B, a pedestrian—hemmed in between the robot and a lamppost—twists their body sideways and lifts their bag to maintain distance from the robot and post.

While such accommodations are rarely accompanied with fanfare or comment, we also found moments in our video data where anticipation and accommodation of delivery robot mobility became problematic for members of the street. In Fig. 9 a person almost bumps into the robot when it brakes abruptly. The pedestrian is

Figure 8: People squeezing past lamp poles to make space for the robot (A: Barry Road [00:25:10-00:25:17]), B: Edmund Street [00:29:46-00:30:20])

walking behind the robot, adjusting their speed dynamically (Fig. 9.1). When driving over floor markings the robot suddenly stops (see the back wheels in the air from sudden impact in Fig. 9.2). The pedestrian stops rapidly, holding balance with their left arm out (Fig. 9.3). As the robot starts moving again, the pedestrian walks on the left side, as if to overtake this way (Fig. 9.4). Only when the robot stops again at a crossing, the pedestrian finally moves away from it, walking away towards the right (Fig. 9.5).

We found (and experienced ourselves) many such instances during our fieldwork. This exemplifies the ways in which robot mobility can be illegible [16, 77] to members of the street, unaccountable to the situation (there was no street-readable obstruction here), and therefore difficult to anticipate. This illegibility of robot mobility demonstrates potential dangers to members of the street, with the robot itself turning into an obstacle, ironically—it turns out—as part of its own obstacle avoidance routines.

Overall we want to highlight the wide range of routine accommodations performed by members of the street who effectively have to 'grant passage' to robots. These range from the very explicit to the very subtle. We have seen how people change their formation to make space for a robot, or adjust their speed and anticipate its trajectories. Members of the street draw on various methods from existing street practices (e.g., of mobility) to deal with robot

Figure 9: A pedestrian almost tripping when the robot stops abruptly **(Edmund Street [00:32:23-00:32-36])**

behaviour as they pass by, follow behind, and so on. In doing so, pedestrians surface various design assumptions about legibility and mobility which such robot systems and infrastructures are constructed from.

6 DISCUSSION

In Section 4, we distinguished three key stages of delivery. Our observations on loading and receiving the order mirror prior work. On the surface, delivery robots offer a service that involves customers and vendors as main users [46]. Our capture included notable encounters with non-primary users that echo existing HRI studies on robots in public, whether it is helping [15, 90, 91] or abusing robots [3, 12, 56]. Perhaps understandably, media reports tend to focus on such salient interactions e.g., a robot being 'rescued' while stuck in snow [5] (see also [15]).

And yet, a more complex picture emerged in Section 5.1 when we considered how the *streetscape* presents an often unmapped and frequently changing socially meaningful landscape of objects that robots encounter when passing through. Rather than treating objects as mere 'obstacles', we argue that we need to appreciate how objects are enmeshed with the social life of the street. Focusing on 'implicit' interactions with robots [34], we then extended our analysis to focus on the largely overlooked but hugely significant way in which members of the street typically worked to enable the robot's successful passing through this streetscape. Our work highlights that the streetscape is an inhabited, lived-in space, that members of the street work in (Section 5.2) and pass through (Section 5.3) everyday. While this could be seen as the unremarkable 'negative space' between the headline grabbing encounters that HRI has tended to focus on for delivery robots, it is nevertheless critical—perhaps even *more* central than moments of assistance or robot abuse, important though they may be—for better understanding what happens when we 'go public' with autonomous robots in public spaces.

To this end, we suggest three *sensitising questions* that researchers and designers of HRI in public can take away from this work: **1. Who is the 'user'?**; **2. What are 'users' doing?**; and **3. How might we study human-robot interaction in public?**

6.1 Members of the Street as 'Users'

Customers and vendors interact with the robot through their smartphones. For the delivery service user, the robot is then mostly *absent*, manifest only within the app until arrival. In contrast, Section 5 showed how members of the street typically come across the robot *without* this mediation; instead they are left to make sense of the robot from its machinic behaviours alone. Thus in many cases designers' imagined users are likely *not* those actually spending the majority of time with robots. Focus on the 'primary' user—the customer ordering the delivery robot—and even a 'secondary' user like the vendor—packing and sending the robot on its way—would miss the myriad fleeting moments of subtle 'negotiation' our data captures and which are essential for delivery success: between robots and people working on the street, between robots and shoppers, between robots and drivers, and so on. But this leads us to ask, in these circumstances, **who is 'the user'?**

The EM notion of *membership* and correspondingly people as *members of the street* offers a possible conceptual shift for thinking about HRI in public that better accounts for the sheer dynamism of public interaction. Thinking about people not as individuals interacting but rather as *members* of complex, layered and unfolding circumstances and groups, with different competencies and normative orientations, acts as a constant reminder of the primacy of the social circumstances robots are placed in. For instance, competent members of the street will immediately see not only that a person is a window cleaner (Section 5.2) but crucially they will also see the concomitant social implications of this, walking around their work site. Similarly a pedestrian walking-alone will be competent in seeing a group walking-together and (in most cases) reliably yield space to them [71].

The implication of this view is a caution against becoming too formal about terms like *bystander* or *passerby*, which do not capture this kind of fluid dynamic of membership. The term "incidentally co-present" seems more neutral, but we would go further and argue that the activities of members of the street are only "incidental" from the perspective of the robot's designer(s). Members of the street all have their own 'projects', whether it is shopping with friends or restocking goods for a restaurant. Working with the concept of the member enriches existing approaches beyond assigning static 'roles' to people [88] or treating them as 'incidental' obstacles. We want to encourage HRI scholars to ask 'who lives and works in the spaces that robots enter?' Membership categories that humans orient to (e.g. tourist, resident, window cleaner, shop worker) could provide conceptual apparatus for HRI researchers in seeing how people in public present and analyse one another in these categorical, membership-oriented terms and adapt their behaviour accordingly. This enables HRI researchers to 'see more' when making studies of public HRI, be it video-ethnographic studies or more 'loose' observations. In line with [39], we would like to underscore that for HRI in public, it is particularly important that designers look at the actual people who are there and their actions, not only abstract user personas. The reconsideration we propose goes beyond existing approaches to further interrogate the notion of the 'user' (see [4]).

6.2 Accommodation Work

Going beyond our deconstruction of 'the user', we now ask: **what is it that people are doing on the street?** Section 5 exhibited what we think is a much more vast space of human action that could be glossed as 'accommodation work'—i.e., the mundane work people do 'for' delivery robots. This point resonates with recent discussions on human care *of* robots [23, 42, 97], and enriches prior observations of the ways robots in public "reshape municipal infrastructures" and in doing so can cause access issues [8]. Our study adds to this discussion by revealing a large class of social practices that emerge from robot deployments in public, encompassing the work that service workers do on the street, and how any pedestrian may interact with the robot.

This raises questions about who gets to 'participate' in design, which our study also feeds into. In the extreme, forgotten people and their practices of accommodation have led to protests and direct action against robots in public, such as robotaxis in San Francisco [76]. Accordingly, recent work in HRI has called for closer scrutiny of power imbalances when designing robots, suggesting adoption of participatory approaches [93, 94]. We pointed out in the previous section that those who mainly encounter a robot may not be its designer's intended 'users'. Equally, practices of accommodation work that is done by them likely passes unnoticed. More diverse representation at the earliest of design stages is vital, but this could be further enhanced with a grounding in accommodation practices —those that mainly pass unnoticed—by those members of the street who are not the designer's intended 'users'. Simple video dispatches (see our supplemental material) of these practices from the street could offer instructive, reflective materials for participatory design processes.

Finally we note that accommodation does not imply *acceptance*. Accommodation instead suggests a *reciprocity* between accommodator and accommodatee. Robot designers are in the challenging position of designing for their systems to deliver that basic reciprocity.

6.3 How Can We Study HRI in Public?

Our study of robots in public demonstrated how important it can be to focus on moment-by-moment, sequentially organised action in making sense of concrete, situated interactions [72, 92]. Studying HRI out in the world with video reveals how implicit [35], mundane interactions can yield a myriad of observations which support this view. Pushing the robot on by kicking it a bit as in Fig. 6 might appear initially as robot 'abuse'. But when looking at how it evolves on a moment-by-moment basis we can see how the window cleaner is first pausing their own activity, then stepping to the side before ultimately giving the slow-moving a robot a little push. This raises questions of when an interaction with a robot truly 'starts' [70]: should only explicit encounters like helping and blocking be considered, or does interaction begin already with adjusting one's trajectory? What is the unit of analysis when we study public HRI?

More studies that look at how fine-grained interactions evolve will be needed. We hope that our work can inform how such an approach could look like, highlighting how HRI can learn from other perspectives and fields including EMCA and HCI. Although translating such findings to design can be fraught [29], video extracts and transcripts could provide intermediate-level knowledge for designers [31, 44]—specific enough for practical problems, but general enough to stand in for a whole class of activities.

6.4 Limitations and Future Work

Our study was limited by not capturing the operators' perspective i.e., those monitoring fleets of robots from afar. Nor did we investigate the work of robot wranglers [80], supporting robots (e.g., charging them, repairing them, etc.). It is critical in future that this is investigated to unpack how autonomous delivery robots achieve their apparent 'autonomy' as a concerted effort of both extensive behind-the-scenes work, and those of people on the street. We have also not had space to discuss how the researcher themselves are part of street phenomena. We selected video where such matters were less relevant to the situation, but this is still an ever present concern. Finally, we only examined a limited subset of street environments delivery robots are deployed in. Different cities or towns elsewhere in the UK, or further afield will present specific sets of localised practices for further investigation.

7 CONCLUSION

Our video-ethnographic field study of delivery robots in the UK (supported by observations in Estonia) has three main takeaways. Firstly, we have to pay more attention to the implicit interactions that happen in public HRI. Robots in such spaces are grounded in the social, interactional relevance of members of the street. Secondly, the social world of those "incidentally co-present" persons is not incidental. People are working on their own interactional projects which happen to intersect with others on the street. Ultimately, robots are being sent into these complex interlocking lifeworlds, where people are performing labour, hurrying to work or simply present for leisure. Thirdly, we think there is great value in capturing and examining mundane, everyday circumstances of robot deployments in the 'real world'. Accordingly, although ethnographic, video-based studies are still less common in HRI, we encourage their adoption as one way to methodologically approach such phenomena.

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