Transforming Last-Mile Logistics: Opportunities for more Sustainable Deliveries

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ABSTRACT
Road congestion, air pollution and sustainability are increasingly important in major cities. We look to understand how last-mile deliveries in the parcel sector are impacting our roads. Using formative field work and quantitative analysis of consignment manifests and location data, we identify how the effectiveness of life-style couriers is contributing to both environmental and non-environmental externalities. This paper presents an analysis of delivery performances and practices in last-mile logistics in central London, quantifying the impacts differing levels of experience have on overall round efficiency. We identify eleven key opportunities for technological support for last-mile parcel deliveries that could contribute to both driver effectiveness and sustainability. We finish by examining how HCI can lead to improved environmental and social justice by re-considering and realizing future collaborative visions in last-mile logistics.

Author Keywords
last-mile logistics; sustainability; life-style couriers; mixed-methods; logistics infrastructure; e-commerce; parcel sector; on-demand economy; gig-economy; smart city; environmental and social justice

ACM Classification Keywords
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INTRODUCTION
Online shopping and e-commerce have grown rapidly in the UK: they accounted for 14.2% (£50 billion per year) of all retail spending in July 2016, seeing an increase of 17.3% spent weekly between July 2015 – July 2016 [61]. Sales are projected to continue increasing, with one forecast predicting a 10-12% sales growth per annum in the UK to 2021 [58]. The most commonly used vehicle for deliveries of online shopping is the van (i.e. a goods vehicle of up to and including 3.5 tonnes gross weight) [3]. The increase in e-commerce and related deliveries in cities [65] is contributing to the increase in van traffic. In the UK, the number of vans on the road increased by 82% between 1993 and 2015 (compared with only 11% and 18% increases in heavy goods vehicle and car traffic respectively). Vans comprised 15% total vehicle kilometers travelled on UK roads in 2015, compared with 10% in 1993 [24]. As well as contributing to traffic levels and congestion, especially in urban areas, vans are estimated to have resulted in 13.3 million tonnes of carbon dioxide (CO_2) equivalent emissions in 2014 [90]. In terms of air pollution, van traffic is estimated to have been responsible for 56,000 tonnes of carbon monoxide emissions, 63,000 tonnes of nitrogen oxides, and 2,200 tonnes of particulates (PM10) in 2014 [24]. These levels of road-borne local air pollution are leading to efforts to reduce the emission levels of vans, through electrification and other means.

The "last-mile" refers to the final stages of delivery in logistics networks. We refer to last-mile parcel deliveries as the final journey a parcel makes between the local parcel depot and the customer who has purchased goods. The cost of the last-mile is increasing: rising business overheads, increased fuel costs and pressure on real estate in urban centres, pushes depot locations farther from delivery locations, all contribute to making this a very competitive sector that is suffering from marginal profits (typically around 1-2%) [2, 19]. Growth in the expectation of low price (or free to the consumer) deliveries and collections [26, 55, 59] and the real cost of home deliveries to retailers [83] has put further pressure on the sector and increased the reliance on cheaper sources of labour such as life-style couriers. These workers are self-employed in UK law meaning they have varied and often no guaranteed work, a fixed-term or zero-hour contract, or are working flexible hours dependant on industry demand (cf. 'gig-economy' and on-demand workers). Their rights and employment categorization remain a contested social, political, and legislative issue [60, 89].

We identify parcel logistics as an important area where HCI's strong history of usability, UX and designing technology can help achieve more efficiency and promote sustainability in the last-mile parcel sector. HCI could help drivers plan their rounds and helping a changing workforce get up to speed. The last-mile context is rapidly changing due to growing demands and taxation aiming to lower carbon emissions and reduce pollution (cf. London's Ultra Low-Emissions Zone [85, 56]) opening up space for digitally mediated innovation. HCI could thus promote not just efficiency, but contribute towards national and international sustainability goals (e.g. UN's Sustainable Development Goals [84]) by helping cities plan better for growth [36]. HCI can study this domain empirically, offering new guidelines that help last-mile logistics and design of better civic infrastructure.

Drawing on a detailed mixed-methods inquiry we establish the impact of varying knowledge in the practices of delivery drivers and how this contributes to variation in driver effectiveness in last-mile logistics. Our discussion begins the journey of re-imagining the last-mile, the demand for curbside stopping locations, how parking and walking strategies relate to driver effectiveness and how to reconsider fair and just work in the last-mile. Based on our discussion we present eleven opportunities for HCI to help redesign the last-mile parcel sector so that it is better suited to novice and life-style couriers and promotes more sustainable delivery strategies. We finish by presenting four larger socio-technical challenges to demonstrate how HCI is central in shifting norms surrounding environmental and social justice, round optimization, consolidation and collaboration, and the 'cornucopian paradigm' in last-mile logistics.

BACKGROUND

HCI has a long history of studying workers in various contexts and situations and the role of technology in a variety of workplaces and work forces. We add to this body of research by introducing life-style couriers and last-mile parcel deliveries, situated in a rich body of work focusing on casual, on-demand and gig-economy work including: crowd sourcing and crowd-work [51, 79], sharing and local economies [81, 46], gig-economy [63], and knowledge workers (e.g. mechanical turk [57]). While it is not our aim to directly tackle workers' rights or challenges for labour in last-mile logistics, there are important lessons that could help novice and life-style couriers in the last-mile parcel sector [4, 12].

Couriers and drivers in the last-mile use technology to support their work as they navigate cities to deliver parcels. How drivers use their vans on their deliveries links to pollution, environmental externalities, as well as road use and congestion. Parcel delivery workers can be subdivided into those who are employed by the parcel delivery company and those who are not. In UK law those who are not employees are either contractors to the company or self-employed. The term *'life-style couriers'* is used to describe those workers who are either contractors or self-employed [29, 80, 40]. While there are similarities between gig-economy or on-demand workers and life-style couriers in terms of performance-based pay and workers' rights [29, 80, 40] the main distinction is that we focus on the last-mile parcel delivery sector. In addition, parcel delivery companies can be subdivided into those that offer same-day delivery services and those that offer next-day deliveries or longer. Same-day delivery companies have never employed drivers, whereas next-day delivery companies vary in the recruitment models they adopt, with some companies using employees, and others not [7]. All next-day delivery companies hire in additional drivers on a casual basis to cope with seasonal peak periods, and some of these companies chose to subcontract portions of their delivery work to other companies.

Related transport and logistics research in HCI has focused on mobility and access to transport [78], lessons from ridesharing in Namibia [49], and the impact of ridesharing on low-resource populations [25]. The research closest to last-mile logistics concerning gig-economy, on-demand labour, life-style couriers *and* social justice focuses primarily on city transport platforms such as Uber [17, 35] and the effect of measuring the performance of bus drivers in London [67, 69]. Workers in the last-mile parcel sector and life-style couriers are facing similar battles with guaranteed work, workers rights and legislation [59] to those taking action in crowd work [74] and using on-demand labour to help senior citizens find local jobs [6]. Jack and Jackson [47] demonstrate the messiness of global logistics and highlight the overlap with local infrastructure in their ethnographic work. Logistics has also been discussed in the context of local rural economies and how logistics mediated by digital technology can be used in the support of these [20, 21].

Sustainable HCI (SHCI) is a field within HCI that looks to develop more sustainable technologies and trajectories through the application of HCI. Related SHCI work has focused on helping commuters and travellers make more sustainable transport choices [32], interfaces and information system for promoting more sustainable transport systems [50], environmentally sustainable urban mobility [14, 33], developing a sourcemap for sustainable supply chains [13], reducing energy consumption and improving commuters' experiences [16], dilemmas around transportation choices when considering sustainability [41] and designing interventions for more sustainable transport practices [44]. Prior work has also explored the design of persuasive interfaces to encourage eco-driving [62, 54], and mapping of more fuel efficient routing between locations [34]. Location data has previously been used to improve city mobility and route sensing, to infer driver preferences from GPS traces [23], routing under uncertainty [45], sense and map better biking practices [71] and perform urban sensing based on human mobility [48]. To our knowledge this has not yet focused on last-mile logistics.

HCI is positioned well to help improve optimal use of logistics infrastructure [43], further collaboration [11], and carefully consider logistics as a smart city application [87]. Through working closely to help understand the last-mile parcel landscape [8], HCI can contribute to the development of new public policies [82, 87], helping policy makers in enabling sustainability objectives [5], and better infrastructure planning [36]. We position our work at the intersection of workers in transport and logistics, on-demand work forces and sustainability. We focus on understanding where HCI is situated to help novice and life-style couriers in the last-mile parcel sector and realize the role of the workforce in more sustainable last-mile logistics. We argue that human decision making and relationships are key to last-mile parcel sector where face-to-face encounters and snap decisions play a more considerable role in the present than route optimization of delivery rounds through more effective vehicle interfaces, vehicle sensing and predicting mobility in cities [8]. We build on these formative findings and demonstrate how HCI is critical in understanding the bearing of variation in driver practices on the efficiency of last-mile parcel deliveries.

METHODOLOGY AND DATA

Our empirical study leverages a mixed-methods approach, combining a three-day ethnographic field study [72, ch. 12] supplemented with quantitative data and analysis of 25 accompanied delivery rounds to explore the varying effectiveness of drivers in last-mile parcel deliveries. With a Scandinavian practice approach in mind [52] we aim to uncover the role(s) of digital technology in the "*accomplishment of social practices*" [73] relating to last-mile parcel deliveries, their daily routines and how technology is situated in the performance of these practices [15, 44, 64, 77].

Our analysis draws on formative work with two logistics companies (referred to as carriers throughout) who primarily work in the business-to-consumer (B2C) and business-to-business (B2B) markets. B2C items are typically consumer goods between a business and a consumer (e.g. deliveries and collections of e-commerce purchases such as clothing to an individual), while B2B provide regular deliveries and collections of items to business clients (e.g. procured business purchases, new stock or stock to be moved between stores). The study was designed to uncover the routines of 27 delivery rounds in a major European City between 25–27 October 2016. Participating drivers were selected on the day by the depot managers based on the drivers temperament and likelihood to cooperate (e.g. "*D16 doesn't bite*"). The surveyors aimed to survey a different round/driver each day, but overlap occurred at one of the two B2C depots due to five rounds/drivers being available in total. All our drivers were male, and had a mixture of age, experience and proficiency. Three surveyors starting from one of three depots each day (2 x B2C, 1 x B2B); due to circumstances beyond the control of the researchers team, one surveyor was absent one day and another had problems with the sensing equipment used to capture location data. This resulted in total of 25 rounds being captured (i.e. 3x3x3 -2). The surveyors took field notes, capturing accounts of each driver's deliveries and collections, times of arrival, odometer reading (miles driven), parking location (latitude, longitude, and address), whether they were parked on or off the street, the address of the customer, time departed from stopping location and the number of items delivered (and collected).

Primary quantitative and location data was collected to supplement analysis of driver performance. GPS location data for both vehicles and the drivers was gathered using Qstarz GPS location trackers placed both in the vehicles and on the drivers, recording location data every 3s. A pre-study trial of location logging techniques and sample rates identified considerable problems with urban canyon effects due to proximity to dense urban environments [76]. Location trackers were supplemented by the surveyors notes using smart phone based data logging (polling every 5 seconds) as well as manual recording of stopping locations (GPS, address).

Our field work and surveys capture raw data for the quantitative analysis of driver effectiveness. Statistical analysis of this data was performed in R and Microsoft Excel, with manual coding of distance and location data using Google Maps. Leveraging OpenStreetMap APIs purpose built scripts were developed in Python and Processing to analyze and visualize driver and vehicle location traces further.

While our study was not designed to capture interview data we are able to provide accounts of the driver practices and routines based on the observations and detailed notes captured by the surveyors. These feature throughout our analysis to provide further evidence of the driver's routines and practices. To maintain anonymity of the drivers they have each been assigned a pseudonym. To maintain anonymity of customers of the parcel companies, all address data presented has been aggregated to the postcode level.

Our fieldwork and findings are naturally scoped to dense urban areas, where walking and optimal stopping locations are critical and strongly linked to driver knowledge and experience.

EXPLORING THE LAST-MILE

In this section, we detail the daily routines of a delivery driver, and provide a summary of their delivery round performances.

A Performance Perspective

Given the narrow profit margins at stake and performance based pay, the logistics industry is highly sensitive to goals of performance and so-called key performance indicators. Stringent targets and service level agreements set around these glue the various actors together and underpin their delivery contracts. We start by considering what our drivers achieved, as viewed from this perspective.

The 25 rounds spent a combined total of 185.2 hours delivering parcels, 68.1 hours (min: 1.53 (D5), max: 4.38 (D16)) of this was spent driving, including stem mileage (Table 1). Stem mileage accounts for the distance between the depot and the first delivery and the distance from the last delivery back to the depot, varying from 0.9 km (D19) to 27.80 km (D17), with an average of 11.94 km. Stem mileage accounts for 50.26% (286 kilometers (km)) of the 570.05 km driven. Round mileage, ignoring stem, varied from 3.73 (D8) – 20.53 (D13) km. The average round duration (from the vehicle leaving the depot until its return) was 7.3 hours and the average distance driven within the delivery area (excluding stem mileage) was 11.9 km with a mean speed of 9 km per hour. In total, the drivers delivered 2,960 parcels (min: 62 (D18), max: 274 (D12)), collecting 218 (min: 1 (D3, D21, D25), max: 62 (D12)). On average, 127 items were delivered/collected to 72 addresses per vehicle round. Drivers made between 14 (D5) and 72 (D9) unique stops on their rounds. The vehicles made 37 stops on average to service these customers, with 3.4 parcels delivered/collected per stop.

Table 1. Quantitative summary of 25 delivery rounds from 25-27 Oct. 2016. Missing data is represented by '–'. *Stem* mileage is common to all drivers, and refers to the distance from the depot to the first delivery location and from the last delivery location back to the depot. Total parked time includes unloading, walking, delivery, sorting in van, and breaks. $^\wedge$ = minimum value, $^\vee$ = maximum value.

Driver *(B2B/ B2C)*	Date	Round Time (hr)	Total Driving Time (hr) *(Total parked time (hr))*	Distance Driven (km) *(Excluding stem km)*	Total Deliveries *(Total Collections)*	Total No. Stops *(off street stops)*	Total Walking distance (km)	Walking distance per item (m/item) *(Walking distance per customer (m/customer))*
D1 *(B2C)*	25-Oct	7.82	1.76 *(6.05)*	14.80 *(6.70)*	119 *(5)*	35 *(7)*	12.48 $^\vee$	100.66 *(145.14* $^\vee$*)*
D2 *(B2C)*	26-Oct	7.30	1.7 *(5.60)*	18.50 *(7.80)*	131 *(10)*	46 *(5)*	10.26	72.79 *(104.73)*
D3 *(B2C)*	27-Oct	6.13	2.69 *(3.45)*	17.50 *(10.00)*	73 *(1* $^\wedge$*)*	33 *(1)*	5.23	70.63 *(108.90)*
D4 *(B2C)*	25-Oct	6.92	2.45 *(4.47)*	11.26 *(5.96)*	109 *(8)*	23 *(2)*	6.48	55.36 *(102.83)*
D5 *(B2C)*	26-Oct	5.12 $^\wedge$	1.53 $^\wedge$ *(3.58)*	12.87 *(5.97)*	135 *(6)*	14 $^\wedge$ *(0* $^\wedge$*)*	5.74	40.68 *(78.59)*
D6 *(B2C)*	27-Oct	6.98	1.58 *(5.40)*	11.26 $^\wedge$ *(6.26)*	174 *(3)*	40 *(1)*	–	– *(–)*
D7 *(B2C)*	25-Oct	7.82	1.8 *(3.83)*	16.09 *(8.99)*	128 (6)	41 *(2)*	12.09	90.21 *(109.90)*
D8 *(B2C)*	26-Oct	5.42	1.56 *(3.85)*	14.48 *(3.58* $^\wedge$*)*	124 *(2)*	34 *(1)*	–	– *(–)*
D9 *(B2C)*	27-Oct	9.08	2.76 *(6.32* $^\vee$*)*	22.53 *(9.43)*	148 *(4)*	72 $^\vee$ *(0* $^\wedge$*)*	9.31	61.21 *(83.08)*
D10 *(B2B)*	25-Oct	8.50	2.45 *(6.05)*	22.53 *(3.73)*	140 *(10)*	41 *(4)*	–	– *(–)*
D11 *(B2B)*	26-Oct	9.17	2.85 *(6.32* $^\vee$*)*	38.96 *(16.96)*	99 *(12)*	22 *(1)*	7.21	64.91 *(128.66)*
D12 *(B2B)*	27-Oct	7.73	3.4 *(4.33)*	38.05 *(15.05)*	274 $^\vee$ *(62* $^\vee$*)*	26 *(1)*	–	– *(–)*
D13 *(B2B)*	25-Oct	8.40	3.33 *(5.07)*	45.53 $^\vee$ *(20.53* $^\vee$*)*	156 *(12)*	59 *(4)*	–	– *(–)*
D14 *(B2B)*	26-Oct	8.67	2.95 *(5.72)*	34.59 *(13.59)*	88 *(5)*	41 *(0* $^\wedge$*)*	8.82	94.78 *(124.15)*
D15 *(B2B)*	27-Oct	8.72	3.38 *(5.33)*	41.83 *(16.83)*	138 *(6)*	52 *(7)*	–	– *(–)*
D16 *(B2B)*	26-Oct	10.30 $^\vee$	4.38 $^\vee$ *(5.92)*	36.21 *(13.51)*	137 *(10)*	37 *(3)*	8.24	56.02 *(108.36)*
D17 *(B2B)*	27-Oct	8.58	2.73 *(5.85)*	39.50 *(11.70)*	151 *(12)*	40 *(1)*	7.90	48.48 *(77.47)*
D18 *(B2C)*	25-Oct	6.62	2.53 *(4.08)*	– *(–)*	62 $^\wedge$ *(19)*	25 *(0* $^\wedge$*)*	–	– *(–)*
D19 *(B2C)*	26-Oct	6.92	2.88 *(4.03)*	19.31 *(18.41)*	76 *(8)*	35 *(2)*	–	– *(–)*
D20 *(B2C)*	27-Oct	6.90	4.05 *(2.85)*	20.92 *(19.12)*	92 *(5)*	29 *(1)*	–	– *(–)*
D21 *(B2C)*	25-Oct	5.58	2.91 *(2.67)*	24.14 *(17.14)*	76 *(1* $^\wedge$*)*	43 *(4)*	4.64 $^\wedge$	60.23 *(67.22* $^\wedge$*)*
D22 *(B2C)*	26-Oct	5.87	3.31 *(2.55*$^\wedge$*)*	16.09 *(10.89)*	82 *(2)*	40 *(1)*	7.50	89.23 *(87.15)*
D23 *(B2C)*	27-Oct	7.22	3.45 *(3.77)*	16.09 *(13.09)*	73 *(3)*	25 *(0* $^\wedge$*)*	–	– *(–)*
D24 *(B2C)*	25-Oct	7.08	2.81 *(4.27)*	20.92 *(16.12)*	71 *(5)*	32 *(1)*	6.67	87.73 *(136.08)*
D25 *(B2C)*	27-Oct	6.33	2.76 *(3.57)*	16.09 *(12.19)*	104 *(1* $^\wedge$*)*	48 *(1)*	6.54	62.31 *(109.05)*

We were surprised to find that on average, the vehicles spent 62% (114.9 total hours) of the total round time (min: 2.55 (D22), max: 6.32 (D11), avg. 4.6 hours per vehicle round) *parked at the curbside* while the driver unloaded, sorted and delivered the parcels *on-foot*. From the fifteen drivers with reliable walking data, 119.08 km of walking was performed across the delivery rounds. Our analysis shows a considerable difference in the walking distance between drivers, ranging from 4.64 (D21) – 12.48 (D1) km, with an average of 7.94 km (*SD 2.32*). This average accounted for 28% of the total journey distance travelled from the depot (i.e. including distance driven on the stem mileage), with 95% of vehicle stops taking place on-street at the curbside. The average number of customers visited per stop for each driver varied from 1.10 (D20) – 5.21 (D5), with an average of 2.06. Derived from the number of customers visited per stop we have calculated that the average walking distance per parcel delivered and per address visited were 70 meters and 105 (min: 67.22, max: 145.14) meters respectively. The average driving time between vehicle stopping locations was 3.7 minutes, with an average 8.1 minutes curbside parking time at each vehicle stop. Average driving and parking times per parcel were 1.5 and 2.3 minutes respectively.

Our averages show that drivers spent a considerable portion of time in the van, and typically drove for short amounts of time between delivery addresses. On further analysis of the drivers, we can see that there is a large variation between the proportion of parcels that two drivers (D12, D13) handled compared to the rest. These two drivers are able to deliver and collect 15.9% of the total parcels, in similar amounts of overall round time and spend considerably less time driving between addresses and less time per delivery or collection. D12 alone handles 10.6% of the parcels with skew due to the large proportion of collections made (9.25% deliveries, 28.4% collections).

The Delivery Round

The key to understanding this variation in driver performance is understanding the significance of driver knowledge and experience. Logistics companies allocate their drivers to specific 'delivery rounds' within the same geographic area or patch. By maintaining them on the same rounds, carriers attempt to build up the driver's familiarity in a round and surrounding area, helping them learn the most efficient routes, build personal relationships with customers and maintain knowledge of a round. These patches are within the same approximate geographical area each day, but these boundaries are flexible dependent on the workload and how this workload is spread across drivers. This body of tacit knowledge the drivers accumulate is known colloquially as 'the bible'. A driver with this knowledge and experience is significantly more effective than a novice driver.

The day starts with all parcels and drivers at the depot, with parcels having been transported overnight to the depot and organized based on their round and geographical patch. In the morning (around 6am) the driver lines up their parcels and scans each item with their terminal as they load it onto their van. Drivers are assigned a van (LGV) from the depot's fleet. Vans vary in size and power train (e.g. diesel, electric)—factors that may affect where the van can go (larger vans struggle to tackle narrow streets) and the range of the vehicle. B2C Drivers load their van themselves, dependent on the order of their deliveries, ensuring the van is as full as possible to reduce the chance of having to return to the depot. At this point, the driver must prioritize time-sensitive parcels (5% of parcels in our data sets), ultimately effecting the miles driven and how they optimize the round. Neither carrier uses route optimization software, preferring manual ordering and prioritization of deliveries or collections that leverage the knowledge of experienced workers. Once the van is loaded and route planned to ensure any collections have been factored in, the driver prints their final manifest (also available on their terminal), and leaves the depot to start their round.

Stem mileage is a result of the drivers' journey from the depot to the first delivery location. For our analysis, we focus on the deliveries themselves, and are therefore discounting stem mileage from our comparisons of driver effectiveness. D16 and D17's approach to time-sensitive deliveries was to do these in strict order (e.g. all 9am deliveries before the 10am deliveries) even if driving past a later delivery – the rationale given was that they could not afford the risk of being delayed (e.g. by customer not being available) and missing the earlier delivery deadline or that it was "*too challenging otherwise*". This means that there can be 'doubling back' on the round, that is, re-visiting the same or nearby locations more than once on the round. For one delivery of D16, only a short time window was available to deliver a parcel due to the store only opening at 9:30am. The B2B depot manager complained that the sender of the goods is the one who pays for the premium delivery and the recipient does not necessarily care what time the goods arrive, making some time windows appear unnecessary.

Vehicles and Technology. While the driver may not get to choose their vehicles, the size of van influences the roads they can drive down, and the stopping locations that they can pick. A larger van may make the round harder due to it being unable to fit down narrow streets or be difficult to park in small spaces. Conversely, larger loads (typically long running B2B contracts as part of a regular movement down the supply chain) may well necessitate larger vehicle to cope with bulk transport of items, heavy, or specialist items. The internal space of vehicles, both in terms of volume and shape, effect the order in which items can be loaded.

All drivers have the same model terminal which provides details of the next delivery or collection and is used to collect proof of delivery (PoD). Smart phones are invaluable to drivers, providing maps that help identify areas of congestion and alternative routes, and are a primary line to the depot enabling ad hoc deliveries. Digital technology is not without its pitfalls in the last-mile as those who rely on GPS may struggle in urban environments [76], with urban canyoning and misleading coordinates for building entrances (GPS often snaps to the middle of a postcode or building). GPS is also ineffective once the driver is in the building. Route finding software, even if effective at finding a premises, does not typically capture the important differences between the customer entrance and the delivery location (reception desk, loading bay etc.), or the optimal place to park without incurring a parking fine. A driver who is less reliant on digital technology to navigate the city, using their own knowledge, can make choices more efficiently in the last-mile.

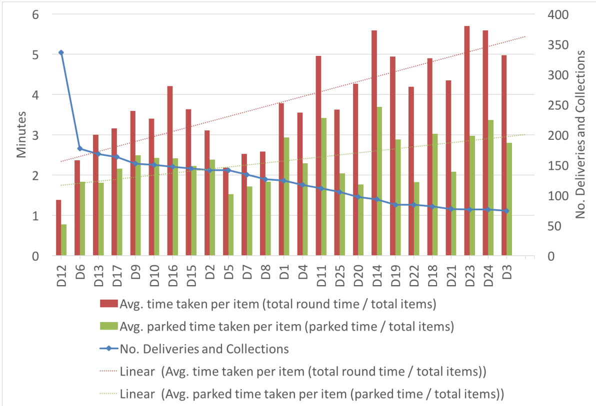

Figure 1. Comparing driver effectiveness, sorted by number of parcels delivered/collected descending. There is a moderate negative correlation (Pearson's R) between number of successful delivery/collections and the average round time required to deliver each parcel ($r = -0.602$). The correlation between average parking time per parcel and number of deliveries/collections complete is weak negative ($r = -0.463$), while the correlation between average time required to deliver each parcel and average parked time is strong positive ($r = 0.851$). Trend lines show that the amount of driving per parcel grows from left to right. This indicates that there is a relationship between number of deliveries & collections and the amount of time spent in the vehicle by the delivery driver.

Varying driver effectiveness. The difference between two of our drivers (D22 and D24) with similar round sizes and parcel volumes shows a considerable variation in effectiveness, with D22 driving 44% less distance, spending 35% less time per parcel, 29% less driving time per parcel, and 39% less parking time per parcel. The variation in effectiveness of our drivers relates to better route planning, exploitation of accumulated knowledge of the round, personal relationships with other stakeholders, the amount of time spent at the curbside and the influence of walking. These statistics show that more effective drivers achieve higher rate of delivery of parcels per minute while spending less time driving and parking in the van. Figure 1 shows that there is a negative correlation between total number of delivered (or collected) items and the amount of time spent in the vehicle by the driver. Figure 1 is skewed in favour of those drivers who have multiple deliveries or collections at the same address or within very close proximity typically from larger volumes of B2B consignments for the same recipient (e.g. D2, D13).

From our field study, we have found that the decision of whether to walk or drive close to a drop off point is the driver's personal preference. More time walking doesn't necessarily mean faster or more effective delivery rounds. For example, D22 expressed that he isn't a fan of walking, out performing D24 in terms of driving further, more quickly and completing a similar number of deliveries with 28% more stops. One driver in particular (D21) is so efficient that he is given more work to do than most other drivers, and when he finishes he contacts another driver, meets them on-street, and takes some of their parcels off them to help. He also mentally works out where to stop his vehicle on his round and which customers to deliver to at each stop before leaving the depot.

Depending on others. Our surveyors observed two memorable occasions where unpredictable delays occurred: one where a recipient (at a pub) refused to sign for delivery not wanting to take responsibility, and an occasion where the driver and surveyor were waiting for 20 minutes due to a shop manager being late to open up their shop in the morning (D16)—this could have resulted in a failure for a less patient driver. It was also captured in our field notes, that businesses that have closed down (which driver's may or may not already know about) still continue to receive parcels for sometime after closure. How well a driver can find a delivery point has hold over whether a delivery will fail. If a driver becomes lost or cannot find the address within a given amount of time they may choose to deliberately fail this delivery to ensure that they complete their round in a timely fashion.

Driver knowledge and personal relationships. A driver's knowledge helps them make decisions that reduce the amount of time spent delivering each parcel. Knowledge of the best parking locations (e.g. within range of multiple addresses, the longest loading times in loading bays), knowing when and where to walk, and where they can drive the van gives them the upper hand in the city. Before a driver gets to a building they must decide where to stop and unload their van. This is not a trivial task. *Are they taking one parcel, or multiple? How long can they stop at the curbside for given the twenty-minute loading times? Is there space for them to stop and unload their van? Will they get a parking ticket for parking illegally or beyond the loading time?* Once the driver has decided on where to stop, how many parcels they will carry, and how far they are willing to walk, they need to navigate from the vehicle stopping point to the address in the manifest and then work out where and with whom they can leave the parcel with. A challenge for the drivers is picking a stopping point that is optimal for a dropping point, or in relation to multiple dropping points. When proof of delivery (PoD) is required, drivers have to find this person (a concierge, or the recipient of the parcel) and obtain their signature.

Knowledge of the last-mile (e.g. areas and times of congestion, opening hours of businesses) is built up through spending time on the streets and gaining experience of the road network, parking spots, delivery points and understanding how to navigate the interior of buildings. How can the carriers help their drivers, short of spending hours training each driver on the intricacies of all road and buildings in their patch? Beyond the individual's knowledge of the last-mile, we have observed that the interactions and relationships with others offer drivers advantages on the round. Personal relationships can help understand where a delivery is likely to fail (e.g. if D16 knew about the store manager's lateness), who can provide PoD or handle packages at the point of drop off, and when they can bend the rules when it comes to parking (e.g. knowing that you can get away with 40 minutes of stopping on double yellow lines). The knowledge and personal relationships of a driver was described by one surveyor as the "Driver's Bible" by which every decision on the round is made.

Stopping and walking. The decision whether to walk or drive is determined by a driver minimizing the amount of time related to traffic, road layout (e.g. one way streets), parking options and distances/times between stops. In pedestrianized areas, parking is prohibited, leaving the driver with no alternative other than to park on a side street and walk. The general fitness of the drivers is moderately high[1] – no surprise with walking distances reaching 12.48 km in a day – and none are averse to walking *if* it is perceived as a quicker option. Heavy rain may influence their decision (e.g. might wait for a closer parking spot). Route planning seemed to be a combination of tried and tested routes combining walking and driving, with the vehicle being loaded in a certain way to match these, along with some dynamic reactions to traffic conditions. Although "*no two days are the same* (D16)" the streets visited are typically the same each day so one would expect to see routing patterns developing. Most drivers said that their routes were fairly fixed each day. Only 5% of stopping locations were off street locations (e.g. dedicated loading bays for building, private car parks). The normal stopping location is curbside loading bays. One driver expressed a dislike to using off street parking due to risk of being blocked in the space when he returned to the vehicle. Circling the block two or three times looking for an appropriate space also adds time and mileage (D16).

Multistory, multipurpose buildings. Buildings in the city are mixed-use and multistory, meaning that there might not always be a clear entry point. Once inside the building there are numerous points for delivery, on different floors, depending on the customer. Typically, high rise buildings and skyscrapers which are common in the city comprise a mixture of commercial, domestic and retail addresses. This is a challenge that is not currently met by current commercial routing software, and requires drivers to have prior knowledge of the building to be effective (e.g. front door on the street, service access, internal address in buildings). Concierge services in these buildings benefit delivery drivers, as typically these services are located near the entrance and reduce the amount of time a driver has to spend inside the building.

From our results it's clear that a driver's knowledge, personal relationships and planning and not simply the delivery destination used in route finding software, makes for the most effective delivery workers. How a driver prepares, clusters and orders parcels when loading at the depot based on their knowledge of the streets and where they will stop to optimize walking to multiple delivery points is critical to their delivery performance.

DISCUSSION

In our study of last-mile logistics in dense urban areas, experience, knowledge and relationships appear to have the largest impact on driver effectiveness (e.g. number of parcels delivered per minute, most efficient use of walking, knowing

[1] Surveyors found that walking with the driver was liable to slow them down unless the surveyor was a fast walker.

when they can carry multiple parcels). Given HCI's long history of developing design artifacts for workers, it is positioned well to help increase the effectiveness of novice and life-style couriers, promoting both environmental and social justice while encouraging more optimal delivery rounds. We have observed that the last-mile is ripe with opportunities for digital technology to help address the variation in effectiveness between workers. In this section, we reflect on areas for re-configuring last-mile parcel delivery strategies in order to speed up the improvement of air quality and reduction of carbon emissions.

Demand for the curbside

Last-mile deliveries and collections rely heavily on appropriate stopping locations. Only 5% of the stops made by our drivers were made at off street locations (e.g. locations not directly outside of delivery locations). Parking a van in the most optimal spot is difficult given the size and shape of the vehicle, the driver's knowledge of stopping locations, and deliveries that are far apart or hard to optimize. It is important to note that policy makers are eager to control loading and stopping zones to reduce congestion, better control illegal stopping and parking, and promote pedestrianized zones to lower air pollution. A reduction in parking locations will likely increase the need for walking in cities as drivers fight for prime spots to complete deliveries and collections. Leaving and entering parking spaces or having nowhere to park all have an impact on congestion, the latter even leading to parking illegally or accruing extra mileage while looking for another stopping location. Optimal use of the curbside should allow for drivers to park their vehicle and walk between the maximum number of delivery addresses and return to their vehicle in time to not receive a parking ticket. The utilization of loading bays and safe places to park means that drivers may have to walk further and may not be in direct line of sight of their delivery address. Less preferred stopping points or points with a greater distance can be utilized more to help combat wasted curbside (e.g. using empty loading bays) and congestion problems during rush hours due to the time and space required for vans to leave and enter spaces.

Walking is still honest

Of the time spent on a delivery round, the time that is spent walking can be more than that of driving (D7, D20, D21, D22). Reducing the time that the drivers spend in vans helps improve their per-parcel efficiency (see Figure 2). It is clear from our findings that a larger distance of walking correlates with more parcels delivered quicker, and that walking is key in helping drivers perform better and reduce environmental impacts.

Figure 2 shows that the geographic area in which these rounds operate can overlap significantly, for only three rounds. The same areas are being delivered to throughout the day by different drivers, from different couriers. This overlap in space and time highlights an inefficient use of the street in terms of road use (congestion), curbside stopping (stopping at the same places). Not only is this clear for the roads used, there is also clear overlap in where the drivers are making deliveries, with a considerable number of deliveries being made within

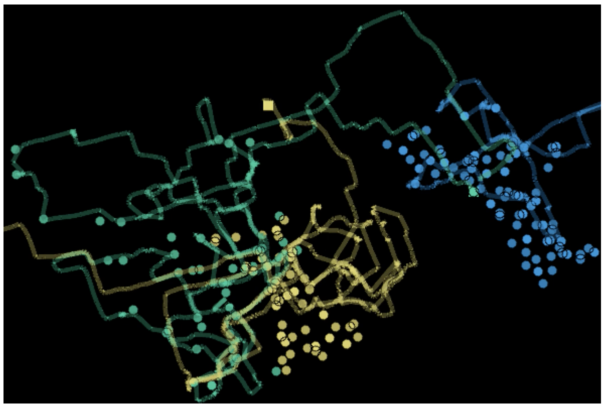

Figure 2. The overlap of 3 of the rounds in the city on 25th October 2016. This demonstrates how delivery rounds from 3-5% of all carriers working in this area use the same roads and deliver within close proximity. (Blue is B2B, Yellow and Green are B2C). Circles represent deliveries and collections.

walking distance of each other. The overlap of consignments in the last-mile means that a poorly optimized round is not the only factor. Overlapping rounds create congestion, reduce the availability of stopping locations and are a largely inefficient circumstance in the last-mile.

We acknowledge that it is difficult to quantify the precise impact of walking in terms of environmental gains or losses, but there are numerous benefits to drivers walking more. These include fitness and health benefits, reduced pollution, less vehicles on the street, lower carbon emissions, less vehicle accidents, and less unsightly vans clogging up curbsides and city vistas.

Challenges in re-imagining the last-mile

Carriers, capacity and deliveries in the current model are restrained by the capacity of infrastructures, sizes of warehouses, and the limited number of locations to place new depots in cities. This is compounded by the increasing demand and competition for the curbside and road network. A future concern of a growing last-mile parcel sector is logistics sprawl due to affordability and availability of land for local depots, leading to depots being relocated ever further from urban centers and longer stem mileage to/from first/last delivery point. Compounding this issue further is the overlap in drivers from competing carriers delivering in the same 50 meters as each other. As e-commerce retailers (e.g. Amazon, ASOS) lower the price of delivery and increase the speed at which consumers can receive items (e.g. same and next day delivery slots), opportunities for better load consolidation and optimization are undermined, encouraging less predictable clusters of deliveries at unusual hours (e.g. Amazon now delivers within two hours up until midnight same day).

The available fleet and ways in which vehicles are driven also impacts carbon emissions. Electric vehicles offer the benefit of reduced carbon emissions in-use, especially when charged with electricity from renewable sources, but this does require replacement of the last mile fleet, with the associated cost, embodied energy and emissions this entails. Reducing CO_2

and improving air quality is not as simple as replacing the entire fleet of vans with bikes or electric vehicles. Current electric vehicles and (e)bikes are limited in their capacity – parcels are too big, too heavy, or require more secure transportation, leading to trade offs in the number of trips vehicles make and sizes of rounds [86]. The roll out of such an electric vehicle fleet is restricted by the availability and cost of required infrastructure [18].

Respecting the workforce

The employment status of life-style couriers and other gig-economy workers in the transport and logistics sector leaves many without pensions, limited or no guaranteed working hours, no holiday or sick pay and no guarantee of a living wage [22]. Any solution needs to ensure that the reshaping of last-mile parcel deliveries is respectful of its workforce, striving for a more fair and just employment for life-style couriers [12].

A number of unpredictable hurdles in the last-mile affect the delivery driver's performance based pay, such as: unpredictable urban congestion, unknown availability of curbside unloading locations ahead of arrival, navigating from street address of a consignment to a delivery point (which could be a side- or back-door or even a different building). Delivery drivers can spend a considerable amount of time walking on the street and in buildings. This time and distance isn't accounted for in current route optimization software that novice drivers may be more reliant on, creating a disadvantage for those who are less familiar with the geographic area that translates into less pay.

We see HCI and SHCI as enablers of the variety of different strategies that are required to enable more optimal, socially just and environmentally sustainable last-mile parcel deliveries. It is important to emphasize that advocating the digital capture and sharing of this tacit knowledge needs to be handled with sensitivity. This presents a tension given that this knowledge and associated experiences and relationships are the livelihood of the employee. The advantage gained by this knowledge and relationships can result in more work complete and more payment, which is becoming increasingly present in systems where performance is measured and linked to pay (e.g. Uber, Bus Services deliveries) [35, 68, 67].

OPPORTUNITIES FOR HCI

Meeting carbon emission targets, supporting business-as-usual growth of parcel deliveries and challenging the socially unjust job market of life-style couriers requires "*significant policy, social and technical intervention, on a scale that has not yet been evident*" [27, p. 175]. We have identified eleven opportunities for HCI to help reshape business and operational practices in the last-mile to combat increasing vehicle mileage (leading to associated fossil fuel use, greenhouse gases, local air pollution), road and curbside occupancy and social justice of work forces who have few rights and performance-based income.

Making novice drivers instantly better

Our first set of opportunities identifies how HCI can help make novice and gig-economy drivers better, instantly. Without a "Driver's Bible", containing all the knowledge and shortcuts in the last-mile it is impossible for novice drivers to make good decisions. This knowledge and associated experience is unlikely to accrue for the casual or gig-economy worker, who arguably is the person who needs it most. It takes time to develop the knowledge of the city and build up personal relationships. With these workers less likely to work in a common patch they are faced with a significant (financial) disadvantage. Additionally, carriers are faced with high churn in employees in last-mile parcel sector leading to significant knowledge being lost that is expensive to recover. Given that it takes significant financial capital to train new workers and much more time for them to accrue local knowledge that makes them more effective we see opportunities for HCI to aid novice workers in the last-mile. We do not advocate blithely sharing tacit knowledge, any solution must sensitively handle the deep tensions between knowledge and experience sharing [1]. Instead we encourage the design of solutions that enable novice drivers to perform better within existing ways of working. We suggest various points at which existing processes can embed this knowledge:

O1. Vehicle scheduling decisions. Deciding the order in which to carry out the parcel deliveries is important. The route that the driver decides upon should respect time guaranteed deliveries that minimize overlap with both periods and areas of congestion as well as other delivery rounds in the same area. While optimization is already done by software or dedicated workers, ensuring that the overlap between rounds is reduced and encouraging more optimal routing through the city help reduce the carbon emissions of last-mile deliveries.

O2. Loading sequence of the parcels. Parcels should be loaded in sequence so that they are accessible at a stopping point to minimize searching time when parked. Time guaranteed deliveries will affect order in which items are loaded (by the driver, or by ICT system) onto the van at the depot. More optimally loaded vans help drivers spend less time unloading their van at the curbside, lowering their stopping time and reducing the risk of additional parking charges and fines.

O3. On-route vehicle navigation decisions. Once the vehicle departs from the depot, it is critical that the route taken between stopping points is short, efficient and in central locations between consignment addresses. Drivers with more experience show that taking account of known road work and traffic problems allows for optimal vehicle routing in relation to stopping points. "Gut" decisions based on the driver's tacit knowledge can help reduce the amount of time in congestion, and reduce associated carbon emissions and pollution.

O4. Picking the best stopping point. Given that our most effective driver can spend significantly less time parking, knowledge of where to park and when to walk is key in reducing parking time. The best spot isn't always outside the front door of a building, knowing this ahead of time can reduce the time (and kilometers) the driver spends parking.

O5. Last-mile ability and recall skills. Enabling the driver to quickly and accurately locate the parcels required on-board the vehicle at each stopping location, ensuring that each consignment delivered includes the correct number of parcels. This further reduces the amount of time a driver is parked.

Delivering to people, not postcodes

Our second set of opportunities aid drivers to be effective at the point of delivery. Oftentimes consignments aren't mailboxes they are people in buildings that can be difficult to navigate to without prior experience. It might be tempting to improve location services and deploy an indoor or more effective routing system [53]. Unfortunately, these systems won't always help a driver find a specific office, apartment or the concierge. We believe that we should rethink how addressing is done in multistory, multipurpose buildings. The last-mile parcel service could aim to deliver parcels to people instead of postcodes (e.g. Uber delivers taxis within 100m of a person's location). This could be done using services such as what3words [30, 75, 88], enabling addressing to be made at a finer grain level (3m x 3m square). Utilizing such a method could also allow drivers to locate and access building entrances more easily. Once the access point to a building is located, a more optimal solution than delivering to a specific address within a building is to leave parcels at a set location with each multipurpose building having an in-house logistics system or concierge who delivers the parcels the last 50m. With private residents and businesses already subsidizing utilities and services in these buildings to be in these buildings, a subsidy could be paid to cover this cost.

O6. On-foot decision making. Deciding how many delivery addresses to deliver to on-foot each time the vehicle is parked and in which order. More optimal ordering of deliveries and carrying multiple parcels can reduce the amount of time parking and total round time.

O7. Optimizing Walking routes. Once the driver has stopped and parked their vehicle, they should establish the best walking route from the vehicle to their delivery points. Given the challenges of using location and GPS in major cities we see that opportunities for sharing knowledge or educating drivers on walking and on-foot best practice.

O8. Locating point of entry. On arrival at the building the driver should enter the through the appropriate entrance for deliveries. This may differ from the street address on the terminal or printed manifest. Knowledge of the appropriate point of entry can help reduce the amount of time that drivers spend working out how to get to a delivery point.

O9. The journey inside the building. Effectiveness inside the building comes from ensuring the optimal route to the person to whom the goods need to be handed. Knowing where the drop offs are supposed to be made reduces the amount of time spent walking in buildings.

O10. Decisions about what to do when no-one is available to receive delivery. To not accrue additional time per parcel through re-delivery or spending too long attempting the deliver, the driver must be comfortable deciding on whether to leave the parcel in a safe place, with someone else or to depart without making completing the delivery.

O11. Accepting collections. Drivers must be able to make decisions on whether to accept a collection request from the depot while carrying out their delivery round. An ad hoc collection may be time constrained and may add unwanted kilometers onto a round through congested city streets.

RETHINKING THE LAST-MILE

Beyond changing the practices of drivers, there are a number of larger socio-technical challenges that can be addressed to promote environmental and social justice in the last-mile. The current demand on the last-mile sector is driven by cheap and free next day deliveries, perpetuated by cheap subscription models that provide infinite free delivery and collection of parcels. Online retailers are not charging people the true cost of deliveries. This (near) zero cost is increasing the demand for next-day and same-day deliveries. These pricing models are forcing logistics companies to promote loss-leading tactics to compete with one another. As they look to make savings in their business often the first to be affected are the employees, their benefits and their opportunities to work (e.g. making costly employees redundant) leading to driver unemployment, and helping the up rise of unethical "zero-hour contracts". It is essential that any new business model considers both the real cost of parcel deliveries and the social justice of last-mile logistics workers in order to help reform the current market failure.

Environmental and Social Justice

Our findings have demonstrated that there is considerable variation in the vehicle mileage of last-mile logistics workers. Increasing the number of vehicles on the streets or parcels in a round to meet consumer demand increases carbon emissions, congestion and pollution. To help combat these issues the industry is innovating in alternative vehicles (e.g. electric vans, electric cargo cycles [39, 86]) for enabling low-carbon and zero pollution delivery fleets. HCI can help last-mile logistics work within the current constraints of these vehicles (e.g. limited range and load capacity) and transition last-mile parcel deliveries towards more environmentally friendly configurations that account for variations in driver practices.

One opportunity for HCI to do good (cf. [10, 31]) is to challenge the social injustice of zero-hour contracts and the exploitation of gig-economy workers in an industry that is creating large amounts of low-pay work, with no benefits or legal support [22, 29, 80, 89]. Like others who focus on gig-economy, on-demand, and knowledge workers we see ensuring fair pay and just work as dimensions that are broadly missing in the somewhat exploitative gig-economy and lifestyle courier workforce [12, 35, 37]. We are encouraged by recent work that promotes social justice, fair pay and sustainability in the gig-economy and tackles the exploitation of knowledge workers [69, 31, 12, 42, 4, 37]. Through the design of new socio-technical systems we see HCI as a core tool that can encourage social justice in last-mile logistics as the demand on its workers increases.

Rethinking Round Optimization

Our human-centred findings bring new empirical insights as to how last-mile logistics can be improved by HCI. Last-mile logistics is often treated as a graph optimization or simulation problem assuming delivery is from the hub to the delivery address (cf. [38, Fig. 3]). In contrast, our work shows that this is a hierarchical optimization problem, involving human contextualized problem solving split at a further location—*the stopping point*. In dense urban settings, walking, where to stop, and how to optimize loading are critical and not currently supported by digital technology. This also changes the optimization problem by effectively introducing an additional dynamic 'hub' location where the vehicle stops. This *radically changes the optimization as it must now include both walking and driving*. From our findings we encourage hybrid optimization approaches that consider the optimal ordering of deliveries as well as the dynamics of both the delivery round and the routines and practices of the drivers themselves. Future visions of the last-mile should consider hybrid optimization, the role of more environmentally friendly technologies (e.g. eVehicles, cargo cycles) and ways of restructuring the curbside, such as unattended drop boxes, to offer opportunities for re-configuring last-mile logistics in a more sustainable manner [28, 39, 86].

Consolidation and automation at the curbside

While we advocate improving the effectiveness of drivers, there is scope to rethink where (and to whom) drivers drop off parcels. While drop boxes and concierges are potential options, the curbside is not the final destination. In some cases items have strict delivery slots or require proof of delivery. Due to this, much of a driver's time is spent running in and out of buildings and getting signatures. The most effective drivers are already carrying small caches of parcels between multiple addresses within about 100 meters (sometimes further) of their parked van. This can be seen as an example of how drivers are utilizing very small and localized mobile depots. Pairing the concept of mobile depots and localized knowledge is the most efficient way of getting parcels from a stopping point to the final address. Last-mile logistics should consider dropping off numerous parcels to mobile parcel depots, where curbside workers deliver the parcels the last $\tilde{1}00$ meters, leaving the delivery driver to quickly continue to the next location. Applying this model may create new jobs for mobile parcel porters and reduce the (excessive) load and expectations on last-mile drivers, making it a more accessible job with less opportunities for variations in performance (e.g. no more routing in buildings, quick drop off times).

Challenging the 'cornucopian paradigm' in logistics

Our findings and discussion speak to optimization and business-as-usual trends that likely contradict broader sustainability concerns (e.g. finite resources, climate change). To tackle the increasing parcel demand, social injustice of gig-economy and on-demand work forces, and increasing levels of pollution and growing environmental concerns we should think more critically about where to intervene. Challenging the "cornucopian paradigm" in last-mile parcel deliveries (cf. [66, 70]) requires change beyond just the last-mile. In order to combat unsustainable growth in the parcel sector, HCI could consider disrupting the increasing flow of deliveries by challenging default same or next day deliveries, considering new policies and allowances that limit deliveries to workplaces, developing design interventions that challenge non-essential and negotiable purchases and use of subscription models (cf. non-negotiable technology [9]).

CONCLUSION

In this paper we have introduced last-mile parcel deliveries and life-style couriers to HCI. Through our empirical study of this domain in central London, we have shown how studying variation in delivery effectiveness of drivers and understanding their practices and routines can help identify opportunities for designing technology to support more effective delivery of parcels. From our qualitative field study, we have illustrated the importance of driver knowledge, personal relationships, and decision making about when to walk and how to navigate multistory and multipurpose buildings all contribute to driver effectiveness. Exploiting this insight as a resource for design we have explored how HCI can lead to new technology to help utilize the curbside better for deliveries, encourage better walking strategies that promote consolidation and collaboration, and help challenge policy frameworks and unsustainability of logistics and life-style couriers. We have identified eleven opportunities for HCI from our empirical work to make novice drivers instantly better and help deliveries get to people (not postcodes) when delivering parcels in cities. We finish by, we hope, stimulating a new discussion in HCI about how we can help bring about new and future business models in last-mile logistics that can more profoundly intervene in the last-mile to promote greater environmental and social justice.

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